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The Moroccan Association of Agricultural Economics (AMAECO)

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Climatic constraints play a predominant role in the performance of national agricultures and their capacity to support economic growth and assure food security for the population. With the climate changes and projected inter and intra annual fluctuations, management of the agricultural sector takes a particular dimension including management of risks inherent in the sector and searching for sustainable growth for the sector. Agricultural policies must permit a continual adaption of the processes of agricultural production and a reduction of negative effects of climate change in order to assure food security for the population.

In the face of climate change, the adaptation strategies can generate important development opportunities. Also, governments have need for pertinent evaluations of the impacts of climate change.

Considering the importance of this problem; to permit an exchange of ideas among professional staff, researchers, and specialists in the domain of development; to contribute to a richer understanding of methods and analytical tools ; and to contribute to better preparation of decision making in this domain – the Moroccan Association of Agricultural Economics (AMAEco) in collaboration with the International Association of Agricultural Economics (IAAE) and the World Institute For Development Economics Research of the United Nations University (UNU-WIDER) are organizing an international conference 6-7 December in Rabat, Morocco under the theme:

« Impacts of climate change on agriculture »

Rabat, Morocco December 6-7, 2011

The principal themes proposed are the following::

1. Analysis of the impacts of climate change on agriculture: simulations and projections
2. **Climate change and sustainability of agricultural production systems**
3. **Adaption strategies for agriculture in the face of climate change: systems of production, risks in agriculture, and policies for food security**
4. **Water management in the context of climate change**

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Conservation Agriculture as a strategy for responding to climate change in dry Mediterranean-type Environments

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Abstract

Mediterranean agriculture is highly vulnerable to climate change. A crop production strategy that responds to climate change must address both adaptability and mitigation aspects, and should also contribute to decreasing the overall agricultural carbon footprint in the economy. Over the past decades, there have been concerted efforts to promote such strategy through application of conservation agriculture (CA). CA is a set of soil management practices that minimize the disruption of the soil's structure, composition and natural biodiversity. Despite high diversity in the types of crops grown, all forms of CA share 4 core principles. These include (i) maintenance of permanent or semi-permanent soil cover, (ii) direct seeding with minimum soil disturbance, (iii) regular crop rotations or sequences and (iv) integrated weed control. It also uses or promotes where possible or needed various management practices such as utilization of green manures/cover crops, integrated pest and disease management, use of well adapted, high yielding varieties and good quality seeds, efficient water management and controlled traffic over agricultural soils. The origins, inventions and evolution of CA principles and practices are embedded in North and South American farming societies who, out of necessity, had to respond to the severe erosion and land degradation problems and productivity declines on their agricultural soils due to "intensive" tillage-based production agriculture. CA is currently practiced on 117 million hectares in all continents and all ecologies, including the dry Mediterranean environments. Presently, CA is advertised as a climate-smart agriculture permitting to (i) cope with drought and climate variability, (ii) invert erosion processes, (iii) mitigate greenhouse gas emissions, and (iv) sustain food production and tackle food security. For Mediterranean environments, many researchers believe that agriculture has the potential of becoming a much larger sink for CO_2, if CA principles are followed. In fact, the accumulated scientific and farmer's evidences have shown that CA can successfully provide a range of unequivocal productivity, socio-economic and environmental co-benefits to the producers and the society at large. To achieve these benefits, CA needs heightened attention in agricultural policy processes and strategies from national to regional levels. This paper is addressing these issues in order to smooth policy shifts to CA in dry Mediterranean areas.

Keywords: Conservation agriculture, Mediterranean climate, ecological intensification, climate-smart agriculture, no-tillage systems.

I. Introduction : Conservation agriculture as smart-climate agriculture

a. Major edaphic features of Mediterranean basin

The Mediterranean basin lies in a transition zone between the arid climate of North Africa and the temperate and rainy climate of central Europe and it is affected by interactions between mid-latitude and tropical processes. The 20th century witnessed a drastic stress on soil and water resources (Garcia-Orenes *et al.*, 2009). In fact, soils of good agronomic quality are limited, yet essential for food, feed, fiber and fuel production (Ryan *et al.*, 2006). In addition, nearly 41 millions of food-insecure population has been reported in Near-East and North Africa (FAO, 2008).

