Morocco: Analysis of Opportunities to Scale up Conservation Tillage in Rainfed Areas – Mobilizing Private Investment

Report 1: Diagnosis of the current state of conservation agriculture in Morocco and economic review

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Prepared by:
Drs Rachid Moussadek, Mina Devkota and Vinay Nangia
with the support of ICARDA and INRA Conservation Agriculture experts

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Introduction and background

Morocco, as all North African countries, is highly vulnerable to the consequences of climate change because of its strong exposure to increases in temperature, changes in freshwater availability, and population growth. Agriculture production is sensitive to changing climatic conditions across northern Africa, and any change in agriculture production is highly linked with national economies as national economy is strongly depends on agriculture or livestock (around 20% of GDP). Due to the already existing water scarcity and this strong dependence on rainfed agriculture, there is additional vulnerability, further exacerbated by an adaptive capacity that is limited by poverty and political instability.

In general, climate change is expected to have important impacts on food security, which may impact on the stability, prosperity, and security of the region. Research in this emerging field has identified some climate-smart agricultural practices that should be disseminated widely to enhance the resilience of the cereal-based systems in Morocco and in North Africa, such as Conservation Agriculture and especially no-tillage farming or conservation tillage. This report presents the following items in relation with CA in Morocco.

- *Stocktaking of the national experience with conservation tillage (CT) in Morocco, including the technical and economic aspects, both on research stations and under real farmer field conditions and a review of the most pertinent international lessons learned from successful large-scale conservation agriculture programs.*

- *Identification of the key obstacles and the barriers to broad-scale adoption (by all key stakeholders: farmers, contractors, etc.) of conservation agriculture practices such as direct seeding/no-tillage.*

- *Identification of policy-level constraints that would need to be addressed to facilitate large-scale adoption of conservation tillage, and macro-level economic analysis and simulations of the effects of application of alternative agriculture support mechanisms.*

1. Agriculture in Morocco under changing climate

Morocco's total area is 71.08 million hectares (M ha), including 9.2 M ha of cultivated land (13%), 5.8 M ha of forest (8%) and 24 M ha of rangeland (30%). The agriculture sector generates 13 to 20% of the gross domestic product (GDP) depending on harvest and 20% of the total export value of the country. It provides employment to nearly 44% of the work force.

Cereal production is the most significant agricultural resource. Wheat and barley are - and have been - the most grown dryland cereals and are of paramount importance in the national economy (Chebbi & El Mourid, 2005). Food legumes (i.e., faba bean, chickpea, and lentil), and oilseed crops represent a small component of the cropping systems (less than 15% of land use). Perennials include olive, almond, fig, pistachio, and fodder trees.

In a period of 50 years, cereal area occupied more than 4.5 M ha contributing to a 3.2-fold increase in cereal production (from 2.5 M tons in 1961-65 to more than 9.8 M tons in 2020-2021); however, the cereal production closely related to the climate variability as water stress became frequent during last decade. In fact, the country is lying within the influence zone of the Atlantic, the Mediterranean and the Sahara, together with very steep mountains. It is characterized by a diverse but dry uncertain climate. Its main features are low mean annual precipitation, high inter- and intra-annual rainfall variability, and high rates of potential evapotranspiration (Chbouki et al., 1995). Most of the country is arid (90%) with aridity tending to increase with distance from the North. About 95 to 98% of yearly rainfall is concentrated from October to April and this coincides with cereal production cycle. Precipitation is inversely related to the concurrent state of the North Atlantic Oscillation (Knippertz et al., 2003).

Owing to the high degree of aridity and variability of rainfall in most of the country, agriculture is particularly vulnerable to drought. Prolonged droughts were reported in 1979-84; 1994-95; 1998-99 (Balaghi et al., 2006) and recently in 2018-2019 and 2020.

Consequently, the agricultural sector is highly sensitive to climate change and subjected to recurrent droughts (Dai et al., 2004; Esper et al., 2007). Touchan et al. (2011) projected more frequent and intense drought-like conditions. Another feature of rainfall is its high intensity, which produces flash-flood conditions.

