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Conservation agriculture in the dry Mediterranean climate

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ABSTRACT

The objective of this article is to review: (a) the principles that underpin conservation agriculture (CA) ecologically and operationally; (b) the potential benefits that can be harnessed through CA systems in the dry Mediterranean climate; (c) current status of adoption and spread of CA in the dry Mediterranean climate countries; and (d) opportunities for CA in the Central and West Asia and North Africa (CWANA) region. CA, comprising minimum mechanical soil disturbance and no-tillage seeding, organic mulch cover, and crop diversification is now practised on some 125 million ha, corresponding to about 9% of the global arable cropped land. The area under CA is spread across all continents and many agro-ecologies, including the dry Mediterranean climate. Empirical and scientific evidence is presented to show that significant productivity, economic, social and environmental benefits exist that can be harnessed through the adoption of CA in the dry Mediterranean climates, including those in the CWANA region. The benefits include: higher productivity and income; climate change adaptation and reduced vulnerability to the erratic rainfall distribution; and reduced greenhouse gas emissions. CA is now spread across several Mediterranean climate countries outside the Mediterranean basin particularly in South America, South Africa and Australia. In the CWANA region, CA is perceived to be a powerful tool of sustainable land management but it has not yet taken off in a serious manner except in Kazakhstan. Research on CA in the CWANA region has shown that there are opportunities for CA adoption in rainfed and irrigated farming systems involving arable and perennial crops as well as livestock.

1. Introduction

Globally, the dry Mediterranean climates occur in the subtropics and temperate regions of every continent, on their western sides between latitudes 30 and 45 degrees North and South, in addition to the countries of the Mediterranean Sea basin in Europe, North Africa and west Asia, and in Central Asia and the Caucasus. Outside the Mediterranean basin region, Mediterranean climates occur in south western South Africa, south western and south central Australia, central Chile, west central Argentina, north west Mexico, parts of the Pacific Northwest in North America including Washington and Oregon, and the south west USA including California. The precipitation is received as rain or snow during the autumn, winter and spring period from October to May in the northern hemisphere and from April to November in the southern hemisphere, and can range from some 200 to 600 mm annually, corresponding to a reference average length of frost-free crop growing season of 90–150 days, with high precipitation variability within and between seasons (Kassam, 1988). In general, the dry Mediterranean climate located near the sea have relatively mild winter temperatures and hot summers (maritime climate); those located away from the sea within a larger land mass have severely cold winter temperatures and hot dry summers (continental climate). At higher altitudes and latitudes inland from the Mediterranean Sea, the severity of winter temperatures is increased but with moderate temperatures during the dry summer period. Thus, in the Mediterranean basin, there is a variety of climatic regimes owing to the complex configuration of seas and mountainous peninsulas in the 3000 km incursion into Central Asia and the Caucasus.

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The Central and West Asia and North Africa (CWANA) region was once the breadbasket of civilizations and food production from the region sustained the most powerful empires of the ancient world, such as the Romans. Yet, already during those ancient times tillage-based agriculture led to soil degradation resulting in reduced human carrying capacity of the land (Montgomery, 2007). Thus, most agricultural soils in the dry climates of the Mediterranean basin today have low organic matter status with poor soil aggregate structure (Lahmar and Ruellan, 2007), and the predominant land use practices such as tillage and overgrazing worsen the situation. In the long run this leads to severe land degradation and finally to desertification, as can be observed in many parts of the region (Montgomery, 2007). In addition to land and water scarcity, tillage-based agricultural land use in the CWANA region is beset with several environmental constraints and threats. These arise from a negative annual water balance, short and variable rainy season, loss of organic matter and soil structure as well as from soil salinity, land degradation from wind and water erosion, and extreme temperatures in the continental parts (Kassam, 1981, 1988; Ryan et al., 2006; Stewart et al., 2007).

The tillage-based agriculture is unable to deliver many of the environmental ecosystem services because of its high and cumulative externalities as well as its inability to serve the needs of resource-poor farmers (Pretty, 2008; Kassam et al., 2009; Wezel et al., 2009; FAO, 2011a). Tillage destroys the natural soil structure and soil organic matter as well as the associated soil life and biodiversity, and many of the soil-mediated ecosystem functions that provide, regulate and protect environmental services (Montgomery, 2007).

Conservation agriculture (CA) spearheads an alternative no-till agro-ecological paradigm that is making an increasing contribution to sustainable production intensification (Hobbs, 2007; Pretty, 2008; Goddard et al., 2008; Kassam et al., 2009). The objective of this article is to review: (a) the principles that underpin conservation agriculture (CA) ecologically and operationally; (b) the potential benefits that can be harnessed through CA systems in the dry Mediterranean climate; (c) current status of adoption and spread of CA in the dry Mediterranean climate countries; and (d) opportunities for CA in the CWANA region.

2. Principles of conservation agriculture

CA is mainly defined by three linked principles which have to coincide in time and space and have to be applied permanently to develop synergies. These principles are (FAO, 2011b):

(1) Continuous minimum mechanical soil disturbance: This translates into the practice of low disturbance no-tillage and the respective low disturbance direct seeding. Soil disturbance in all operations has to be avoided as much as possible, allowing only in very specific conditions disturbance of not more than 25% of the soil surface but not wider than 15 cm in bands.

(2) Permanent organic soil cover: This refers to mulch from crop residues, other organic mulch materials or living crops, including cover crops. The level of soil cover should ideally be 100% of the soil surface, but never less than 30% and should always supply sufficient organic carbon to maintain and enhance soil organic matter levels.

(3) Diversification of crop species grown in sequences and/or associations: This refers to rotations and sequences of annual crops, mixed-, inter- or relay cropping, cover crops in perennial orchard or plantation crops, including legumes for their nitrogen effect as well as for their flowering in support of pollinator populations.

The individual CA principles have been practiced by farmers for a long time (Derpsch, 2004; Montgomery, 2007). What is unique about the modern concept of CA is the conjunction of all three principles that are applied simultaneously through locally devised and tested practices. For production *intensification*, these core CA practices need to be strengthened by additional best management practices, particularly: (i) use of well adapted good quality seeds; (ii) enhanced and balanced crop nutrition, based on and in support of healthy soils; (iii) integrated management of pests, diseases and weeds; and (iv) efficient water management (Kassam et al., 2011).

Thus, sustainable crop production intensification based on CA is the combination of all improved practices applied in a timely and efficient manner. The approach offers farmers many possible combinations of CA-based practices to choose from and adapt, according to their local production conditions and constraints. The relationship between components of CA and desired soil and agro-ecosystem conditions are listed in Table 1. For example, many of the benefits that are 'ticked' in the second column under the no-till component and in the third column under the mulch cover component are not necessarily possible under tillage agriculture.

3. Potential benefits from conservation agriculture

Early development of the CA principles and practices occurred in North and South America as farmers and civil society responded to severe land degradation and productivity losses due to tillage-based production practices (Bolliger et al., 2006). Thus CA largely spread from the land managers up to the administrative and scientific levels. In recent years, CA is receiving greater attention because it can optimise the use of purchased inputs and reduce costs (Friedrich et al., 2009a). In situations of resource-poor farmers in Africa, Asia and Latin America, CA systems are becoming increasingly relevant for addressing the needs of small resource-poor farmers and the challenges of resource degradation, sustainability, food insecurity, poverty alleviation, climate change, labour shortages and high energy costs. Site-specific options of CA are still to be developed and evaluated for their effects on intensification of cropping systems in the resource-poor dry areas by monitoring the long-term effects on yields, production cost, labour requirements, and soil properties. Special attention should also be devoted for the assessment of the biophysical and socio-economic conditions under which CA would be adapted for smallholder farming (Giller et al., 2009).

Over the past 40 years, empirical and scientific evidence from different parts of the world in the tropical, sub-tropical and temperate regions has been accumulating to show that CA principles, translated into locally devised practices to address prevailing ecological and socio-economic constraints and opportunities, can work successfully to provide a range of productivity, socio-economic and environmental benefits to the producers and the society at large (Derpsch, 2004; Bolliger et al., 2006; Goddard et al., 2008; Reicosky, 2008; Derpsch and Friedrich, 2009a; Baig and Gamache, 2009; Lindwall and Sonntag, 2010). This is also true for the dry Mediterranean climates in the CWANA region (Stewart et al., 2007; Goddard et al., 2008; ECAF, 2010) as well as in other parts of the world including in southern Australia, south western South Africa, south and central Argentina, central Chile, north west Mexico, and the Pacific Northwest USA and California (Goddard et al., 2008; Derpsch and Friedrich, 2009a; Friedrich et al., 2009a; Crabtree, 2010).

Key potential benefits that can be derived from well-managed CA systems in the dry Mediterranean climates globally are elaborated in the following sections.

3.1. Higher productivity and incomes

Yield differences resulting from improved soil moisture and nutrient availability have been reported in the range of 20–120 per cent and more between CA systems and tillage systems in the dry Mediterranean climates in different continents (Mrabet, 2000,

Table 1
Agro-ecosystem service features in relation to component practices of conservation agriculture applied simultaneously with good crop and cropping system management for intensification (based on Friedrich et al., 2009a,b).