Climate change may add to existing problems of desertification, water scarcity and food production, while also introducing new threats to human health, ecosystems and national economies of countries. The most serious impacts are likely to be felt in North African and eastern Mediterranean countries. As a consequence, adaptation to climate change and emissions reduction may represent a welcome opportunity to guide the economic development of the region in a more sustainable direction. Hence, significant increase in food production to meet demand will have to be achieved despite the increasing temperature and frequency of extreme vents, decreasing rainfall effectiveness and regressive change to more fragile and harsh environment (degrading soils, declining and polluting water resources, desertification ...).

b. Conservation agriculture: Concepts and principles

Conservation agriculture represents a fundamental change in production system thinking and is counterintuitive, novel and knowledge intensive. The concepts that underpin CA are aimed at resource conservation while profitably managing sustainable production intensification and ecosystem services. They translate into three practical principles that can be applied through contextualised crop-soil-water-nutrient management practices in space and time that are locally devised and adapted to capture simultaneously a range of productivity, socioeconomic and environmental benefits of agriculture and ecosystem services at the farm, landscape and provincial or national scale (Kassam *et al.*, 2009).

The three principles of optimum CA are: (1) Minimizing soil disturbance by mechanical tillage and thus seeding directly into untilled soil, eliminating tillage altogether once the soil has been brought to good condition, and keeping soil disturbance from cultural operations to the minimum possible; (2) Maintaining year-round organic matter cover over the soil, including specially introduced cover crops and intercrops and/or the mulch provided by retained residues from the previous crop; and (3) Diversifying crop rotations, sequences and associations, adapted to local environmental conditions, and including appropriate nitrogen fixing legumes; such rotations contribute to maintaining biodiversity above and in the soil, contribute nitrogen to the soil/plant system, and help avoid build-up of pest populations (Kassam *et al.*, 2009). Climate-smart agriculture includes proven practical techniques and approaches that can help achieve a triple win for food security, adaptation and mitigation (FAO, 2010). Conservation agriculture fits to this definition as well.

c. Conservation agriculture: worldwide trends

No-tillage (NT) systems has become increasingly popular in the world (117 million hectares (Kassam *et al.*, 2009) and in the Mediterranean countries particularly Spain

(Sanchez-Giron *et al*., 2007), France (Trocherie and Rabaud, 2004), Tunisia (AFD, 2006), Portugal (Carvalho and Basch, 1994) and Morocco (Mrabet, 2008) over the last decades. Worldwide, the annual increase in NT acreage is about 5.3 million ha. While adoption of CA under the climatic conditions of the Mediterranean region might be more challenging, it is at the same time more urgent than in other climatic zones (Kassam *et al*., 2009).

II. Conservation agriculture as a mitigation option: can we beat the heat and the splash?

a. Mitigating carbon dioxide emissions

The Mediterranean climate is currently the focus of intense research on climate related issues (Somot *et al*., 2007). The intent is to produce a new climate regime that will launch the world toward a low-carbon future, thus avoiding the potentially devastating effects of climate change. As it appears in IPCC's 2007 report, the Mediterranean basin is climate change vulnerability "hotspot".

Intensification of agricultural production is an important factor influencing greenhouse gas emission, particularly the relationship between intensive tillage and soil carbon loss (Reicosky & Archer 2007). Estimates from Raich and Potter (1995) showed that soil respiration on a global scale is 77 Pg C year^{-1}, which is approximately 10 times the contribution of industrial CO_2 emissions (Schlesinger and Andrews, 2000). Due to the large order of magnitude, small changes in soil CO_2 flux across large areas can produce a great effect on CO_2 atmospheric concentrations. CA production systems were reported by Moussadek *et al.* (2011a) in Morocco, Alvaro-Fuentes *et al.* (2007) and López-Garrido *et al*. (2009) in Spain and Akbolat *et al.* (2009) in Turkey to offset short-term anthropogenic emissions of CO_2 in croplands. From the study by Moussadek *et al.* (2011a), the CO_2 flux was 4.94, 3.95, 2.1 and 0.73 g m2 per hour at initiation of tillage, respectively, for chisel, disk plow, stubble plow and NT. At 96 hours, these fluxes were 1.81, 1.60, 1.30 and 0.80 g m2 per hour (Figure 1).

