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Conservation agriculture and its impact on soil quality: Highlights of Moroccan research results in semi-arid areas

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***Abstract*— Soil degradation is a serious concern in dryland areas of Morocco. These areas are characterized by low soil fertility and predominance of crop/livestock production systems with overgrazing and inappropriate crop management. Farming system is conventional and based upon intensive tillage. This has led to soil quality depletion and reduction in production potential. Our objective through this paper is to review and summarize available results on the effect of conservation agriculture (CA) on soil quality in semi-arid regions of Morocco. In fact, CA is a promising technology for these areas and has been proven efficient for soil quality improvement as well as soil chemical and physical properties. In general, the improvement in soil aggregation, carbon sequestration, nitrogen conservation, and organic matter content as well as the reduction of pH are major changes associated with the shift from conventional production system to CA production system.**

***Keywords: Conservation agriculture, no-tillage, residue management, soil degradation, and soil quality*.**

I. INTRODUCTION

Soil degradation is on the increase worldwide and is becoming an important threat to global food production and food security. In Africa, a study found that 75% of farmlands are plagued by severe soil degradation caused by wind and water erosion and the loss of essential mineral nutrients [1]. Thus, African countries face not only the challenge of increasing agricultural production with scarce overall resources, but must raise productivity in a way that conserves soils and prevents further degradation.

In Morocco, soil degradation, with its various facets, is a critical problem threatening agricultural and rural development [2]. In fact, more than 90% of the country's land is affected by desertification [3] and about 74% of the 22 watersheds are highly threatened by erosion [4]. Soil degradation is a serious concern especially in the semi-arid areas characterized by low soil organic matter and harsh climatic conditions. In these areas, where crop/livestock production systems predominate, a conventional farming system is practiced involving intensive tillage and crop residue removal. The custom is to plow frequently before sowing. Cultivation starts with summer intensive tillage that has been synonymous with farming performance [5]. Harvesting is done to obtain both grain and straw yields, leaving no residue as a soil cover. There is also free grazing of animals on the stubble after harvest. These practices, based upon unnecessary abusive tillage, overgrazing, and inappropriate crop management, have led to soil quality depletion and thus to yield reduction.

This situation implies the need for a compromise between sustainable agricultural production that conserves soils, yet provides income to farmers at an acceptable level of productivity [6] and conventional and or intensive agriculture. Conservation agriculture (CA) is a promising technology for these regions and has been proven to have a positive effect on soil resources conservation and the improvement of water use efficiency and reducing the effects of droughts [7]. CA is defined as a sustainable production system that combines the following basic principles [8]:

i. Reduction in tillage: The objective is the application of zero tillage or controlled tillage seeding systems that normally do not disturb more than 20 to 25% of the soil surface;

ii. Retention of adequate levels of crop residues and surface cover of the soil surface: The objective is to maintain an adequate soil cover through the retention of sufficient crop residues on the soil surface to protect the soil from water/wind erosion, water run-off and evaporation to improve water productivity and to enhance soil physical, chemical and biological properties associated with long term sustainable crop production;

iii. Use of crop rotations: The objective is to employ economically viable, diversified crop rotations to help moderate/mitigate possible weed, disease and pest problems and offer economically sound cropping alternatives to help minimize farmer risk.

These CA principles seem to be applicable to a wide range of crop production systems including both low-yielding rainfed and high-yielding irrigated systems conditions [8]. In the semi-arid area of Morocco, numerous studies have been conducted to identify the effect of CA on soil quality and productivity in comparison to conventional farming practices. The objective of this paper is to review and summarize available information and results on CA system and its effect on soil quality in semi-arid Morocco.

II. Semi-arid areas of Morocco: Resource bases

A. Climate

The climatic context of the region is mostly Mediterranean, characterized by high variability of annual rainfall in amounts and distribution. In general, the precipitation is low and highly variable from one season to another and within the cropping season. Although drought can occur at any time during the growing season, two main periods of drought are more likely; the early one that coincides with seed germination and seedling emergence and the terminal drought that is more frequent and affects grain set and growth [9]. Moreover, a study conducted in the region showed that the total amount of rain is decreasing significantly (Fig. 1) reducing the growing season from 180 days in 1960–1965 to 110–130 days for the period 1995–2000 [10]. In addition, an increase in temperature has also been observed, leading to a high evapotranspiration rate, increasing the water deficit. Hence, the challenge for sustainable productivity in this area is accentuated by extremely harmful climatic conditions making the soil more vulnerable to the different degradation processes. The effect of the climatic conditions is also exacerbated by low soil fertility and inappropriate farming practices.