Relevant features of agro-ecosystem	System component			
	No tillage (minimal or no soil disturbance)	Mulch cover (crop residues cover-crops, green manures)	Crop rotation (for safety biodiversity, profit, etc.)	Legumes (for fixing nitrogen, supplying nutrients, creating biopores)
Simulate optimum 'forest-floor' conditions	√	√		
Reduce evaporative loss of moisture from soil surface	√	√		
Reduce evaporative loss from soil upper soil layers	√	√		
Minimise oxidation of soil organic matter, CO_2 loss	√			
Minimise compactive impacts by intense rainfall, passage of feet, machinery	√	√		
Minimise temperature fluctuations at soil surface	√	√		
Maintain regular supply of organic matter as substrate for soil organisms' activity	√	√	√	√
Increase, maintain nitrogen levels in root-zone	√	√	√	√
Increase CEC of root-zone	√	√	√	√
Maximise rain infiltration, minimise runoff	√	√		
Minimise soil loss in runoff, wind	√	√		√
Permit, maintain natural layering of soil horizons by actions of soil biota	√	√		
Minimise weeds	√	√	√	√
Increase rate of biomass production	√	√	√	√
Speed soil-porosity's recuperation by soil biota	√	√	√	√
Reduce labour input	√	√		
Reduce fuel-energy input	√		√	√
Recycle nutrients	√	√	√	√
Reduce pest-pressure of pathogens			√	
Re-build damaged soil conditions and dynamics	√	√	√	√
Pollination services	√	√	√	√

2002; Fileccia, 2009; Crabtree, 2010; Fernández-Ugalde et al., 2009; Piggin et al., 2011).

Improvements in the soil's porosity under CA are thought to have two effects: a greater proportion of the incident rainfall enters into the soil; and the better distribution of pore-spaces of optimum sizes results in a greater proportion of the received water being held at plant-available tensions (Shaxson, 2006). Thus, after the onset of a rainless period, the plants can continue growth towards harvest – for longer than would previously been the case – before the plant-available soil water is exhausted. Also, the combination of improved porosity and soil moisture holding capacity as well as the lowering of evaporation due to the soil cover serves to buffer the plants from dry spells that frequently occur during the rainy season in the dry Mediterranean climates. In south western Australia, Crabtree (2010) reports that CA farmers regularly state that their water use efficiency has nearly doubled after 10 years of no-till. In addition, increased quantities of soil organic matter result in improved availability of plant nutrients, and duration of their release into the soil water. Thus the availability of both water and plant nutrients is extended together.

The magnitude of and mechanisms for long-term differences in soil fertility under no-tillage and conventional tillage are still relatively poorly understood. CA has been shown to be an effective strategy to improve soil quality and fertility as well as yield and yield stability in the dry Mediterranean climate in Morocco (Mrabet et al., 2001; Lahlou et al., 2005; Magnan et al., 2011), Spain (López-Fando and Almendros, 2000; Fernández-Ugalde et al., 2009; Moreno et al., 2010), Tunisia (Ben Moussa-Machraoui et al., 2010), Iraq and Syria (Piggin et al., 2011), Uzbekistan (FAO, 2009;), Kazakhstan (Fileccia, 2009), Australia (Llewellyn et al., 2009; Crabtree, 2010) and Mediterranean Europe (Stagnari et al., 2010).

FAO (2001b) indicated that machinery and fuel costs are the most important cost item for mechanised producers and so the impact of CA on these expenditure items is critical. Most analyses of mechanised agriculture suggest that CA reduces energy and machinery costs and improves energy efficiency and profit (e.g., Crabtree, 2010; Piggin et al., 2011). CA systems require much less input of energy per unit area, per unit output, and lower depreciation rates of equipment. Over time, less fertilizer is required for the same output. Long-term research and practice has shown that after several years of CA, the soil has a higher amount of biological nitrogen and a greater ability to release nitrogen than a tilled soil (Lafond et al., 2008; Crabtree, 2010), while nutrient availability to plants is increased (Duiker and Beegle, 2006). Better soil protection by mulch cover minimizes both runoff volumes and the scouring of topsoil, carrying with it seeds and fertilizers, representing waste and unnecessary cost. Production costs are thus lower, thereby increasing profit margins as well as lessening emissions from tractor fuel. CA systems are less vulnerable to drought because of better soil and plant conditions, and organic soil cover, provide greater biotic diversity of potential predators on pests and diseases, while crop rotations break insect pest and pathogen build-ups. Here, much of the cost of avoiding or controlling significant pest attacks is diminished because of it being undertaken by healthier plants, breaks in pest life cycles and natural predators, and allelochemicals (Settle and Whitten, 2000; Blank, 2008; Wolfarth et al., 2011).

Research reported from long-term CA trials in the Canadian Prairie, which have biophysical similarities to continental dry Mediterranean climates in Central Asia, has shown that crop rotation and short-term green manure cover crops during the summer fallow period can reduce the cost of herbicides drastically, due to reduction in weed infestation over time, although there can be a shift towards more perennial weeds (Blackshaw et al., 2007; Harker and Blackshaw, 2009). Similar studies conducted in northern Kazakhstan have shown that reducing and gradually eliminating summer fallow with legume cover crops is feasible (Suleimenov and Akshalov, 2006). There is a perception that CA is 'chemically-dependent' for weed control but in reality CA promotes integrated cultural weed management. CA systems with effective residue management and crop rotations involving cover crops or green manure crops can be effective in suppressing weeds (Upadhyaya and Blackshaw, 2007; Crabtree, 2010). Weed control is often highlighted as a special challenge for CA, but it is a challenge in all production systems. More research is necessary to provide local solutions based on integrated weed management in CA systems that can keep the use of herbicides to a minimum or avoided where necessary or possible.

The economic benefits for farmers who have adopted CA have been striking. According to Crabtree (2010), crop productivity in south western Australia has lifted 30–50 percent since the widespread adoption of no-tillage systems. This yield improvement equates to an extra 32 Mt of grain over 10 years. Without the adoption of no-till farming many farmers could not have survived the recent long string of droughts. Beneficial effects of CA have been shown to be cumulative over space as it spreads, and can accumulate over time from relatively degraded condition to improved stabilized condition, with yields and income rising over time, as in the example of mechanised wheat production under CA in the dryland conditions in northern Kazakhstan. Analysis of historical data over 14 years by Fileccia (2009) of the increase in wheat yields and income benefits after changing from conventional tillage to no-till agriculture shows an internal rate of return to investment of 28 per cent. In a wheat-sunflower crop rotation in southern Spain, González Sánchez et al. (2010) reported Euro 235 per ha extra benefit for no-tillage farms in comparison to farms using conventional soil tillage system.

3.2. *Climate change adaptation and reduced vulnerability*

Overall, CA systems have a higher adaptability to climate change because of the higher effective rainfall due to higher infiltration and therefore reduced surface runoff and soil erosion as well as greater soil moisture-holding capacity. Thus crops under CA systems can continue towards maturity for longer than those under conventional tillage (Stewart, 2007).

Increased biopores created by roots and earthworms have been shown to have a role in improving infiltration under CA, and rates of 100 mm/hr or more have been recorded in the dry Mediterranean climate of the Pacific Northwest (Wuest, 2001). Similar higher numbers of biopores and earthworms under CA and increased infiltration have been reported from California's Central San Joaquin Valley (Herrero et al., 2001). Elsewhere in dry Mediterranean Spain, elimination of tillage and maintenance of crop residues show two to three fold increases in precipitation storage efficiencies (Cantero-Martinez et al., 2007). Improved infiltration provides a means to maximize effective rainfall and recharge groundwater as well as reduce risks of flooding. It is thought that due to improved growing season moisture regime and soil storage of water and nutrients, as well as legume cover crops and surface mulch and build-up of soil organic matter, crops under CA require less fertilizer and pesticides to feed and protect the crop (Lafond et al., 2008; Crabtree, 2010; Lindwall and Sonntag, 2010). Good mulch cover provides 'buffering' against extreme temperatures at the soil surface which otherwise are capable of harming plant tissue at the soil/atmosphere interface, thus minimizing a potential cause of limitation of yields. By protecting the soil surface from direct impact by high-energy raindrops, it prevents surface-sealing and thus maintains the soil's infiltration capacity, while at the same time minimizing soil evaporation (Mrabet, 1997 in Morocco; Akbolat et al., 2009 in Turkey; Ben Moussa-Machraoui et al., 2010 in Tunisia).

In the continental regions of Europe, Russia and Canada, where much of the annual precipitation is in the form of snow in the winter, CA provides a way of trapping snow evenly on the field which may otherwise blow away, and also permits snow to melt evenly into the soil. In the dry areas of continental Eurasia, one-third or more of the precipitation is not effectively used in tillage-based systems, forcing farmers to leave land fallow to 'conserve' soil moisture, leading to extensive wind erosion of topsoil from fallow land, and to dust emissions and transport over large distances (Brimili, 2008). Under CA, more soil moisture can be conserved than when leaving the land fallow, thus allowing for the introduction of additional crops including legume cover crops into the system (Blackshaw et al., 2007; Gan et al., 2008; Mrabet, 2008c).