The general aridity, in conjunction with factors related to topography, is also responsible for the widespread occurrence of soils with poor or no profile development (Regosols), calcareous soils (Calcisols) and dark cracking clays (Vertisols). These latter soils have poor physical and structural properties and are low in organic matter, which makes them vulnerable to water stress, erosion and compaction under heavy machinery use (Ryan et al., 2006). An estimated 8.7 million hectares of 19 percent of Morocco’s land is subjected to severe degradation, with agriculture activities being the only driver for the degradation (World Bank, 2019).
Climate change has and will impact agricultural productivity through increased mean temperatures, alterations in rainfall patterns, more frequent occurrences of weather extremes (including temperature, precipitation, drought, heat), and altered patterns of pest pressure. In addition, drought and rainfall variability are expected to be more spatially heterogeneous. This may exacerbate existing water scarcity. Climate change is predicted to reduce rainfall by 10–30% by 2050, while temperatures rise by 1.2–1.8°C (Driouech et al., 2013). This will affect the crop productivity, as shown in the map below, the wheat yield will be reduced by 8% by 2030, (Mosaicc project, 2021).

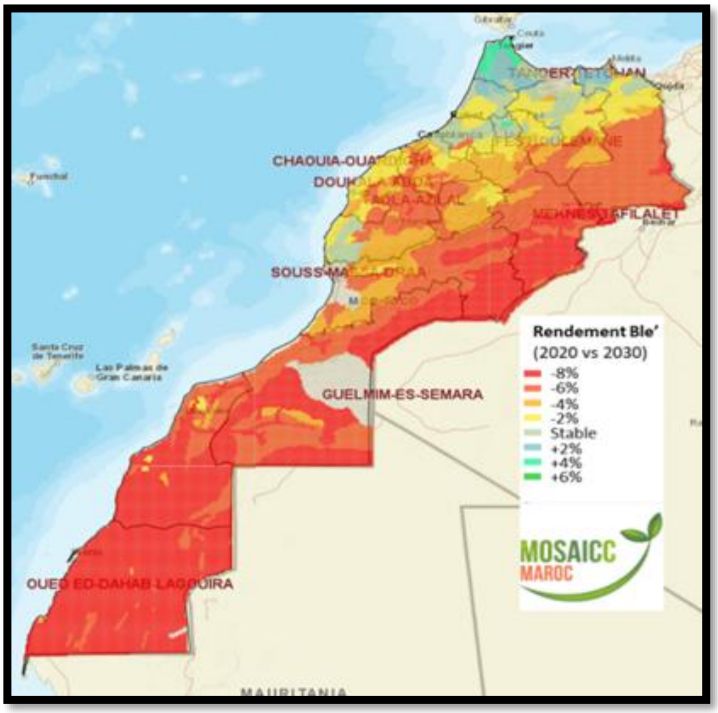

Figure 1: Effect of Climate change on Wheat yield by 2030 (FAO, 2013)

2. Conservation Agriculture; from concept to an integrated approach

Conservation Agriculture (CA) is an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment (FAO, 2002). CA is based on the integrated management of soil and water resources to reach the objectives of economically, ecologically and socially sustainable agricultural production systems. It is characterized by three principles which are linked to each other, namely:

- (i) minimum mechanical soil disturbance throughout the entire crop rotation;
- (ii) permanent soil cover, and
- (iii) diversified crop rotations in case of annual crops or plant associations in case of perennial crops (FAO 2014) (Figure 1).

Dumanski et al. (2006) described CA as the integration of natural resources management with sustainable and economic agricultural production, providing beneficial ecosystem services such as (1) food and fiber and biofuels, and (2) less erosion, less pollution, clean water, fresh air, healthy soil, natural fertility, C sequestration, sustainability and higher production.

Parr et al. (1990) defined no-tillage (NT) system as a specialized type of CA consisting of one-pass planting and fertilizer operations during which the soil and surface residues are minimally disturbed. CA systems eliminate soil manipulation except at the time of combined seeding and fertilizer placement. Other terms used to describe this system include zero-tillage, slot-tillage and direct seeding systems. The NT systems are composed of three dependent components: direct seeding without previous tillage operations or seedbed preparation; crop residue maintenance at or near the soil surface; and weed control mainly with herbicide application or with crop rotations.