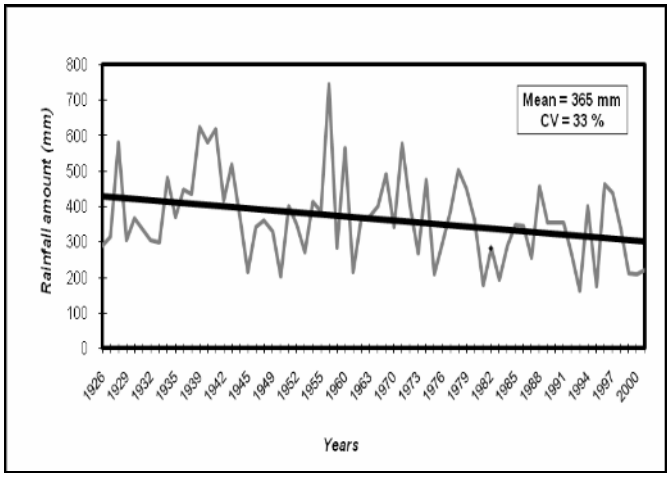

Figure 1. Rainfall evolution in Settat [10]. (CV = coefficient of variance)

B. Soils

Soils in semi-arid Morocco represent an enormous variability according to various soil taxonomic systems [11]. In general, these soils are characterized by their high content of calcium and calcium carbonates and are rich in clay [12]. According to the French soil classification system, these soils are Calcimagnesic with a tendency to vertic behavior, or Chromic Calcixerert in the US Taxonomy. This silty clay soil swells and shrinks, but is also susceptible to seal or crust formation. Organic matter content is low and therefore soil structure is rather poor [13]. Also, these soils tend to be medium to poor in fertility with low P and N levels [14]. These soil characteristics result in inherent fragility which can cause rapid deterioration of soil productivity [2].

C. Cropping systems

The main cultivated crops in the area are barley and wheat with a cropping system of one crop per year or three crops in two years. Crop rotations practiced are either continuous cereals or in rotation with follow, food legume, forage, or spring crops such as chick pea. However, wheat–fallow is the dominant cropping system. Also, in these areas, most farmers integrate livestock in their cropping system, which become more important as the quality of soils and annual rainfall decrease. Beyond social and economic consideration, the cropping system is dictated by the average annual rainfall, soil quality and water storage capacity (Table I).

TABLE I. Common crop rotations for different agro-climatic conditions [5].

Soil depth	**Rainfall (mm)**		
	< 300	**300–400**	**> 400**
Deep soil	wheat/fallow	wheat/wheat/fallow or wheat/wheat/faba bean or spring chick pea	wheat/wheat/sunflower wheat/wheat/winter or spring food legume
Shallow soil	continuous barley	wheat/forage wheat/lentils	wheat/forage crop continuous wheat

In these areas a conventional farming system is practiced involving intensive tillage and crop residue removal. The tradition is to plow frequently before sowing. Actually, cultivation starts with summer intensive tillage that has been synonymous with farming performance [5]. Harvesting is done to obtain both grain and straw, leaving no residues as soil cover. There is also free animal grazing on the stubble after harvest. These practices based upon unnecessary abusive tillage, overgrazing and inappropriate crop management have led and will led, in the long-term, to depletion in soil quality leading to reduced yield.

D. Limiting factors for agriculture productivity

Besides climatic constraints, low soil quality is one of the major problems facing agriculture productivity in the semi-arid areas of Morocco. Indeed, the soils have some properties that limit crop production such as: (i) low structural porosity and consequently high bulk density which reduces root penetration and water circulation, (ii) a tendency for compacting during the dry season that results in high runoff, (iii) poor infiltration due to rapid surface crusting even after cultivation,(iv) low values of available water, and (v) poor soil chemical fertility [2]. Moreover, long-term overuse of machinery, intensive cropping, short crop rotations, intensive grazing, and inappropriate soil management have led to a further decline of soil quality. According to Lopez Bellido [15], tillage is responsible for most soil degradation in the Mediterranean basin. Repeated tillage operations can induce greater soil erosion.

To alleviate these problems, CA has been recognized as an alternative to conventional tillage in the semi-arid areas of Morocco [16]. In the early 1980s, Moroccan research has addressed the issue of CA based on no or reduced tillage as one of the main research programs in this area. Numerous studies have been conducted to identify the influence of CA on soil quality. Highlights of related results are outlined in the following sections.

III. Conservation agriculture and its impact on soil quality

The concept of soil quality can be defined as the capacity of soil to function as a living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health [17]. Good quality soil is critical for crop production sustainability and environmental health and is vital to global function. Research on CA systems all over the world has shown its positive effect on the indicators of soil quality [18]. In semi-arid Morocco, it was found that the soil's attributes have drastically changed due to elimination of soil manipulation with tillage tools [16].