3.3. *Reduced greenhouse gas emissions*

No-till farming also reduces the unnecessarily rapid oxidation of soil organic matter to CO_2 which is induced by tillage (Reicosky, 2008; Nelson et al., 2009). Together with the addition of mulch as a result of saving crop residues, there is a reversal from net loss to net gain of carbon in the soil, and the commencement of long-term processes of carbon sequestration (West and Post, 2002; CTIC/FAO, 2008; Baig and Gamache, 2009). Root biomass, making use of crop residues and the direct rhizospheric exudation of carbon compounds into the soil represent the main sources of the atmospheric C captured by the plants and retained above and below the ground. Some becomes transformed to soil organic matter of which part is resistant to quick breakdown (though still with useful attributes in soil), and represents net C-accumulation in soil, eventually leading to C-sequestration towards a new equilibrium level over the longer-term. Expanded across a wide area, CA has the potential to slow/reverse the rate of emissions of CO_2 and other greenhouse gases by agriculture (Lal, 2002, 2008).

Although exceptions have been reported for some reduced tillage systems, generally there is an increase in soil carbon content under CA systems, as shown by the analysis of global coverage by West and Post (2002) and Corsi et al. (2011). In systems where mineral nitrogen was applied as a fertilizer, the carbon contents increased even more compared to where it was not. Baker et al. (2007) found that crop rotation systems in CA accumulated about 11 t/ha of carbon after 9 years. In the semi-arid areas of Morocco, soil carbon was shown to be 13.6% higher on zero-tilled land but only 3.3% on conventionally tilled land (Mrabet et al., 2001) and soil organic carbon and nitrogen concentrations were significantly higher over a period of 4–13 years (Mrabet, 2008c). The sequestration ability of this soil may go further due to its initial low soil organic matter status and its high clay content. In Morocco, the best results of no-tillage system seem to be obtained on the heaviest clay soils. In three distinct long-term experiments located in northeast Spain, the no-till system increased soil organic carbon content at the soil surface (0–10-cm depth) due to the accumulation of crop residues and lower CO_2 emissions (López-Bellido et al., 2010). In central Spain, López-Fando et al. (2007) reported 13% more soil carbon in no-tillage compared to conventional tillage in the 0–30 cm depth. Also, Ordóñez Fernández et al. (2007) in southern Spain measured 20% more SOC stock under no-till in the top 26 cm soil depth.

The study by Akbolat et al. (2009) in southern Turkey showed that no-till plots produced the lowest soil respiration (CO_2 efflux) relative to mouldboard, chisel plow, heavy disc harrow and rotary tiller plots for a period of 46 days. It is also clear from this study that the rainfall event had less influence on soil CO_2 efflux in the no-till plots than in the tilled plots. In Spain, soil disturbance by tillage caused an immediate sharp increase in soil CO_2 flux. This was a relatively short process lasting less than 3 h from tillage (López-Garrido et al., 2009). In a four-season study in southern Spain, Carbonell-Bojollo et al. (2011) measured higher CO_2 values on the order of between 39% and 90% in the tilled soils compared to no-tilled plots. The amount of CO_2 emitted immediately after tillage was proportional to the degree of soil disturbance produced (Álvaro-Fuentes et al., 2007).

With CA, reduced use of tractors and other powered farm equipment results in lower CO_2 emissions. Up to 70 per cent in fuel savings have been reported (FAO, 2008). CA systems can also help reduce the emissions for other relevant greenhouse gases, such as methane and nitrous oxides, if combined with complementary

Table 2
Extent of adoption of conservation agriculture in countries with dry mediterranean climate.

Country	Area under CA ('000 ha)
USA	26,500
Argentina	25,553
Australia	17,000
Kazakhstan	1600
Spain	650
South Africa	368
France	200
Chile	180
Italy	80
Mexico	41
Portugal	32
Syria	18
Tunisia	8
Morocco	4
Lebanon	1
Total	72,235

Source: Aquastat (http://www.fao.org/ag/ca/6c.html).

techniques. Both methane and nitrous oxide emissions result from poorly aerated soils, from severely compacted soils, or from heavy poorly drained soils. CA soil management favours the abundance of methane oxidizing bacteria leading to reduced methane emission (Ceja-Navarro et al., 2010).

The soil is a dominant source of atmospheric N_2O (Houghton et al., 1997). The rate of production and emission of N_2O depends primarily on the availability of a mineral N source, the substrate for nitrification or denitrification, on soil temperature, soil water content, and (when denitrification is the main process) the availability of labile organic compounds. These variables are universal and apply to cool temperate and also warm tropical ecosystems.

Addition of fertilizer N, therefore, directly results in extra N_2O formation as an intermediate in the reaction sequence of both processes which leaks from microbial cells into the atmosphere (Firestone and Davidson, 1989). In addition, mineral N inputs may lead to indirect formation of N_2O after N leaching or runoff, or following gaseous losses and consecutive deposition of N_2O and ammonia (Kuikman et al., 2006). Nitrogen leaching and nitrogen runoff are minimal under CA systems, and over the longer-term CA generally reduces the need for mineral N by 30–50 per cent in the longer run (Crabtree, 2010). Thus overall, CA has the potential to lower N_2O emissions as reported by Parkin and Kaspar (2006) and Baig and Gamache (2009). Increase in N_2O under no-till has been reported (e.g. Bhogal et al., 2007) and this can happen with soils that have a history of intensive tillage prior to being used for no-till research or from traffic compaction on poorly structured soils. Such soils suffer from blocked or poor drainage due to compaction and hard plough pan. While tillage temporarily reduces water logging or surface compaction during the season and therefore can show lower N_2O emissions, in general, however, soils with good drainage under CA have lower N_2O emissions than from regularly tilled soils (Baig and Gamache, 2009; Omonode et al., 2010).

4. Adoption of CA in the dry Mediterranean climate

According to the FAO global data base (www.fao.org/ag/ca), during the last 11 years CA worldwide has expanded at an average rate of about 7 million ha per year from 45 million ha in 1999 to some 125 million ha in 2011, about 9% of global cropland, or 14% of the cropland in the countries that have adopted CA (Friedrich et al., 2012).

In the Mediterranean basin, modest adoption has occurred in several countries (Table 2). These include Spain, Portugal, France and Italy in Europe; Morocco and Tunisia in North Africa. Applied and adaptive research work on CA has also produced promising results in several countries in West Asia such as Syria, Lebanon, Jordan, Turkey and Iraq and in Central Asia and the Caucasus such as Uzbekistan and Kazakhstan. Only in Kazakhstan has the extent exceeded one million hectares. Outside the Mediterranean basin region, there are several countries with a dry Mediterranean climate that have shown successful adoption of CA. These include the USA, Chile, Argentina, South Africa and Australia but the information on the actual extent of adoption in the Mediterranean climate in these countries is not known.

A brief description of the status of adoption in countries with dry Mediterranean-type climate is presented below based on Derpsch and Friedrich (2009a,b) and Kassam et al. (2010) and on the recently updated FAO-AQUASTAT global CA adoption data base (FAO, 2011c).

4.1. North and South America

United States in 2007, according to CTIC, shows no-tillage adoption on 26,493,000 ha, corresponding to 16% of total cropland area. The numbers reveal that the majority of farmers in this country are still using conventional intensive or reduced tillage practices despite the fact that the adoption of CA has increased steadily over the years, and is expected to continue in the future.

The adoption of CA in the dry Mediterranean area of the Pacific Northwest shows that without no-till farming it would be highly risky to produce crops in the very dry areas with less than 200 mm rainfal (e.g., Williams et al., 2009). Many of the key benefits mentioned in Section 3 have been reported for no-till systems in this area but only some 10–15% of winter wheat and 20% of the spring wheat are under no-till systems (Young and Upadhyay, 2003). In Washington and Oregon, the lowest rainfall amount for wheat production with no-till is 150–200 mm received as snow and rain. This amount is exceptionally low to produce a grain crop but with good CA practices, yields of 1.5–1.8 t/ha have been reported. The key contribution of CA in this dry area is that it reduces risks of failure due to climatic variability and extends the limits of arable cropping into very low rainfall area. Also, no-till farming has allowed the cultivation of very steep slopes which would not have been possible under tillage-based system. There is little no-till farming being practised in the Mediterranean-type climate of the south western USA.

Argentina first research and farm experiences with no-till started in Argentina in the early 1970s. A milestone in the development and spread of CA in Argentina was the foundation in 1986 of AAPRESID, the Argentinean Association of No-till Farmers, based in Rosario. Since the founding of AAPRESID, Argentina also experienced an exponential growth in no-till farming (Derpsch and Friedrich, 2009b) including in the dry Mediterranean climate of central Argentina. Currently, adoption covers 25.5 million hectares, 76% of all cropland.

In central Argentina with Mediterranean climate, CA is practised on nearly 20 million hectare representing about 60% of the arable land. The adoption of CA in this environment has boosted production by expanding cropping into low rainfall areas which under conventional tillage would not have safely produced a crop (Derpsch and Friedrich, 2009b).

Chile CA was pioneered in 1978 in the Concepción region of central Chile, which has a dry (sub-tropical and temperate) Mediterranean-type climate where there are now about 180,000 ha of CA being practised, which is about 30% of the cropped area in rainfed farming systems (Derpsch and Friedrich, 2009b).