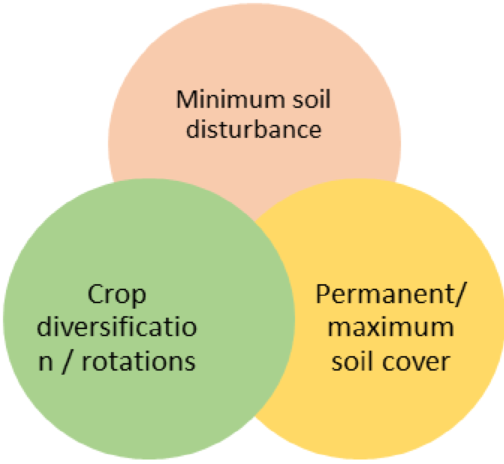

Figure 2: The three key principles underlying Conservation Agriculture

3. The benefits of Conservation Agriculture

When the three principles of CA are used along with good agronomic practices, many significant benefits are produced at different level. The benefits of CA can be broadly characterized into four broad categories: socio-economic (livelihoods and wellbeing), enhanced agricultural productivity (yield, biomass and quality), resource conservation, and improved environmental sustainability. CA is an important way of coping with climate change and increasingly variable and unpredictable rainfall, especially in Mediterranean rainfed environment. Many of these benefits accrue at the farm-level, while others accrue at watershed and community levels – and some at a global level as reported by (Pieri et al, 2002) (Table 1).

Table 1: Benefits and impacts of conservation agriculture (Pieri et al., 2002)

Farm Level	Community, Watershed Level	Global Level
a. Labor, time and farm power savings through reduced cultivation and weeding requirements; b. Less costs due to reduced operations and external inputs; c. Mechanized farms: longer life span, less repair	a. More constant water flow in rivers/stream, improved recharge of the water table with re-emergence of dried-up wells and water sources; b. Cleaner water due to less erosion and reduced sedimentation of water bodies;	a. Improved Carbon balance through reduced carbon emission, less fuel and energy consumption, and increase carbon sequestration in the soil organic matter and biomass; b. Better biodiversity protection at the

Farm Level	Community, Watershed Level	Global Level
costs of equipment, less fuel consumption; d. Better trafficability in the field, less drudgery; e. More stable yields, particularly in dry years due to improved nutrients and moisture availability to the plant; f. Labor savings provide opportunities for diversification (livestock, high-value crops, agro-processing) g. Maintained or increasing yields with decreasing inputs; h. Increased profits, in some cases from the beginning, in all cases after a few years due to increase efficiency of the production system.	c. Less flooding due to increased infiltration; less damage from droughts and storms; d. Improved sustainability of production system and enhance food security; e. Increased environmental awareness and better stewardship of natural resources; f. Lower municipal and urban water treatment costs; g. Reduced rural maintenance costs; h. Increased associative activities; i. Improved rural livelihood and quality of life.	microflora and fauna levels (bird's nest in CA fields, fish in streams and ponds etc.); c. Improve hydrological cycle at river basin and continental levels; d. Improve combat to desertification and land degradation, through reduced risks of soil erosion and enhanced soil build up; e. Recharge of aquifers through the capture and infiltration of rainwater; f. Recognition of the role of rural dwellers and farming activities in providing key environmental services to the society at large.

• Benefit on crop yield and stability

The most important and primary benefit generated by adopting CA, vs conventional tillage, in the relatively dry country as Morocco with its variable climate and frequent drought stress is increased and more stable crop yields. Since the early 1990s, several studies on CA have been conducted in Morocco showed that well established CA systems achieve yield levels comparable or even higher than those under conventional system for diverse annual crops. In their review, Mrabet et al. (2012) stated that CA enables farmers to reverse crop yield decline. Reported yield differences between CA systems and tillage systems in Morocco region (Table 2) resulting from improved soil moisture and nutrient availability in different climate conditions (from 570 mm to 270 mm).

Table 2: Regional assessment of wheat yield (Mg ha^{-1}) under Conservation Agriculture (CA) and conventional tillage (CT) systems in dry areas of Morocco (Mrabet et al., 2012)

Region and Average annual rainfall (mm)	Soil type	Rotation	CA	CT	Years of CA adoption
Abda (270 mm)	Vertisol	Wheat-Fallow	3.10	2.40	19
	Vertisol	Continuous Wheat	1.60	1.60	19
Chaouia (<350 mm)	Mollisol	Continuous Wheat	2.47	2.36	4
	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

Soil type was defined using Soil taxonomy classification

• Soil quality improvement

Soil quality is an integrated function of the biological, chemical, and physical properties of soil. Maintaining and developing soil quality and health is essential not only for agricultural sustainability, but also for environmental stewardship. CA systems have an importance influence on physical, chemical, and biological properties of the soil environment. Soil organic matter build up is the major soil quality change associated with CA implementation. The increase in soil aggregation is an important benefit of soil organic matter buildup.