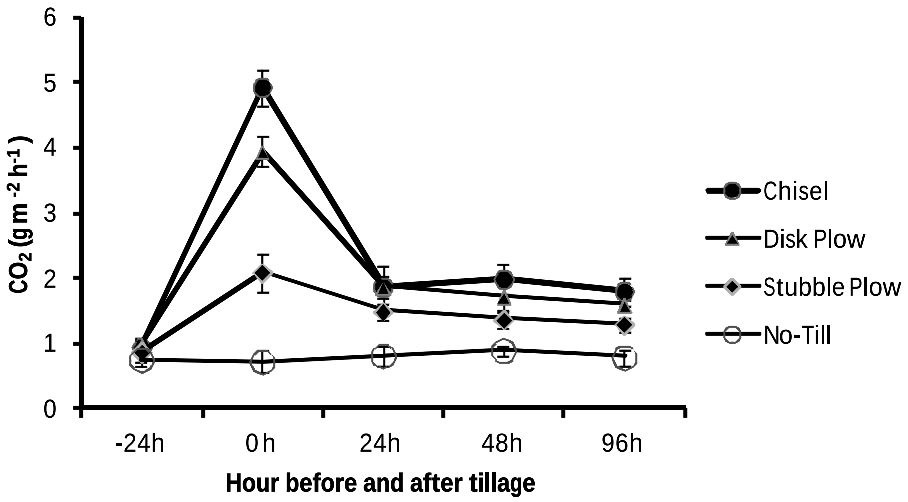

Figure 1. Soil CO_2 flux associated with primary fall tillage as compared to no-tillage (NT) systems (Moussadek *et al.,* 2011a).

b. Erosion mitigation

Mediterranean climate is one of the most aggressive in respect of erosion, as a result principally of violence of autumn storms, which come after several months of absolute drought (García-Ruiz, 2010). Among all soil degrading processes, accelerated soil erosion has the most severe impact on the soil organic matter (SOM) pool. On sloping lands, erosion is depleting SOM.

No-till vegetation cover is crucial to the maintenance of a number of factors that may lessen the impacts of climate change, including reducing the direct temperature effects of sunlight on soil, preserving channels for water infiltration, reduced slaking in heavier soils, and preserving structural integrity of the topsoil to resist water erosion events. The literature overwhelmingly supports success of no-tillage practices in achieving reduction of soil erosion and runoff. The erosion risk decreases as the soil surface is continuously covered mainly during the rainy season. Using radio-isotopic techniques (^{7}Be), Nouira *et al.* (2007) found that no-tillage systems reduce significantly soil erosion rate and sediment losses as compared to conventional tillage (CT) in semiarid Morocco. Using rainfall simulation technique, Moussadek *et al.* (2011b; Figure 2) and Dimanche (1997; Table 1) concluded that CA maximize the green water component of the hydrological cycle and minimize losses by runoff and evaporation in semiarid areas of Morocco. However, knowledge on the impact of erosional processes on soil organic carbon dynamic and understanding the fate of carbon translocated by erosion processes is still lacking but is crucial to assessing the role of erosion on emission of CO2 and other greenhouse gases into the atmosphere.