4.2. Europe

Increased awareness of farmers, politicians and society as a whole that soils are a non-renewable resource is leading to gradual changes in the overall approach to soil conservation (Basch et al., 2008), and some countries in the Mediterranean Europe have begun to make progress such as Spain, France, Portugal and Italy. According to Basch et al. (2011), more and more scientific papers support the use of CA in Europe and more and more farms are successfully implementing CA (e.g. Álvaro-Fuentes et al., 2008; Basch et al., 2008; Tebrügge and Böhrnsen, 1997; Basch et al., 1995).

Spain is the leading country in terms of CA adoption in Europe with research on CA going back to 1982 (Giráldez and González, 1994). According to AEAC/SV (Spanish Conservation Agriculture Association–Living Soils), CA with annual crops is practised on 650,000 ha, corresponding to 5% of cropland. Main crops are wheat, barley and much less maize and sunflowers. Besides annual crops, many olive plantations and fruit orchards have adopted CA. The Spanish Ministry of Environment and Rural and Marine Affairs (MERMA, 2010) reports 1,218,726 ha of CA is being practised with perennial trees, in most cases in combination with cover crops and livestock (generally sheep). Main tree crops in combination with cover crops are olives and grapes and, much less, orange, almond and other perennial fruit trees. The extent of CA with tree crops is not included in the estimates in Table 2.

France long-term experiments with different minimum tillage techniques (including no-tillage) were started by INRA and ITCF in 1970, mainly with cereals (Boisgontier et al., 1994). France is among the more advanced countries in Europe in terms of adoption of CA. APAD (The French No-Till Farmers Association) estimates that CA is practised on about 200,000 ha, corresponding to just over 1% of arable land. Some farmers have developed superior CA systems with green manure cover crops and crop rotation which are working well. CIRAD has also been researching on and promoting CA internationally for many years under the term 'Direct Seeded Mulch-Based Cropping System' (DMC). According to Rass et al. (2011) the performance of farmers who have succeeded and persisted over the years with CA in France can be summarized by the practical experience in Brittany on the farm of Bertrand Paumier as evaluated by Schreiber (2011): yields are being maintained or improved; soil and ecosystem services are being improved including soil organic matter, biodiversity, C sequestration; nitrate pollution is being reduced; competitiveness is increasing; inputs of energy, fertilizers, pesticides, time and finance are reduced.

Portugal and Italy despite showing significant signs of soil degradation and erosion since ancient times (Montgomery, 2007), the levels of CA adoption are fairly low. According to the European Conservation Agriculture Federation (ECAF, 2010), Portugal has some 32,000 ha under CA, and Italy has some 80,000 ha under CA, referred to as *Agricultura Blu* (Pisante, 2007).

4.3. Australia

According to WANTFA (Western Australian No-Till Farming Association), no-tillage system is now practised on about 17 million ha (Derpsch and Friedrich, 2009b). Overall large increases in adoption have been experienced since 2003. Reduced soil disturbance through no-till and CA have led to large increases in profitability, sustainability and environmental impact in the Australian cropping belt (Llewellyn et al., 2009). The proportion of growers using at least some CA is now peaking at levels over 90% in south western Australia. In regions with relatively low adoption five years ago, there have been rapid increases in uptake, particularly in the period 2003–2006 (Llewellyn et al., 2009).

CA is expected to continue to spread, because of the water, time and fuel savings, as well as the other advantages of the system. Most farmers used air seeders equipped with narrow knife point openers, but this is changing and an increasing number of farmers use disc openers (Ashworth et al., 2010). Also, the use of cover crops is getting popular among CA farmers. Combining cropping with livestock (generally sheep) is a common practice throughout the country. Another complementary technology used in Australia on CA farms is controlled traffic farming to avoid soil compaction (Tullberg et al., 2007; Crabtree, 2010).

According to Flower et al. (2008), the success of CA in Australia generally has been due to the farmer-driven adoption. However, collaboration between farmer groups, research, extension, and industry organizations is vital to accelerate and sustain the spread of high quality CA. Similar lessons are known from other dry Mediterranean environments such as Argentina, Spain and Kazakhstan.

4.4. West and Central Asia

Kazakhstan: CA has had a rapid development in recent years as a result of farmers' interest, facilitating government policies and an active input supply sector. CA was promoted for some time by CIMMYT and FAO. Adoption started from 2004 onwards in the north provinces (North Kazakhstan, Kostanai and Akmola) where the highest adoption rates have been registered (Derpsch and Friedrich, 2009b). A survey in the country showed a total area of adoption of 600,000 ha in 2007 and 1.3 million ha in 2008 and 1.6 million in 2011 (FAO, 2011c). Incentive is offered to no-till farmers by government who are also supporting research to maximise effective winter snowfall through stubble trapping; to increase the generation of biomass through cover crops instead of bare or chemical fallows; to diversify cropping systems; and to improve integrated weed management (Gan et al., 2008; Suleimenov and Thomas, 2006; Suleimenov and Akshalov, 2006).

Turkey, Syria, Iraq, Lebanon and Jordan: In these countries there is an increased interest in CA at government level, mainly resulting from pilot research projects and regional meetings on CA. So far only in Syria there has been a significant adoption over some 18,000 ha (Pala et al., 2007; Piggin et al., 2011). There is also a beginning of CA adoption in Ninevah province in Iraq (Piggin et al., 2011), while Lebanon and Jordan are supporting pilot activities in CA.

4.5. Africa

In **North Africa**, no-tillage systems have been promoted particularly in Morocco and Tunisia. In Morocco 4000 ha of no-tillage have been reported, despite long-term research on no-till farming having been initiated in the early eighties. Lack of concerted policy support and multi-stakeholder network to promote CA remains a major constraint (Mrabet, 2008c). In Tunisia the promotion and development was farmer centred and the area under no-tillage increased from 27 ha in 1999 to nearly 6000 ha in 2007 and 8000 ha in 2008 (FAO, 2011c). One limiting factor for further spread of CA is the unavailability of low cost CA equipment.

South Africa has experienced only a modest growth in the area under CA since 2005 when it was 300,000 ha which has increased to about 368,000 ha since then (Derpsch and Friedrich, 2009b).

5. Opportunities for CA Systems in the CWANA region

A good deal of scientific and operational research has been done in most of the countries with dry Mediterranean climate in the CWANA region as well as in the Mediterranean climate more generally (Stewart et al., 2007; Goddard et al., 2008; Lahmar, 2008). By and large, the international work shows that CA does work in the Mediterranean-type climate. The key benefits from CA, as elaborated in Section 3, can be harnessed by small and large farmers alike by introducing the three principles of CA into most of the irrigated and rainfed production systems.

According to Lahmar and Triomphe (2007), CA is perceived as a powerful tool of land management in dry Mediterranean areas of the CWANA region. It allows farmers to improve their productivity and profitability especially in dry areas while conserving and even improving the natural resource base and the environment. However, CA adaptation in drylands faces critical challenges linked to water scarcity and drought hazard, low biomass production and acute competition between conflicting uses including soil cover, animal fodder, cooking/heating fuel, raw material for habitat etc. Poverty and vulnerability of many smallholders that rely more on livestock than on grain production are other key factors.

5.1. Rainfed CA Systems

In general, much of the CA work that has been done in various countries has shown that yields and factor productivities can be improved with no-till systems. Extensive research and development work has been conducted in several countries in the CWANA region since the early 1980s such as in Morocco (Mrabet, 2008a,b,c,d); and more recently in Tunisia (Ben-Hammouda et al., 2007), in Syria, Lebanon and Jordan (Bashour, 2007; Pala et al., 2007; Ghosheh, 2007) and in Turkey (Avci et al., 2007). Similarly in Central Asia, work on CA practices for Eurasia has been reported by Gan et al. (2008), for Kazakhstan by Fileccia (2009) and Suleimenov (2009), and for Uzbekistan by FAO (2009) and Nurbekov et al. (2011). ICARDA and CIMMYT have also been active in CA research in the CWANA region (Pala et al., 2007; Karabayev, 2008; Suleimenov, 2009; Piggin et al., 2011).

Key lessons from international experiences about CA and considerations for its implementation in the Mediterranean region have been summarised by Cantero-Martinez et al. (2007), Lahmar and Triomphe (2007), Pala et al. (2007) and Mrabet (2010). They all endorse the potential benefits that can be harnessed by farmers in the dry environments in the CWANA region while highlighting the need for longer-term research including on weed management, crop nutrition and economics of CA systems. In addition, it is clear that without farmer engagement and appropriate enabling policy and institutional support to achieve effective farmer engagement and a process for testing CA practices and learning how to integrate them into production system, rapid uptake of CA is not likely to occur (Friedrich and Kassam, 2009).

5.2. Potential for adoption in CWANA region

There are some farming regions that present special challenges for introducing sustainable agro-ecological production systems. For example in some dry areas of the Mediterranean climate in the CWANA region, it may not be possible to apply the precepts of CA system to an optimum level in the initial years because the lack of rainfall may limit how much biomass can be produced per unit area and the portion that can be allocated for soil cover. While not tilling the soil reduces carbon losses, it is sufficient in these situations of conflicting uses for residues, for example, to leave only a minimum amount of residues in the field required to reverse the downward spiral of soil degradation. According to FAO (2011a), the minimum amount should allow, as rapidly as possible, the build-up of mulch that covers 30% of the soil surface at planting. Since in CWANA regions water is normally the limiting factor in crop production, water savings from not tilling the soil generally result in yield and biomass increases already in the first years which can compensate for the amounts of residue that may be removed for forage and bioenergy purposes (Piggin et al., 2011). However, it is not unusual to find that 20–30% of the agricultural land in the cropped CWANA region is set aside as fallow land at any given time. It should be possible to bring much of this land back into production with CA systems involving legume cover crops that can improve soil organic matter, soil structure and soil health as well as improve the availability of higher quality livestock fodder (Suleimenov, 2009).