In semi-arid Morocco, researchers have shown that under CA systems, the number of large pores in the soil decreased while the number of small pores increased in comparison to conventional tillage. The small pores are important for storing moisture whereas the large pores drain quickly and hold little water. The increased porosity is especially important for crop growth since it has a direct effect on soil water and aeration and enhances root growth. Research also showed that soil bulk density; infiltration and water retention properties are positively affected by CA systems through reductions in tillage and maintaining stubble. Under CA, the crop residue retention has been reported not only to improve organic matter content but also soil quality and increase soil biological activity.

Effects of CA on soil water storage and crop water productivity

In rainfed environment, crop yields are largely determined by the amount of rainfall and the crop's efficiency in converting rainfall to grain and/or straw. Soil cover using crop residues and no-tillage are the most important factors that influence water entry and thus infiltration rate, which reduces runoff and soil erosion [Moussadek et al. (2011b)] in Vertisols of Zaers region and [by Dimanche (1997)] in clayey soil of Sais region. The improvement in infiltration under CA, increased the amount of soil water available for plants, particularly in fine-textured soils, hence crops under CA shows more tolerance to drought than crops grown under CT.

In low rainfall regions (< 250 mm) such as Abda and Ouardigha, long fallowing is traditionally practiced for water storage and conservation in soil profile. Experimental results showed that water storage efficiency in soil improved from 10% in weedy fallow and 18% in black fallow to 28% in chemical fallow. This increased water availability was reflected in higher wheat yields under NT systems (Bouzza, 1990) (Table 3). No-till crops become more tolerant to drought because of the better storage of water in the fallow or during the growing season, and this can be used either to increase crop yields, or if sufficient water is available, to increase cropping frequency (Bouzza, 1990). From this author, stored water in 1.2 m profile changed from 30 to 84 mm when shifting from disking to no-tillage.

Table 3: Valuing water from rainfall with no-tillage fallow (Bouzza, 1990)

	Fallow management	Storage efficiency (%)	Stored water [a] (mm)
Chemical / no-tillage fallow	Weeds controlled with herbicides only .	28	84
Cultivated/Black fallow	Weeds controlled with tillage implements, mainly disk harrows.	18	54
Minimum / Stubble mulch fallow	Co-control of weeds with herbicides and tillage, mainly sweeps.	21	63
Weedy/Pasture fallow	Uncontrolled weeds. Weeds used as forage.	10	30

[a] = in a 1.2 m deep soil profile.

In the surface soil layer (0-100 mm), water content is usually higher under no-tilled than in tilled soil. Evaporation of water from the soil is reduced with maintenance of mulch cover. Mrabet (1997) showed that time to reach wilting point in a Calcixeroll was proportional to residue cover under no-tillage. As reported by this author, NT with residue cover of 70- 80% permitted higher time to reach wilting point than any applied tillage system.

- **Socio-Economic benefits**

The economic benefits of CA come with savings in expenditures on diesel, labor, and seed, lower depreciation rates for equipment and machinery, and higher yields from better soil moisture conservation. The result from field experiment and farmers survey from Morocco showed that the immediate major benefits that CA come from the opportunity for early sowing and savings in time, seed cost, labor, fuel, and energy cost, where farmers registered savings of up to 40 L of fuel ha^{-1} and saving in fertilizer after few years of CA adoption (Bourarach, 1989; Mrabet et al., 2012).

Labor is one of the key agricultural inputs and increasing the returns to personal and family labor is a key consideration for farmers and the rural community. Appropriate technologies should take into account the availability, accessibility, gender adaptation and health aspects of labor use, with the ultimate goal of enhancing labor productivity. Labor use is reduced in CA systems, which, therefore, permit the release of labor for other economic and social needs (more spare time). The reduction of labor requirements for farm operations can be used for other income generating activities, e.g. crop processing for value addition. Poverty reduction, due to lower costs, greater yields and higher incomes is an important benefit of CA systems.