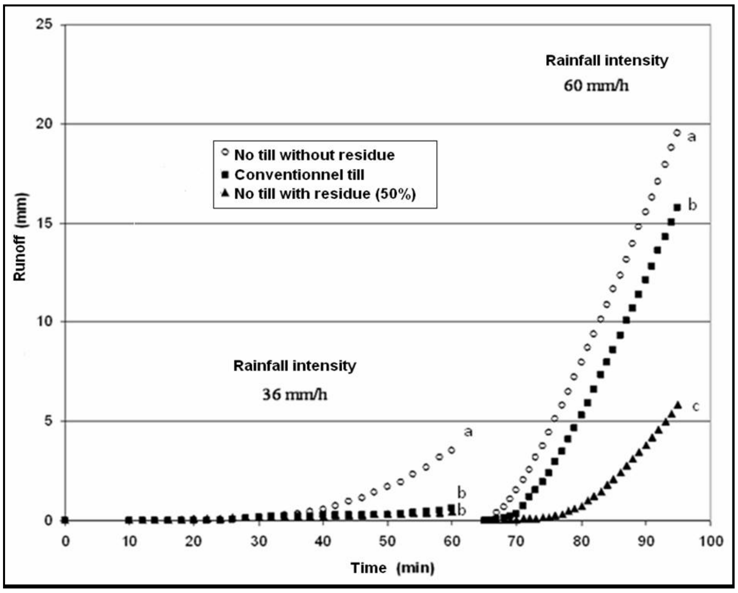

Figure 2. Runoff loss as affected by tillage and NT residue removal under two rainfall intensities in Zaers region (Moussadek *et al.*, 2011b).

Table 1: Percent of runoff volume and detachability under no-tillage and chisel plow as compared to disk plow at Ras Jerri (Meknes, Sais, Morocco) (Dimanche, 1997).

Tillage system		?v = 25%		?v = 30%	
	Rain Intensity (mm/h)	50	80	50	80
Disk plow	Qr and De (%)	100	100	100	100
Chisel plow	Qr (%)	103	96.3	102.4	93.8
	De (%)	93.5	85.4	93.6	92.7
No-tillage	Qr (%)	52.9	66.2	49.2	69.7
	De (%)	28.9	38.9	30.0	49.4

?v = Volumetric soil moisture, Qr = Runoff volume: Quantity of water generated as runoff, De = Detachability (a term used to describe a soil's susceptibility to erosion).

III. Eco-efficiency in Mediterranean agro-systems

The term eco-efficiency was proposed to emphasize creating more goods and services while using fewer resources and inducing less wastes and pollution. In other terms, this is a strategy by which to produce more food without using more land, water and energy-based input (Wilkins, 2008). This is achievable when soils have the capacity to restore their physical, chemical and biological quality through enhancing ecological and biological processes.

a. Carbon sequestration and storage

Soil organic matter of cropland increases only if either the additions can be enhanced or the decomposition rates be reduced. Soils under Mediterranean climate present low levels of organic carbon (Zdruli *et al.*, 2004). Climatic effects inducing high mineralization rates of the organic matter, low biomass production under rainfed conditions, intensive soil tillage used for crop establishment, straw removal and grazing of the stubble and soil erosion can be pointed out as the main reasons for the soil organic carbon depletion of Mediterranean cropland (Basch *et al.*, 2008). In other terms, in the region, soils have not been deliberately managed to sequester carbon and tillage has reduced soil carbon.

Carbon sequestration is the process by which atmospheric carbon dioxide is taken up by plants through photosynthesis and stored as carbon in biomass and soils. Carbon dynamic in the soil is attracting considerable research effort given its implication in terms of global climate change. Lal (2004) proposed a large array of CA management practices in relation to soil organic carbon sequestration (Table 2).

The concentrations of organic matter in top soils in Mediterranean regions routinely increase under no-tillage systems, due to a favorable shift in the balance of accumulation and decomposition (Table 3). As shown by Mrabet *et al.* (2001), the soil organic carbon (SOC) pool to 20 cm depth of a Calcixerol soil increased from 33.92 Mg ha^{-1} in conventional tillage (CT) to 37.28 Mg ha^{-1} in conservation agriculture (no-tillage) system with average SOC sequestration rate of 0.3 Mg ha^{-1} yr^{-1} for the 11-yr period.