5.3. Irrigated CA Systems

CA has not been introduced into irrigated agriculture to any significant degree in the dry Mediterranean climate (Mrabet et al., 2010). However, the principles and practices involved with CA systems apply to both rainfed systems and irrigated systems (Gómez-Macpherson et al., 2009). In the case of irrigated rice, systems of production that avoid or minimize soil disturbance can work well with CA. This is beginning to occur in Egypt where wheat–rice–cotton–legume rotations are widespread. Surface irrigation systems require special attention to residue management, but as all other irrigation systems they likewise benefit from water savings under CA. In Central Asia, particularly in Uzbekistan and Kyrgyzstan, wheat and cotton are dominant irrigated crops produced under tillage-based system and Nurbekov et al. (2011) report benefits of CA in reducing water deficit and soil salinity.

In recent years, supplementary micro irrigation has become popular for cereal crops to harness savings in crop water requirements which can be reduced further under CA systems (Gómez-Macpherson et al., 2009; Mrabet et al., 2010). Vegetable and fruit production under irrigation after rainfed cereal is common in the dry Mediterranean climate including the mountainous areas in Central Asia, and such systems can benefit from the adoption of CA practices with micro irrigation.

5.4. Integration of trees and livestock in CA Systems

Crops, trees and livestock have useful synergies in integrated systems. However, much of the work on CA in the dry Mediterranean climate has focussed on arable crops in rainfed systems. There is little work so far on the integration of trees and livestock into CA systems (Calatrava and Franco, 2011). However, cereal-based CA systems in CWANA region frequently have small ruminants as part of the farming system, and tree crops such as olives are often an integral part of the farming system. In general, it is essential to ensure that where livestock is an integral component of the farming system, there is enough in situ biomass being produced within the cropping system to support its multiple functions including protecting and feeding the soil as well as serving as livestock feed. Where there is a conflict for biomass between livestock and soil, it means that the production system is not generating enough biomass, or the stocking rate is beyond the lands carrying capacity for the production systems being practised (Mrabet, 2008c).

In the dry Mediterranean climate, there are several sources of biomass such as crop residues, fodder crops including sown and natural pastures of annual and perennial grasses, annual and perennial forage legumes, leguminous and non-leguminous cover crops, and trees and perennial shrubs such as cactus and *Atriplex*, *Acacia, Artemesia, Opuntia* and *Salsola* (Thomas et al., 2003). In general, crop residues tend to be consumed by livestock, and there is no allocation of residues to apply to the soil. Also, stubble can be used under CA systems to protect the soil and trap the snow as is done in Kazakhstan. The situation in the dry Mediterranean climate in the CWANA region will need to change in the future to accommodate greater production, retention and build-up of biomass within the system, ensuring sustainable stocking rates. Given the variability in rainfall and the mobility of herds, the maintaining of sustainable stocking rates in line with carrying capacity will need to be managed more dynamically than has been done so far. In many cases the solution will need to be formulated and managed at the community level between the settled crop producers and the pastoralist population who have a long tradition of utilizing all crop residues after harvest. Some researchers see this in terms of competition of crop residue for soil cover and other uses such as livestock feed and fuel. The current arrangement between the sedentary crop producers and the pastoralists is many centuries old but it does not take adequate account of the need to build and protect soil health and rehabilitate and harness environmental services at the landscape level. This aspect, until recently, has not been considered to be a necessary element of the ecological sustainability of agriculture and the larger ecosystem. If CA is to be adopted widely in such areas, this state of affairs will need to change over time, requiring new community-based arrangements for the effective management of the functional biomass (crop residues and other sources of biomass) in space and time between different uses. Kattach (2008) shows, for the example in Syria, how stocking rate and grazing management can influence the biomass production of marginal lands under dry Mediterranean conditions, confirming that with a different land management the productive capacity even under those conditions can be increased to allow for sufficient organic matter addressing both, soil maintenance and animal feed.

Integration of trees and shrubs into CA systems is a compatible practice since no-till favours the establishment and good growth performance of trees and shrubs that can add biomass and resilience to the production system as well as many other advantages related to ecosystem services and livelihood (Duran Zuazo and Rodriguez Pleguezuelo, 2008; Gómez et al., 2009).

6. Discussion

In the dry Mediterranean areas, low and variable of rainfall lead to agro-ecological conditions that can benefit from the use of CA practices to overcome some of the severe natural resource constraints, such as heavy soil erosion through high intensity rain falling on bare soil, generally low soil organic matter contents in agricultural soils and thus poor soil fertility, and water scarcity in the summer season. These constraints severely threaten the ecological, agronomic and economic sustainability of farming.

Despite the obvious productivity, economic, environmental and social advantages of CA, adoption has not happened spontaneously. There are good reasons for individual farmers not to adopt CA in her/his specific farm situation. The origin of the hurdles ranges from psychological, intellectual, social, financial, biophysical and technical, infrastructural to policy issues (Friedrich and Kassam, 2009). Unavailability of suitable CA equipment and machinery is a constraint in general (Friedrich et al., 2009b), and especially in the CWANA region. Knowing the respective bottlenecks and problems allows developing strategies to overcome them. Crisis situations, such as the recent surge in food and agricultural inputs, and increasing environmental concerns may provide justification for policy makers to support CA adoption. This could include payments to farmers for sustainable agricultural land use linked to up-take of CA.

Compared to conventional systems, CA has been found to maintain or increase yields, reduce production cost and labour requirements, improve soil fertility and reduce erosion. These incentives could make CA a viable alternative in drylands of CWANA, where it could help address the challenges of scarcity and degradation of the natural resources. However, these benefits might not be equally applicable for all agro-ecosystems; important variability and system tradeoffs could limit the expansion and adoption of these technologies in smallholdings (Giller et al., 2009; Lahmar, 2008). The development, specific design and hence the sustainability of CA systems seem to be highly site specific. There is a critical need for a comprehensive assessment of the ecological and socio-economic conditions under which CA would be adapted for smallholder farming in dry areas. The transition period during the shift from conventional agriculture to CA should involve all the relevant stakeholders to generate and to share knowledge necessary to adapt, adjust and optimize the systems components. Risk coping mechanism for potential adopters and more importantly effective technical assistance are key elements for uptake of CA under difficult biophysical conditions (Meyer, 2009). The competing uses for crop residues could be potentially resolved through better area and on-farm integration of crop-fodder-tree-livestock systems involving community-based approaches to the effective management of functional biomass and stocking rates. The dynamic functioning and evolution of these integrated systems and their long-term impacts on the potential productivity of agro-ecosystems also deserve a sustained research attention in the future.

While there is increasing research interest being shown towards CA systems in the Mediterranean climate and elsewhere, the spread of CA must involve the engagement of the farmers whose commitment can be mobilised to try new CA practices to harness the productivity, economic and environmental benefits that are possible.

CA has taken off globally and is spreading in several countries with Mediterranean-type climate outside the CWANA region particularly in South and North America, Australia and in South Africa. However, in the countries of the Mediterranean basin and in Central Asia, CA has not taken off as yet in any significant scale, although there has been an expansion in CA adoption in Spain, France, Italy and Portugal in Europe. In the CWANA region, Syria, Tunisia, Iran, Morocco and Lebanon have been promoting CA with some success which shows that it is technically possible to adopt CA under the dry Mediterranean conditions. This slow adoption is also true in Central Asia and the Caucasus, except for Kazakhstan where there are 1.6 million ha of wheat-based CA system. Kazakhstan serves as a good example that shows that accelerated transformation from tillage-based system to CA is possible in the CWANA region if policy and institutional support and relevant knowledge can be provided to farmers. Further, the phenomenal transformation from tillage agriculture to CA (more than 90% of arable cropland) in the dry Mediterranean climate of south western Australia in the last decade has shown that biophysical, economic and knowledge constraints can be surmounted if all the stakeholders can work together.

References

Akbolat, D., Evrendilek, F., Coskan, A., Ekinci, K., 2009. Quantifying soil respiration in response to short-term tillage practices: a case study in southern Turkey. Acta Agri. Scand. Sect. B: Plant Soil Sci. 59, 50–56.

Álvaro-Fuentes, J., Cantero-Martınez, C., López, M.V., Arrúe, J.L., 2007. Soil carbon dioxide fluxes following tillage in semiarid Mediterranean agroecosystems. Soil Till. Res. 96, 331–341.

Álvaro-Fuentes, J., López, M.V., Cantero-Martínez, C., Arrúe, J.L., 2008. Tillage effects on soil organic carbon fractions in Mediterranean dryland agroecosystems. Soil Sci. Soc. Am. J. 72, 541–547.

Ashworth, M., Desbiolles, J., Tola, E.K., 2010. Disc Seeding in Zero-Till Farming Systems: A Review of Technology and Paddock Issues. Western Australia No-Tillage Farmers' Association (WANTFA), Northam, Western Australia.