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

Adequate equipment to be able to seed directly into untilled soil is a pre-requisite for successful implementation of a CA system. While there are many no-till drill choices and options, one thing is common among models; they are generally more expensive than conventional-till drills. The list prices of effective no-till grain drills are from two to five times greater than the list prices of conventional drills. The greater cost associated with purchase of a no-till drill may be offset by decreased total equipment costs. However, with the exception of the initial purchase of a no-till seed drill, CA reduces investment in agricultural machinery and extends the life of tractors. It also reduces labor requirements and simplifies labor management.

CA farmers contribute to environmental conservation, especially of waters, soils and soil biodiversity, which are public goods and should be compensated for these services.

• Environmental benefits

The CA system is one of few agricultural practices that can deliver ecological services that benefit farmers, society, and the environment, including benefits such as reduced erosion and downstream sedimentation, carbon sequestration, and energy conservation. Furthermore, CA systems contribute to cleaner surface water and air as reported by Peggin and Devlin (2012). Research has also shown improved aquifer recharge due to greater density and depth of soil bio-pores due to intense earthworm activity and more extensive and deeper rooting.
For Morocco, policymakers can consider CA systems as the best option there is to both adapt to climate change adaptation, while mitigating the causes of climate change and preventing desertification.

• Conservation Agriculture and climate change

It is predicted that Morocco will face severe and extreme drought. By the end of the century, it is predicted that there will be a 10-20% reduction in precipitation, with both greater spatial variability (from site to site) and temporal variability (between seasons). In this hotspot of climate change, it is important to develop climate-smart practices that facilitate sustainable agricultural development and food security under conditions of climate change. This will involve:

(i) sustainably increasing agricultural productivity and incomes;

(ii) Adapting and building resilience to climate change, where resilience refers to the capacity of the farmer, the community and the country to recover from extreme climatic shocks; and

(iii) Reducing greenhouse gas (GHG) emissions.

There is no single avenue to achieving these goals, but Conservation agriculture is the best opportunity we have at the moment in this dry zone to achieve the needed technological changes in areas of field crop production.

- Mitigation of climate change

With a contribution of 25% to total emissions, agriculture is a significant source of greenhouse gas (GHG) emissions, where tillage is the major cause of CO_2 emission over cropped lands . CA reduces GHG emissions (Moussadek et al., 2011b) and promotes mitigation of climate change through several mechanisms: (i) reduction in the use of fossil fuel, (ii) elimination of burning of crop residues, (iii) reduced oxidation of SOM and increase in C sequestration in soils (Moussadek et Mrabet. 2017, Laghrour et al., 2016), and (iv) reduced need for mineral fertilizers (e.g., N) over the long-term. Increasing soil carbon enhances crop production and mitigates greenhouse gas emissions through carbon sequestration. Research in semi-arid Morocco has shown that CA considerably reduced carbon dioxide emissions compared to conventional tillage practices. In CA, tractor use is substantially reduced when tillage operations are eliminated, thus reducing emissions of greenhouse gases and other pollutants. Commonly fuel use in CA systems is 50-70% lower than in conventionally tilled systems.

Concerns over global warming and rising food prices are growing in North Africa, and this could well increase social and political support for CA to help mitigate these effects.

- Adaptation to climate change

Most models show that climate is likely to get warmer and drier in the West Asia and North Africa region. CA will help farmers adapt to this climate change through improved soil quality development and improved soil-water dynamics (increased infiltration rates, soil moisture storage and crop water availability, and reduced evaporation, runoff and erosion (Moussadek et al., 2011a). Generally, CA has been shown to give better resistance to dry spells and droughts and increased agro-ecosystem resilience and stability.

4. CA Adoption and spread in North Africa and Morocco

In North Africa region, CA systems are practiced in major crops (i.e., cereals, food legumes, forages, oil seed crops). In the region, national NT research-development initiatives were implemented at different times and with varying visions. In Morocco, extensive research and development work has been initiated on CA using the conservation tillage approach since the early 1980s and taken to farmers in 1997 (Mrabet, 2008). Although there are several benefits associated with CA, its adoption at farmers level is quite low. According to Kassam et al. (2020), the level of adoption of CA is still low and not increasing significantly with time. In

2008-09, CA area was 4,000, 6,000 and 100 ha in Morocco, Tunisia and Algeria, respectively. In 2015-16, CA area was 10,500, 12,000 and 5,600 for the same countries (Kassam et al., 2020). Conservation Agriculture is not yet experimented or adopted in Libya and Mauritania yet.