In Tunisia, soil stored 4-7% more carbon under NT than under CT (Ben Moussa Machraoui *et al.*, 2010). Angar *et al.* (2011) found similar amelioration in SOC under NT compared to CT under sub-humid climate but under semiarid climate NT greatly enhanced SOC in comparison with CT (Table 4). This is to confirm that soils with lower initial SOC are more responsive to residue addition under NT and hence to SOC accumulation.

Table 2: Comparison between traditional and recommended management practices in relation to soil organic carbon sequestration (Lal, 2004).

Traditional methods	Recommended management practices
Biomass burning and residue removal	Residues returned as surface mulch
Conventional tillage and clean cultivation	Conservation tillage, no-till and mulch farming
Baer/idle fallow	Growing cover crops during the off-season
Continuous monoculture	Crop rotations with high diversity
Low input subsistence farming and soil fertility mining	Judicious use of off-farm input
Intensive use of chemical fertilizers	Integrated nutrient management with compost, biosolids and nutrient cycling, precision farming
Intensive cropping	Integrated tree and livestock with crop production
Surface flood irrigation	Drip, furrow or sub-irrigation
Indiscriminate use of pesticides	Integrated pest management
Cultivating marginal soils	Conservation reserve program, restoration of degraded soils through land use change.

In Syria, SOM was increased by conservation tillage, particularly by no-till direct drilling from 0.8 to 0.95% in a three-course wheat-lentil-summer crop rotation and from 1.3 to 2.8% in a two-course wheat-lentil cropping systems (Ryan, 1998). After 3-year, Abdellaoui *et al.* (2010) reported an increase in SOC content of 0-8 cm from 1.79% under CT to 1.99% under NT at Mitidja plain (Algeria) without depletion at deeper horizons.

Particularly in France, Oorts *et al.* (2007) reported an increase by more than 2 times of soil carbon content of an Alfisol surface horizon (0-5cm) when shifting from CT to CA in a period of 33 years (Table 3). The same trend has occurred in Spain for Xerofluvent after only 15 years (Alvaro-Fuentes *et al.* (2008), Table 3. Thus carbon sequestration can continue for 20 to 35 years before reaching a new plateau of saturation (Kimetu *et al.*, 2009). However, most studies on SOM dynamics have been made for the plow layer (0–20 cm depth). There is a strong need to assess the land use and management impacts on depth-distribution because of the depth-dependent response of CA practices to temporal changes in the SOM pool (Mrabet, 2008).

Table 3: Tillage systems effect on soil organic matter (g kg^{-1}) in different Mediterranean countries (Compiled by Mrabet, 2011).

Country	Soil order	Horizon (cm)	Years	No-Tillage	Conventional Tillage
France	Alfisol	0-5	4	21.50	17.30
	Alfisol	0-5	33	22.60	11.00
Syria	Inceptisol	0-10	10	17.50	11.00
Tunisia	Isohumic	0-20	4	27.50	24.10
	Fersialitic	0-20	4	22.40	15.50
Morocco	Calcixeroll	0-5	5	17.30	16.60
	Calcixeroll	0-2.5	11	28.90	23.50
Italy	Cambisol	0-40	3	07.50	7.50
	Entisol	0-10	-	20.10	14.30
Portugal	Cambisol	0-20	3	14.82	12.94
	Vertisol	0-10	-	25.30	19.10
Spain	Xerocrept	0-5	18	22.50	15.00
	Xerofluvent	0-5	15	18.81	08.80
	Calciorthid	0-5	16	13.70	08.70
	Calcisol	0-5	7	12.55	10.17
	Haploxeralf	0-5	14	11.00	07.00
	Haploxeralf	0-10	8	11.60	08.80
	Xerofluvent	0-5	3	17.20	15.70

Table 4: 10-year tillage effects on organic carbon content (%) for two contrasting soils and climates in Tunisia (Angar *et al.*, 2011)