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

Bashour, I., 2007. Impact of conservation agriculture on soil fertility in dry regions. In: Stewart, B., Fares Asfary, A., Belloum, A., Steiner, K., Friedrich, T. (Eds.), Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas, 7–9 May 2007. ACSAD and GTZ, Damascus, Syria, pp. 111–120.

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

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

Basch, G., Carvalho, M., Düring, R.-A., Martins, R., 1995. Displacement of herbicides under different tillage systems. In: Tebrügge, F., Böhrnsen, A. (Eds.), Proceedings of the EC-Workshop II on Experience with the Applicability of No-tillage

Crop Production in the West-European Countries. Wissenschaftlicher Fachverlag, Langgöns, Germany, pp. 25–38.
Basch, G., Geraghty, J., Stret, B., Sturny, W.G., 2008. No-tillage in Europe—state of the art: constraints and perspective. In: Goddard, T., Zoebisch, M.A., Gan, Y.T., Ellis, W., Watson, A., Sombatpanit, S. (Eds.), No-Till Farming Systems, Special Publication No. 3. World Association of Soil and Water Conservation, WASWC, Bangkok, pp. 159–168.
Basch, G., González-Sánchez, E.J., Gómez McPherson, H., Kassam, A.H., 2011. Opportunities for Conservation Agriculture in the EU Common Agricultural Policy 2014–2020. In: Proceedings of the 5th World Congress of Conservation Agriculture incorporating 3rd Farming Systems Design Conference, September 2011. Brisbane, Australia.
Ben-Hammouda, M., M'Hedhbi, K., Kammassi, M., Gouili, H., 2007. Direct drilling: an agro-environmental approach to prevent land degradation and sustain production. In: Stewart, B., Fares Asfary, A., Belloum, A., Steiner, K., Friedrich, T. (Eds.), Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas, 7–9 May. ACSAD and GTZ, Damascus, Syria, pp. 37–48.
Ben Moussa-Machraoui, S., Errouissi, F., Ben-Hammouda, M., Nouira, S., 2010. Comparative effects of conventional and no-tillage management on some soil properties under Mediterranean semi-arid conditions in north-western Tunisia. Soil Till. Res. 106, 247–253.
Bhogal, A., Chambers, B.J., Whitmore, A.P., Powlson, D.S., 2007. The Effects of Reduced Tillage Practices and Organic Material Additions on the Carbon Content of Arable Soils. Scientific Report for Defra Project SP0561. Rothamsted Research and ADAS, UK.
Blackshaw, R.E., Harker, K.N., O'Donovan, J.T., Beckie, H.J., Smith, E.G., 2007. Ongoing Development of Integrated Weed Management Systems on the Canadian Prairies. Weed Sci. 56, 146–150.
Blank, D., 2008. A fresh look at life beneath the surface. In: Goddard, T., Zoebisch, M., Gan, Y., Ellis, W., Watson, A., Sombatpanit, S. (Eds.), No-Till Farming Systems, Special Publication No. 3. World Association of Soil and Water Conservation, WASWC, Bangkok, pp. 73–81.
Boisgontier, D., Bartholomy, P., Lescar, L., 1994. Feasibility of minimum tillage practices in France. In: Proceedings of the EC-Workshop I on Experience with the Applicability of No-tillage Crop Production in the West-European Countries, Wissenschaftlicher Fachverlag, Giessen, pp. 81–91.
Bolliger, A., Magid, J., Amado, T.J.C., Neto, F.S., dos Santos Ribeiro, MdeF., Calegari, A., Ralisch, R., de Neergaard, A., 2006. Taking stock of the Brazilian zero-till revolution a review of landmark research and farmers' practice. Adv. Agron. 91, 47–64.
Brimili, W., 2008. A case of extreme particulate matter concentrations over Central Europe by dust emitted over the Southern Ukraine. Atmos. Chem. Phys. 9, 997–1016.
Cantero-Martinez, C., Gabina, D., Arrue, J.L., 2007. In: Stewart, B., Fares Asfary, A., Belloum, A., Steiner, K., Friedrich, T. (Eds.), Evaluation of conservation agriculture technology in Mediterranean agriculture systems. Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas, 7–9 May. ACSAD and GTZ, Damascus, Syria, pp. 157–164.
Calatrava, J., Franco, J.A., 2011. Using pruning residues as mulch: analysis of its adoption and process of diffusion in Southern Spain olive orchards. J. Environ. Manage. 92, 620–629.
Carbonell-Bojollo, R., González-Sánchez, E.J., Veróz-González, O., Ordóñez-Fernández, R., 2011. Soil management systems and short term CO_2 emissions in a clayey soil in southern Spain. Sci. Total Environ. 409, 2929–2935.
Ceja-Navarro, J.A., Rivera-Orduña, F.N., Patiño-Zúñiga, L., Vila-Sanjurjo, A., Crossa, J., Govaerts, B., Dendooven, L., 2010. Phylogenetic and multivariate analyses to determine the effects of different tillage and residue management practices on soil bacterial communities. Appl. Environ. Microbiol. 76, 3685–3691.
Corsi, S., Pisante, M., Kassam, A., Freidrich, T., 2011. Soil organic carbon accumulation in conservation agriculture: a review of evidence. In: Proceedings of the 5th World Congress on Conservation Agriculture, 26–29 September 2011. Brisbane, Australia, pp. 60–61.
Crabtree, B., 2010. Search for Sustainability with No-Till Bill in Dryland Agriculture. Crabtree Agricultural Consulting, Australia.
CTIC/FAO, 2008. Mitigating climate change: conservation agriculture stores soil carbon. Recommendations of the Conservation Agriculture Carbon Offset Consultation. CTIC, West Lafayette, IN, 28–30 October. http://www.fao.org/ag/ca.
Derpsch, R., 2004. History of crop production, with and without tillage. Leading Edge 3, 150–154.
Derpsch, R., Friedrich, T., 2009. Global overview of conservation agriculture adoption. In: Proceedings of the 4th World Congress of Conservation Agriculture, 4–7 February 2009. New Delhi, India, pp. 429–438.
Derpsch, R., Friedrich, T., 2009. Development and current status of no-till adoption in the World. In: Proceedings of the 18th Triennial Conference of the International Soil Tillage Research Organization (ISTRO), 15–19 June. Izmir, Turkey.
Duiker, S.W., Beegle, D.B., 2006. Soil fertility distributions in long-term no-till chisel/disk and moldboard plow/disk systems. Soil Till. Res. 88, 30–41.
Duran Zuazo, V.H., Rodriguez Pleguezuelo, C.R., 2008. Soil-erosion and runoff prevention by plant covers: a review. Agron. Sustain. Dev. 28, 65–86.
ECAF, 2010. European Conservation Agriculture Federation Website at: http://www.ecaf.org/.
FAO, 2008. In: Proceedings of the International Technical Workshop on Investing in Sustainable Crop Intensification: The Case for Improving Soil Health, 22–24 July. Integrated Crop Management, Vol. 6. FAO, Rome.
FAO, 2009. Conservation Agriculture in Uzbekistan. Crop and Grassland Service Working Paper 2. FAO, Rome.
FAO, 2011. Save and Grow a Policymaker's Guide to the Sustainable Intensification of Smallholder Crop Production. FAO, Rome.
FAO, 2011. What is Conservation Agriculture? FAO Conservation Agriculture Website at: http://www.fao.org/ag/ca/1a.html.
FAO, 2011. CA Adoption Worldwide. FAO AQUASTAT Conservation Agriculture Website at: http://www.fao.org/ag/ca/6c.html.
Fernández-Ugalde, O., Virto, I., Bescansa, P., Imaz, M.J., Enrique, A., Karlen, D.L., 2009. No-tillage improvement of soil physical quality in calcareous, degradation-prone, semiarid soils. Soil Till. Res. 106, 29–35.
Fileccia, T., 2009. Conservation Agriculture and Food Security in Kazakhstan. Working Paper, FAO Investment Centre Division, June 2009. Rome, FAO.
Firestone, M.K., Davidson, E.A., 1989. Microbiological basis of NO and N_2O production and consumption in soil. In: Andreae, M.O., Schimel, D.S. (Eds.), Exchange of Trace Gases between Terrestrial Ecosystems and the Atmosphere. John Wiley and Sons, Chichester, UK, pp. 7–21.
Flower, K., Crabtree, B., Butler, G., 2008. No-till cropping systems in Australia. In: Goddard, T., Zoebisch, M., Gan, Y., Ellis, W., Watson, A., Sombatpanit, S. (Eds.), No-Till Farming Systems, Special Publication No. 3. World Association of Soil and Water Conservation, WASWC, Bangkok, pp. 457–467.
Friedrich, T., Kassam, A.H., 2009. Adoption of conservation agriculture technologies: constraints and opportunities. In: Proceedings of the 4th World Congress on Conservation Agriculture: Innovations for Improving Efficiency, Equity and Environment, 4–7 February. New Delhi, India (http://www.fao.org/ag/ca/doc/wwcca-leadpapers.pdf).
Friedrich, T., Kassam, A.H., Shaxson, F., 2009a. Conservation agriculture. In: Agriculture for Developing Countries. Science and Technology Options Assessment (STOA) Project. European Technology Assessment Group, Karlsruhe, Germany.
Friedrich, T., Kienzle, J., Kassam, A.H., 2009b. Conservation agriculture in developing countries: the role of mechanization. In: Paper Presented at the Club of Bologna Meeting on Innovation for Sustainable Mechanisation, Hanover, Germany, 2 November.
Friedrich, T., Derpsch, R., Kassam, A., 2012. Global overview of the spread of Conservation Agriculture. Field Act. Sci. Reports (in press).
Gan, Y., Harker, K.N., McConkey, B., Suleimanov, M., 2008. Moving towards no-till practices in Northern Eurasia. In: Goddard, T., Zoebisch, M., Gan, Y., Ellis, W., Watson, A., Sombatpanit, S. (Eds.), No-Till Farming Systems, Special Publication No. 3. World Association of Soil and Water Conservation, WASWC, Bangkok, pp. 179–195.
Ghosheh, H., 2007. Application of sustainable agriculture principles in weed management. In: Stewart, B., Fares Asfary, A., Belloum, A., Steiner, K., Friedrich, T. (Eds.), Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas. ACSAD and GTZ, Damascus, Syria, 7–9 May, pp. 209–218.
Giller, K.E., Witter, E., Corbeels, M., Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: the heretics' view. Field Crop. Res. 114, 23–34, doi:10.1016/j.fcr.2009.06.017.
Giráldez, J.V., González, P., 1994. No-tillage in clay soils under Mediterranean climate: physical aspects. In: Proceedings of the EC-Workshop I on Experience with the Applicability of No-tillage Crop Production in the West-European Countries, Wissenschaftlicher Fachverlag, Giessen, 27–28 June, pp. 111–117.
Goddard, T., Zoebisch, M.A., Gan, Y.T., Ellis, W., Watson, A., Sombatpanit, S. (Eds.), 2008. No-Till Farming Systems, Special Publication No. 3. World Association of Soil and Water Conservation (WASWC), Bangkok.
Gómez, J.A., Sobrinho, T.A., Giráldez, J.V., Fereres, E., 2009. Soil management effects on runoff erosion and soil properties in an olive grove of Southern Spain. Soil Till. Res. 102, 5–13.
Gómez-Macpherson, H., Boulal, H., Mrabet, R., Gonzalez, E., 2009. Rational and application of conservation agriculture for irrigated production in Southern Europe and North Africa. In: Proceedings of the 4th World Congress on Conservation Agriculture: Innovations for Improving Efficiency, Equity and Environment, Delhi, India, 4–7 February, pp. 129–135, http://www.fao.org/ag/ca/doc/wwcca-leadpapers.pdf.
González Sánchez, E., Pérez García, J.J., Gómez Ariza, M., Márquez García, F., Veroz González, O., 2010. Sistemas agrarios sostenibles económicamente: el caso de la siembra directa. Vida Rural 312, 24–27.
Harker, K.N., Blackshaw, R.E., 2009. Integrated cropping systems for weed management. Prairie Soils Crops J. 2, 52–63.
Herrero, E.V., Mitchell, J.P., Lanini, W.T., Temple, S.R., Miyao, E.M., Morse, R.D., Campiglia, E., 2001. Calif. Agric. 55, 30–34.
Hobbs, P.R., 2007. Conservation agriculture: what is it and why is it important for future sustainable food production? J. Agric. Sci. 145, 127–137.
Houghton, J.T., Meira Filho, L.G., Lim, K., Trennton, I., Mamaty, I., Bonduki, Y., Griggs, D.J., Callander, B.A. (Eds.), 1997. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, 1–3. Intergovernmental Panel on Climate Change. WMO/UNEP, Cambridge University Press, Cambridge, UK.
Karabayev, M., 2008. Improvement of soil and water management in Kazakhstan: conservation agriculture for wheat production and crop diversification. In: Proceedings of the International Technical Workshop on Investing in Sustainable Crop Intensification: The Case for Improving Soil Health, Integrated Crop Management, Vol. 6. FAO, Rome, 22–24 July.