Literature and studies on the adoption and adaptation of CA are limited in North Africa. In spite of a large development effort across the region, there is no comprehensive assessment of no-tillage system adoption in the Maghreb. In Morocco, research on water conservation started early 1980s in semiarid Morocco in order to propose to farmers the best options for managing soils and crops under erratic rainfall. First adoption studies were initiated in 1998 with support from FAO, CIRAD and government's extension services and development agencies. In 2011, the area under no-tillage farming did not exceed 5,000 ha and concerned mainly large farms having imported direct seed drills.

According to El Gharras et al. (2017), no-tillage use by farmers spread over an area of 9,000 ha. The World Bank supported a project to promote CA in semi-arid zones of Morocco (PICCPMV, World Bank 2014). The 2018 estimates of no-tillage area showed an increase of NT area to 12,826 ha, with 8,033 have being managed by 800 smallholder farmers (with less than 10 ha) and 4,793 ha by 120 large-farmers (with more than 10 ha). In 2019, OCP Group and Mohammed VI Polytechnic University (Ben Guerir) have launched with the technical support from INRA, the Al Moutmir Initiative, a large-scale adoption of no-tillage systems in Morocco in order to reach 2,000 farmers for a land area of 10,000 ha. This program has mobilized 35 direct seeders and concerned 600 innovation platforms in 18 provinces. The no-tillage surface in Morocco increased to 21,000 ha. According to a study by INRA-ICARDA (Moussadek et al. 2014), in Central Morocco region, the NT systems can be extended to 63% of agricultural land. The model by Bonzanigo et al. (2016) gave an estimate of 40% of farmers in Central Morocco region would adopt no-tillage systems.

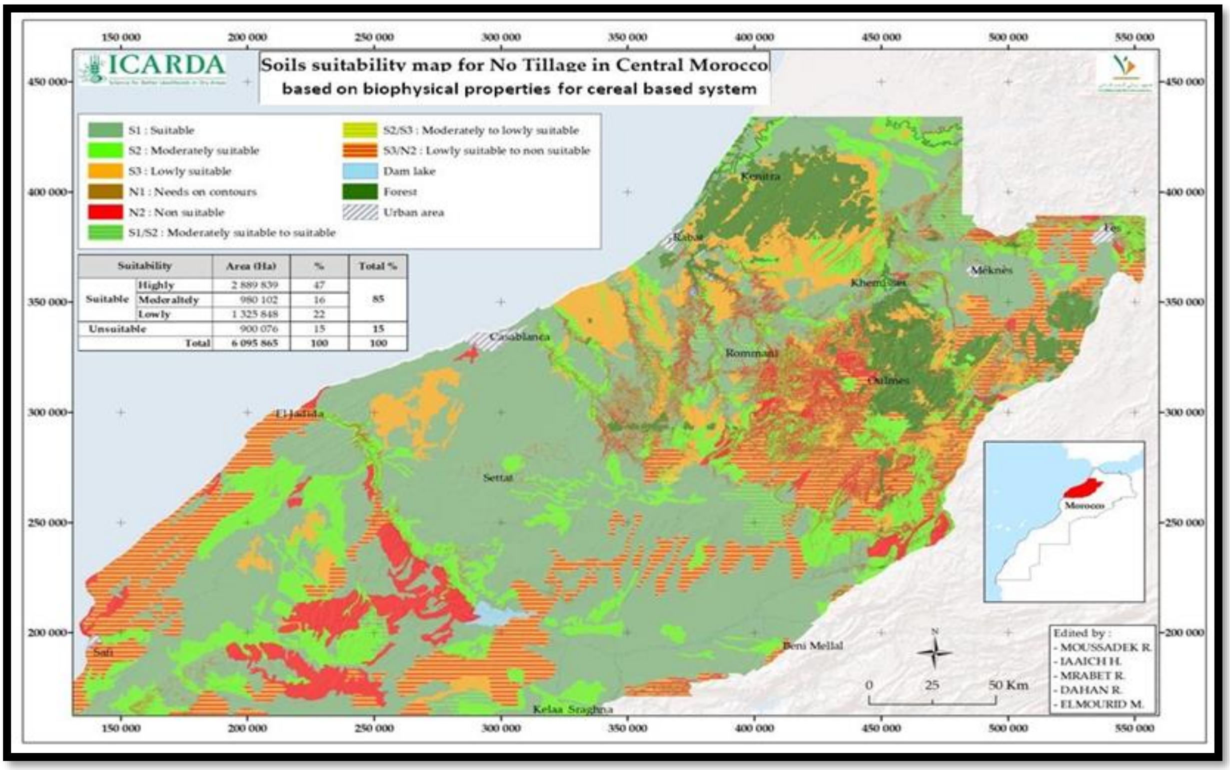

Figure 3: Soils suitability map for no-tillage in Central Morocco based on biophysical properties for cereal-based system (Moussadek et al., 2016)