Horizon (mm)	Sub-humid (Clay soil)		Semiarid (Clay sandy soil)	
	No-tillage	Conventional Tillage	No-tillage	Conventional Tillage
0-100	2.31	1.93	2.17	1.50
100-200	2.23	1.82	2.10	1.30
200-300	2.14	1.74	2.05	1.50
300-400	2.09	1.63	1.90	1.40

b. Soil fertility buildup with CA:

In the past, much of the focus of soil fertility research, conducted under conventional tillage systems, was on diagnosis of nutrient deficiencies and behavior of these elements in soils as well as responses to fertilizers in the fields. Soil fertility should be oriented to soil and crop management changes; in order words it has to be dynamic not static. The negative nutrients and carbon budgets of cropping systems must be changed to positive balances to set in motion soil restoration trends in dry areas of Mediterranean basin. Conservation agriculture (no-tillage with mulch; NT) has proven to be an effective strategy to improve soil quality (aggregation, porosity, infiltrability, etc) and fertility (N, P and K contents, biological activity etc) in Mediterranean semi-arid areas of Spain (Cantero-Martínez *et al.*, 2003; 2007; Fernandez-Ugalde *et al.*, 2009), Portugal (Basch *et al.*, 2008); Tunisia (Ben Moussa Machraoui *et al.*, 2010), Algeria (Abdellaoui *et al.*, 2011), Morocco (Mrabet, 2008), Turkey (Ozpinar, and Cay, 2006; Avci, 2005), Italy (De Vita *et al.*, 2007) and Syria (Ryan, 1998).

The increase of plant nutrients such as N, P, and K in the soil under NT practice was also reported in various sites across Mediterranean basin and would be beneficial to soil chemical and physical properties and crop production and yield in the long-term. Furthermore, improved soil fertility will allow to reduce mineral fertilizer input contributing thus to reduced energy use for its manufacturing and a reduced potential for the emission of nitrous oxides.

c. Agricultural sustainability with conservation agriculture: unlocking the potential and mitigating drought

Management of the SOM pool to improve soil quality and agronomic productivity is now related to the urgency to increase food production. At the same time, generally, the yield potential of improved varieties is not realized when soils are degraded and crops grown under sub-organic and edaphic conditions. Mrabet (2008) and other authors from Mediterranean countries have shown that optimal soil management (conservation agriculture with mulch) is essential to achieving the agronomic potential of improved varieties even under drought. According to various research studies (Table 5) pertaining to comparing yields of CA vs. CT, crops under NT system showed the highest values if not equal ones (Mrabet, 2011 in Morocco; Alvaro-Fuentes *et al.*, 2009; Lopez-Bellido *et al.*, 2000; Angàs *et al.*, 2006 in Spain; Mazzoncini *et al.*, 2008 in Italy; Ben Moussa-Machraoui *et al.*, 2010; Angar *et al.*, 2011 (Figure 3) in Tunisia; Pala *et al.*, 2007 in Syria). Higher yields result in a greater amount of crop residues left in the field, which consequently contribute to the SOC pool. The superior yield effect of NT in comparison to CT can be due to lower water evaporation from soil combined with enhanced soil water availability. It is then worth saying that CA helps adapt agricultural production to Mediterranean climate change. This is even more remarkable due to early seeding allowed by CA in order to maximize the utilization of rainfall received during the entire crop growing season. In addition, due to better water use efficiency, crops have higher vigor and resilience to biotic stresses (ie disease, pest and weeds).

The inclusion of forage or food legumes in crop rotations as a recommended management practice within the concept of conservation agriculture can also be regarded as a strategy to not only prevent nutrient leaching and reduce fertilizer input but also to enhance SOC accumulation and to improve soil fertility and biomass production (Mrabet, 2008).