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

Kassam, A.H., 1988. Some agroclimatic characteristics of high-elevation areas in North Africa, West Asia and Southeast Asia. In: Srivastava, J.P., Saxena, M.C., Varma, S., Tahir, M. (Eds.), Winter Cereals and Food Legumes in Mountainous Areas. ICARDA, Aleppo, Syria, pp. 1–32.

Kassam, A.H., Friedrich, T., Shaxson, F., Jules, P., 2009. The spread of conservation agriculture: justification, sustainability and uptake. Int. J. Agric. Sust. 7, 292–320.

Kassam, A.H., Friedrich, T., Derpsch, R., 2010. Conservation agriculture in the 21st century: a paradigm of sustainable agriculture. In: Proceedings of the European Congress on Conservation Agriculture, 6–8 October, Madrid, Spain.

Kassam, A.H., Friedrich, T., Shaxson, F., Reeves, T., Pretty, J., de Moraes Sa, J.C., 2011. Production Systems for Sustainable Intensification – Integrating Productivity with Ecosystem Services. Technology Assessment – Theory and Prexis, Special Issue on Feeding the World, July.

Kattach, G., 2008. The use of forage plants for landscape management and soil conservation in dry areas. In: Stewart, B.I., Fares Asfary, A., Belloum, A., Steiner, K., Friedrich, T. (Eds.), Proceedings of the International workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas, 7–9 May 2007. ACSAD/GTZ, Damascus, Syria.

Kuikman, P.J., van der Hoek, K.W., Smit, A., Zwart, K., 2006. Update of Emission Factors for Nitrous Oxide from Agricultural Soils on the Basis of Measurements in the Netherlands. Alterra Report 1217, Wageningen, The Netherlands.

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

Lahlou, S., Ouadia, M., Malam Issa, O., Le Bissonnais, Y., Mrabet, R., 2005. Modification de la porosité du sol sous les techniques culturales de conservation en zone semi-aride Marocaine. Etude et Gestion des Sols 12, 69–76.

Lahmar, R., 2008. Adoption of conservation agriculture in Europe: lessons of the KASSA project. Land Use Policy 27, 4–10, doi:10.1016/j.landusepol.2008.02.001.

Lahmar, R., Ruellan, A., 2007. Dégradation des sols et stratégies coopératives en Méditerranée La pression sur les ressources naturelles et les stratégies de développement durable. Cahiers Agric. 16, 318–323.

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

Lal, R., 2002. Carbon sequestration in dryland ecosystems of West Asia and North Africa. Land Degrad. Dev. 13, 45–59.

Lal, R., 2008. Carbon sequestration in dryland ecosystems. Environ. Manage. 33, 528–544.

Lindwall, C.W., Sonntag, B. (Eds.), 2010. Landscape Transformed: The History of Conservation Tillage and Direct Seeding. Knowledge Impact in Society. University of Saskatchewan, Sakskatoon.

Llewellyn, R.S., D'Emden, F., Gobbett, D., 2009. Adoption of no-till and conservation farming practices in Australian grain growing regions: current status and trends. Preliminary Report for South Australia No-Till Farmers Association (SANTFA) and CAAANZ, 26 January.

López-Bellido, R.J., Montan, J.M., López-Bellido, F.J., López-Bellido, L., 2010. Carbon sequestration by tillage rotation, and nitrogen fertilization in a Mediterranean Vertisol. Agron. J. 102, 310–318.

López-Fando, C., Almendros, G., 2000. Interactive effects of tillage and crop rotations on yield and chemical properties of soils in semi-arid central Spain. Soil Till. Res. 36, 45–57.

López-Fando, C., Dorado, J., Pardo, M.T., 2007. Effects of zone-tillage in rotation with no-tillage on soil properties and crop yields in a semi-arid soil from central Spain. Soil Till. Res. 95, 266–276.

López-Garrido, R., Díaz-Espejo, A., Madejón, E., 2009. Carbon losses by tillage under semi-arid Mediterranean rainfed agriculture (SW Spain). Spanish J. Agric. Res. 7, 706–716.

Magnan, N., Lybbert, T.J., Mrabet, R., Fadlaoui, A., 2011. The quasi-option value of delayed input use under catastrophic drought risk: the case of no-till in Morocco. Am. J. Agric. Econ. 93, 498–504.

MERMA, 2010. Encuesta Nacional de Superficies y Rendimientos. Análisis de las técnicas de mantenimiento del suelo y métodos de siembra en España 2010. Viewed 4 July 2011 at: http://www.marm.es/es/estadistica/temas/encuesta-sobre-superficies-y-rendimientos-de-cultivos-esyrce-/EstudioMantenimientoSuelo2010_tcm7-147011.pdf.

Meyer, T., 2009. Direct Seed Mentoring Project Final Report. Spokane County Conservation District, Washington State, USA.

Montgomery, D., 2007. Dirt: The Erosion of Civilizations. University California Press, Berkeley, Los Angeles.

Moreno, F., Arrúe, J.L., Cantero-Martínez, C., López, M.V., Murillo, J.M., Sombrero, A., López-Garrido, R., Madejón, E., Moret, D., Álvaro-Fuentes, J., 2010. Conservation agriculture under Mediterranean conditions in Spain. Sust. Agric. Rev. 5, 175–193.