5. Barriers to broad-scale adoption of CA practices

In Morocco, CA began to be promoted in 1990s, in response to issues of soil conservation, drought mitigation, and soil quality management. Field tests by the National Institute of Agronomic Research (INRA) in collaboration with other international institutions (ICARDA) and development organizations (WB, AfDB, etc.) have successfully demonstrated that the introduction of CA would bring more stable yields and lower production costs, reduced soil erosion, greater soil water conservation, improved soil quality, stable and higher crop yields, and lower production costs (Boughlala and Dahan, 2011; Moussadek et al., 2011a; Mrabet et al., 2012). For Central Morocco, Boughala and Dahan (2011) estimate a net gain of about 60% for large farmers and 200% for small farmers. Nevertheless, these data derive largely from demonstration trials, where all necessary requirements - such as NT drill, residue management - are optimally available and implementable. Reality may not be as favorable, as the implementation of the three principles, and especially residue retention and the appropriate rotation are often challenging, especially amongst smallholders (<5ha) (Haggblade and Tembo, 2003).

Also, the low adoption of CA could be explained by many factors: the first of these is the cost of learning about the new system and its management. The second is that CA requires good and precise management and is more complicated to manage than a continuous cereal-fallow system with tillage.

The CA user (farmer, researcher and extension personnel) must acquire new knowledge, and be prepared to adapt the system to their needs.

Many of the benefits of CA only develop in the longer term, whereas farmers need short term benefits – farmers cannot afford to make short term investments only for the promise of long-term gain. It is important therefore to ensure that there are short-term benefits to the adoption of CA. This may need some incentives for adoption. Crop residue management and balancing the needs of the soil and the need for livestock feed is a major difficulty in CA, especially in the early stages of adoption. The fact that farmers use the crop residues means that there is a cost associated with leaving some of the residues on the soil surface and this cost must be considered in analyzing the benefits of the system.

Table 4: The advantages and the inconveniences of Conservation Agriculture (from Mrabet et Wall, 2015)

Advantages	Inconveniences
• Reduced energy costs • Reduced labour requirements • Increased crop yields (especially in dry conditions). • Reduced equipment needs. • Increased profitability • Reduced soil erosion by more than 30% • Increased water use efficiency. • Improved soil health. • Enhanced Carbon sequestration. • Increased food security. • Climate change adaptation and mitigation. • Other environmental services	• Higher knowledge and managerial requirements to shift to CA • Competition for residues (feeding soil or animal). • Costly necessary CA equipment • Early heavier reliance on herbicides. • Probable shifts in weeds, pest and diseases. • Early higher nitrogen fertilizer requirements. • Difficult in clay soils with poor drainage and excess water.

6. Policy-level to facilitate large-scale adoption of Conservation Agriculture

For successfully promoting CA adoption, it is often not sufficient that demonstration trials show a potentially higher productivity and economic analysis suggest potential cost savings (as in Boughala and Dahan (2011)). For policy makers, the successful promotion of CA to replace conventional tillage systems requires that farmers fully understand the large economic, social, and environmental benefits that these systems offer (Kassam et al., 2014).