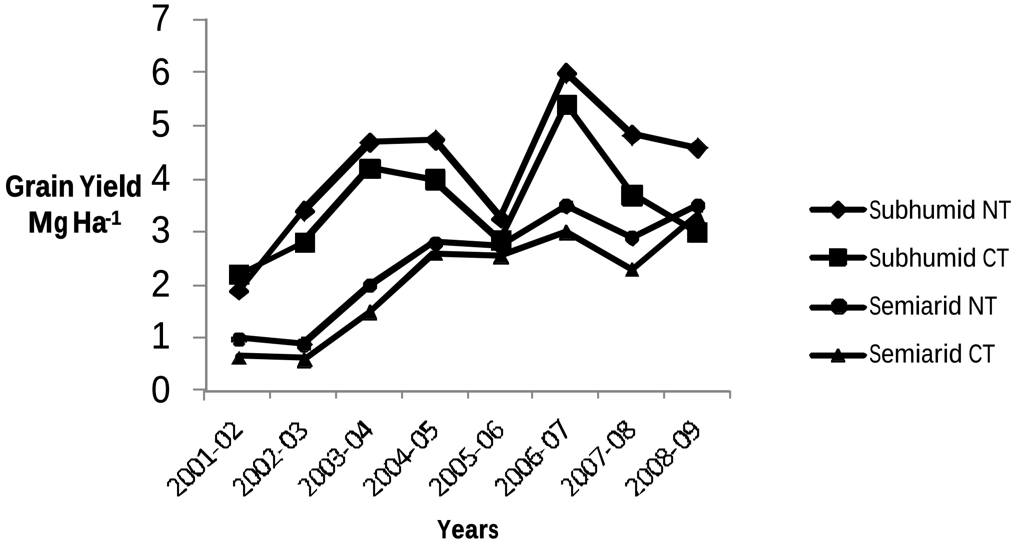

Figure 3. Durum wheat grain yield as affected by tillage systems for two contrasting climates of Tunisia (Angar *et al*., 2011).

Table 5: Regional assessment of wheat yield (Mg ha^{-1}) under no-tillage (NT) and conventional tillage (CT) systems in Morocco (Compiled by Mrabet *et al*., 2011).

Region and Average annual rainfall (mm)	Soil type	Rotation	NT	CT	Years
Abda	Vertisol	Wheat-Fallow	3.10	2.40	19
(270 mm)	Vertisol	Continuous Wheat	1.60	1.60	19
Chaouia	Mollisol	Continuous Wheat	2.47	2.36	4
(358 mm)	Vertisol	Wheat-Fallow	3.70	2.60	10
	Vertisol	Continuous Wheat	1.90	1.40	10
	Mollisol	Different rotations	2.21	1.90	9
	Vertisol	Wheat-Chickpea	1.87	0.76	3
	Rendzina	Wheat-Chickpea	2.53	1.47	9
Zaers (410 mm)	Vertisol	Wheat-Lentils	1.97	1.41	4
	Entisol	Wheat-Lentils	2.99	2.72	4
	Alfisol	Wheat-Lentils	2.71	2.49	4
Sais	Vertisol	Different rotations	2.55	2.49	4
(438 mm)	Alfisol	Different rotations	2.72	2.74	4
Gharb (570 mm)	Vertisol	Continuous Wheat	2.80	2.26	3

IV. Conclusions

Technologies that enhance land, water and labor productivity and that allow an increase in long-term productivity without associated ecological harm are urgently needed for Mediterranean basin. The sustainability of cropping systems can be increased by introducing CA in Mediterranean basin. CA- and especially no-tillage systems are recognized as the main measures to turn the soil into a tremendous carbon sink. It was found that, with CA, carbon sequestration in agricultural soils can contribute to offsetting CO_2 anthropogenic emissions and also to enhance soil fertility, soil water retention and crop production. Higher and stable grain yields under CA should allow to increased adaptation to climate change and allowed food security. However, to fully achieve these benefits, CA needs heightened attention in agricultural policy processes and strategies from national to regional levels. In other terms, the greater impact that can result from the adoption of CA as a matter of policy and good stewardship is that agriculture development in the Mediterranean region will become part of the solution of addressing regional and global challenges including resource degradation, land and water scarcity as well as climate change.

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