Mrabet, R., 1997. Crop Residue Management and Tillage Systems for Water Conservation in a Semiarid Area of Morocco. Ph.D. Dissertation. Colorado State University, Fort Collins, CO, USA.

Mrabet, R., 2000. Differential response of wheat to tillage management systems under continuous cropping in a semiarid area of Morocco. Field Crops Res. 66, 165–174.

Mrabet, R., 2002. Wheat yield and water use efficiency under contrasting residue and tillage management systems in a semiarid area of Morocco. Exp. Agric. 38, 237–248.

Mrabet, R., 2008a. Lasting benefits from no-tillage systems: erosion control and soil carbon sequestration. In: Stewart, B.I., Fares Asfary, A., Belloum, A., Steiner, K., Friedrich, T. (Eds.), Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas. 7–9 May 2007, ACSAD and GTZ, Damascus, Syria, pp. 72–92.

Mrabet, R., 2008b. Conservation agriculture in Morocco: a research review. In: Stewart, B.I., Fares Asfary, A., Belloum, A., Steiner, K., Friedrich, T. (Eds.), Proceedings of the International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas. 7–9 May 2007, ACSAD and GTZ, Damascus, Syria, pp. 183–208.

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

Mrabet, R., 2008d. No-till practices in Morocco. In: Goddard, T., Zoebisch, M., Gan, Y., Ellis, W., Watson, A., Sombatpanit, S. (Eds.), No-Till Farming Systems, Special Publication No. 3. World Association of Soil and Water Conservation, WASWC, Bangkok, pp. 393–412.

Mrabet, R., 2010. No-tillage agriculture in West Asia and North Africa: paradigms, trade-offs and perspectives. In: Proceedings of the International Conference on Combating Land Degradation in Agricultural Lands (ICCLD' 10), World Association of Soil and Water Conservation (WASWC), 11–15 October. Springer, Xi'an, Shaanxi Province, PR China, pp. 1140–1144.

Mrabet, R., Saber, N., El-Brahli, A., Lahlou, S., Bessam, F., 2001. Total particulate organic matter and structural stability of a calcixeroll soil under different wheat rotations and tillage systems in a semiarid area of Morocco. Soil Till. Res. 57, 225–235.

Mrabet, R., Essahat, E., Gomez-Macpherson, H., Falisse, A., Alghoum, M., 2010. Coupling conservation agriculture and supplementary irrigation for improving yield and yield stability of wheat and chick pea in semiarid Morocco. In: Proceedings of the European Congress on Conservation Agriculture: Towards Agro-Environmental, Climate and Energetic Sustainability, Madrid, Spain, 4–7 October, pp. 581–584.

Nelson, R.G., Hellwinckel, C.M., Brandt, C.C., West, T.O., Ugarte De La, T., Marland, G., 2009. Energy uses and carbon dioxide emissions from crop-land production in the United States, 1990–2004. J. Environ. Qual. 38, 418–425.

Nurbekov, A., Suleimenov, M., Freidrich, T., Taher, F., Ikramov, R., Nurjanov, N., 2011. No-till practices in the drought and salt-affected region of Uzbekistan. In: Proceedings of the 5th World Congress on Conservation Agriculture, 26–29 September, Brisbane, Australia, pp. 410–412.

Omonode, R.A., Smith, D.R., Gál, A., Vyn, T.J., 2010. Soil nitrous oxide emissions in corn following three decades of tillage and rotation treatments. Soil Sci. Soc. Am. J. 75, 152–163, doi:10.2136/sssaj2009.0147.

Ordóñez Fernández, R., González Fernández, P., Giráldez Cervera, J.V., Perea Torres, F., 2007. Soil properties and crop yields after 21 years of direct drilling trials in Southern Spain. Soil Till. Res. 94, 47–54.

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

Parkin, T.B., Kaspar, T.C., 2006. Nitrous oxide emissions from corn-soybean systems in the mid-west. J. Environ. Qual. 35, 1496–1506.

Piggin, C., Haddad, A., Khalil, Y., 2011. Development and promotion of zero-tillage in Iraq and Syria. In: Proceedings of the 5th World Congress on Conservation Agriculture, Brisbane, Australia, 26–29 September, pp. 304–305.

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

Pretty, J., 2008. Agricultural sustainability: concepts, principles and evidence. Philos. Trans. R. Soc. Lond. B 363, 447–466.

Rass, G., Lavier, B., Kassam, A.H., Derpsch, R., Friedrich, T., Richard, J.-F., Reicosky, D., 2011. From local min-till experience towards a strategy for development of conservation agriculture in the European Union. In: Proceedings of the 5th World Congress of Conservation Agriculture Incorporating 3rd Farming Systems Design Conference, September 2011. Brisbane, Australia.

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

Ryan, J., de Pauw, E., Gomez, H., Mrabet, R., 2006. Drylands of the Mediterranean Zone: Biophysical Resources and Cropping Systems, in: Peterson, G.A., Unger, P.W., Payne, W.A. (Eds.), Dryland Agriculture, second ed. American Society of Agronomy Monograph No. 23, pp. 577–624.

Schreiber, K., 2011. Agriculture 2050 Starts Here and Now. Institut de l'Agriculture Durable (IAD), Paris.

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

Shaxson, F., 2006. Re-thinking the conservation of carbon, water and soil. A Different Perspective. Agronomie 26, 1–9.

Stagnari, F., Ramazzotti, S., Pisante, M., 2010. Conservation agriculture: a different approach for crop production through sustainable soil and water management: a review. Sust. Agric. Rev. 1, 55–83.

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

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

Suleimenov, M., 2009. From conservation tillage to conservation agriculture. In: Proceedings of the International Consultation Conference on No-till with Soil Cover and Crop Rotation: A Basis for Policy Support to Conservation Agriculture for Sustainable Production Intensification, 8–10 July, Astana-Shortandy, Kazakhstan, pp. 56–68 (References and further reading may be available for this article. To view references and further reading you must purchase this article.).

Suleimenov, M., Thomas, R., 2006. Central Asia: ecosystems and carbon sequestration challenges. In: Lal, R., Suleimenov, M., Stewart, B.A., Hansen, D.O., Doraiswamy, P. (Eds.), Climate Change and Terrestrial Carbon Sequestration in Central Asia. Taylor and Francis Group, New York, NY, USA, pp. 165–176.

Suleimenov, M., Akshalov, K., 2006. Eliminating summer fallow in black soils of Northern Kazakhstan. In: Lal, R., Suleimenov, M., Stewart, B.A., Hansen, D.O., Doraiswamy, P. (Eds.), Climate Change and Terrestrial Carbon Sequestration in Central Asia. Taylor and Francis Group, New York, NY, USA, pp. 267–279.

Tebrügge, F., Böhrnsen, A., 1997. Crop yields and economic aspects of no-tillage compared to plough tillage: results of long-term soil tillage field experiments in Germany. In: Tebrügge, F., Böhrnsen, A. (Eds.), Proceedings of the EC Workshop-IV Experience with the Applicability of No-tillage Crop Production in the West-European Countries. Wissenschaftlicher Fachverlag, 35428 Langgöns, Germany, pp. 25–43.

Thomas, R.J., El Mourid, M., Ngaido, T., Halila, H., Bailey, E., Shideed, K., Malki, M., Nefzaoui, A., Chriyaa, A., Awawdeh, F., Hassan, S.H., Sweidan, Y., Sbeita, A., 2003. The development of integrated crop-livestock production systems in the low rainfall areas of Mashreq and Maghreb. In: Harwood, R.R., Kassam, A.H. (Eds.), Research Towards Integrated Natural Resources Management, 97–110pp. Interim Science Council and Centre Directors Committee on Integrated Natural Resources Management. CGIAR, Rome.

Tullberg, J.N., Yule, D.F., McGarry, D., 2007. Controlled traffic farming — from research to adoption in Australia. Soil Till. Res. 97, 272–281.

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

West, O.T., Post, W.M., 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. Am. J. Soil Sci. Soc. 66, 1930–1946, http://ecoport.org/ep?SearchType=reference&ReferenceID=558810.

Wezel, A., Bellon, S., Doré, T., Francis, C., Vallod, D., David, C., 2009. Agroecology as a science, a movement and a practice. Agron. Sust. Develop. 29, 503–515, doi:10.1051/agro/2009004.

Williams, J.D., Gollany, H.T., Siemens, M.C., Wuest, S.B., Long, D.S., 2009. Comparison of runoff, soil erosion and winter wheat yields from no-till and inversion tillage production systems in northeastern Oregon. J. Soil Wat. Cons. 64, 43–52, doi:10.2489/jswc.64.1.43.

Wolfarth, F., Schrader, S., Oldenburg, E., Weinert, J., Brunotte, J., 2011. Earthworms promote the reduction of *Fusarium* biomass and deoxynivalenol content in wheat straw under field conditions. Soil Biol. Biochem. 43, 1858–1865.

Wuest, S.B., 2001. Earthworm infiltration, and tillage relationships in a dryland pea–wheat rotation. Appl. Soil Ecol. 18, 187–192.

Young, D., Upadhyay, B.M., 2003. Economic strategies for managing risk in the transition to direct seed systems in the Pacific Northwest. In: Proceedings of the Sixth Annual Northwest Direct Seed Cropping Systems Conference and Trade Show, WestCoast Hotel, Pasco, Washington, 8–10 January.