Rogers (2003) identifies five characteristics that an innovation needs to satisfy for users to adopt it. These five characteristics are: i) relative advantage; ii) compatibility; iii) complexity; iv) trialability; and v) observability. Relative advantage is the degree to which an innovation is perceived to perform better than the existing system. Compatibility expresses the degree to which an innovation is compatible with the existing values and fulfils the needs of the potential adopters. Complexity refers to the degree to which an innovation is perceived difficult to understand and/or to use. Trialability is the degree to which an innovation may be experimented with on a limited basis. Finally, observability is the degree to which the results of an innovation are visible to others. Moreover, the efforts of the change agents in diffusing the innovation also play a role - but they are per se not sufficient. To date, efforts in Central Morocco have been focusing primarily on demonstrating the relative advantage of CA versus conventional tillage systems (i, in Rogers' conditions). Local institutes first began with demonstration trials in their own experimental fields and they have recently begun to collaborate with large farmers who adopt CA on a small portion of their land. The hope is that experimenting the innovation on a limited basis (iv), which is at the same time very visible to all farmers (v), may raise more interest and confidence in the CA package (iii). The limited adoption in Morocco may partly depend on the fact that, to our knowledge, a comprehensive and quantitative assessment of the conditions for adoption by the different typologies of local farms (i.e., compatibility) does not yet exist. Yet, compatibility is an essential feature of adoption. Research found that even in Europe, the frequent incompatibility with either the farm systems or the fields' physical conditions, made it difficult and socio-economically risky for farmers to move away from tillage (Lahmar, 2010). The inability to manage the poor adoption of technologies that perform well in demonstration projects often resides in the poor understanding of different farmers' contexts and constraints (Baudron et al., 2012).

Kassam (2014) highlights that too little *ex ante* analysis has been conducted to better understand how specific policies will work and what impact they may have on farmers. Most past research on adoption focused on *ex post*, rather than *ex ante* assessments (Knowler and Bradshaw, 2007; Baudron et al., 2012; Moussadek et al., 2014).

There is no one size fits all policy to promote CA. Adoption rates and reaction to the same policy package vary tremendously between different typology of farmers, and within specific pedoclimatic and socioeconomic conditions. It is, therefore, crucial to design appropriate policy packages for each specific typology of farmers, within their own contexts; in particular, if the objective of introducing CA is to improve food security in Morocco, decision makers should pay particular care to smallholders' limiting conditions to the adoption (Bonzanigo et al, 2016).

7. Risks associated with adoption of in promoting CA adoption

Conservation agriculture requires a site-specific adaptive research, persistence in discovering the key risks to avoid and to resolve for making the CA principles work.

Table 5: Risk associated with adoption of Conservation Agriculture (from Mrabet and Wall, 2015)

Type of risk	Explanation
Pest and disease management	- Switching to CA may cause a shift in the makeup of insect and pest populations. A few harmful insects are indirectly affected by tillage in terms of how it impacts the habitat they need for survival.

Type of risk	Explanation
	- Usually, an increase in disease incidence and/or severity occurs because a greater quantity of inoculums of the pathogen is present on the wheat residues left above the soil surface.
Soil fertility management	- Nitrogen may be temporarily tied-up by microorganisms as they decompose crop residue with a high C:N ratio. - No-till seeder placement of fertilizers should be far enough from seeds to avoid toxicity problems.
Soil physical management	- NT systems are favoring crop productivity under different soil types. Hence, CA may only be riskier in clay soils with limited internal drainage under excessive rainfall events. - It important to remove the plough pan layer before setup CA system.
Weed management	Ineffective herbicide weed control will increase the risk of impaired crop performance.
Economical risk	-Changing from conventional farming to CA requires investment in equipment, tools and agro-chemicals, which is often a constraint for poor farmers. Initial investments may not compensate for eliminating tillage operations (mainly in dry years). -To recover the cost of no-till machines would require an increase in crop yields.

8. Achieving widespread adoption of CA: Lessons learned from other regions

Conservation agriculture systems have been developed and adopted in many countries around the world over the last half century. Lessons learned from a wide range of diverse agricultural systems, soil types, climatic conditions (including tropical, sub-tropical and temperate climates) and farm sizes provide a wealth of information to help in developing CA systems in new areas. CA systems are practiced by at least some farmers in most countries around the world, and the system has been adopted on over 180 million hectares worldwide, equivalent to 9% of the world's cropped lands. The regions with the greatest areas of CA are South America, USA and Canada, Argentina and Australia and New Zealand (Kassam et al., 2020). Recently there has been a large expansion of CA area in Asia (13.9 Mha) and Europe (3.5 Mha) but CA is not well promoted in Africa (less than 2 Mha).

Table 6: Status of CA adoption in the world (Kassam et al. 2020)

Continent	Cropland under CA (M ha)	Percent of global CA area	Percent of cropland
South America	69.90	38.7	63.2
North America	63.18	35.0	28.1
Australia and New Zealand	22.67	12.6	45.5
Asia	13.93	7.7	4.1
Russia and Ukraine	5.70	3.2	3.6

Europe	3.56	2.0	5.0
Africa	**1.51**	**0.8**	**1.1**
Global	180.44	100	12.5

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

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