A. Soil physical quality

1) Soil structure and aggregation

Soil structure research showed that the lack of annual tillage, as provided under continuous no-tillage management, encouraged the development and persistence of a soil surface horizon rich in stable aggregates in semi-arid Morocco [19]. No-tillage was found to increase mean weight diameter and wet aggregation index compared to reduced tillage systems [20]. Mrabet [21] reported higher mean weight diameter and aggregation index at the surface (0–7 cm) of a self-mulching swelling clay soil under no-tillage than under conventional tillage. The reduced aggregation in conventional tillage is a result of direct and indirect effects of tillage on aggregation ([22]; [23]). The aggregate formation process in conventional tillage is interrupted each time the soil is tilled with the corresponding destruction of aggregates [18]. Lahlou [24] also found an increased wet aggregation index with increased residue cover under no-tillage, mainly at the soil surface (0–2.5 cm). Indeed, higher soil organic matter was often associated with aggregation improvement under no-tillage.

2) Soil moisture

CA can increase infiltration and reduce runoff and evaporation compared to conventional tillage and no-tillage removing residue. Consequently, the soil moisture is conserved and more water is available for crops [18]. Tillage can influence the evaporation process because of its effects on the physical properties of the soil surface (albedo, roughness, mulch) and on the hydraulic properties [2]. Keeping residue on the soil surface is known to reduce soil evaporation. In fact, Mrabet [25] proved that the soil can maintain its moisture above the wilting point in the seed zone for up to 5 weeks in no till with residue cover whereas it is only able to maintain it for 15 days in tilled plots.

3) Soil bulk density

The effect of CA on bulk density is a controversial issue. In fact, the influences of different tillage practices on bulk density are variable. Some studies reported that no-tillage results in a higher bulk density of the soil and consequently greater soil strength. However, in other studies, the bulk density was similar or lower with no-tillage than with conventional tillage.

In semi-arid Morocco, after 4 years of experimentation, Lahlou [24] reported a natural consolidation and mechanical compaction in no-tillage causing denser packing of top soil. However, AitCherki [26] did not find a significant increase in dry bulk density under no-tillage systems compared to conventional after 6 years of experiments. According to Kacemi [27] differences in soil bulk density, between no-tillage and minimum tillage with V-swep, were negligible among rotations.

4) Water infiltration

Many studies have reported that the permanent soil cover in CA reduces run-off, leading to higher infiltration rates and more water available to crops [28, 29, 30]. The research on water dynamics in CA systems executed in Morocco under dry regimes showed clearly that not tilling the soil and mulching extended the humid period significantly [26]. Rainfall infiltration is improved under no-tillage systems, which increases the amount of soil water available for plants for heavy textured soils [19, 27, 31].

The rate of infiltration is controlled by pore size distribution and the continuity of pores or pathways. Hence, the effect of tillage and residue cover on water infiltration is probably due to changes in soil structure [2]. Indeed, the presence of crop residues over the soil surface prevents aggregate breakdown by direct raindrop impact as well as by rapid wetting and drying of soils [28]. Moreover, aggregates are more stable under no-tillage with residue retention compared to conventional tillage and no-tillage without residue retention [18]. Dimanche and Hoogmoed [32] compared two soil tillage systems (off-set disking and reduced tillage with spring tine cultivator) under simulated rainfall on a Chromic Calcixert soil of the semi-arid region of Meknes and concluded that disc harrow caused excessive pulverization and seal formation. Consequently, reduced tillage systems had higher infiltration rates than conventional tillage.

In addition, the rotation of different crops with different rooting patterns combined with minimal soil disturbance in no-tillage systems promotes a more extensive network of root channels and macropores in the soil that helps with water infiltration to deeper depth [27].

B. Soil chemical quality

1) Soil organic matter

Organic matter plays an important role in nutrient availability and soil aggregate stability. In semi-arid Morocco low organic matter is the major feature of soils. Hence, good organic matter management is essential for sustainable agriculture. There is evidence that elimination of tillage can result in sequestration of carbon [33].

Mrabet et al. [34] recorded increases in soil organic matter of 13.6% with no-tillage, and 3.3% with conventional tillage over an 11-year period, with differences being greater in the top 25 mm layer. Generally, there is a trend towards a stratification of soil organic matter at the surface under no-tillage [35]. At 0–25 mm, soil organic matter increased from 5.6 to 7.2 Mg ha-1 under no-tillage, after 4 and 11 years, respectively. At the same horizon, soil organic matter level did not change under conventional tillage after the same periods [16, 19, 36]. It is also reported that no-tillage soil has sequestered 3.5 and 3.4 Mg ha-1 of soil organic matter more than conventional tillage in the 0–200 mm horizon, after 4 and 11 years, respectively. No-tillage also increased organic matter content of aggregates in all classes of a Calcixeroll soil in Morocco [37].

2) Soil nutrients

Tillage, residue management and crop rotation have a significant effect on nutrient distribution and transformation in soils [18, 39]. Due to its impact on soil organic C and N mineralization, CA can influence soil N availability [40]. However, the literature concerning the effect of reduced tillage with residue retention on N mineralization is inconclusive. Zero tillage is generally associated with lower N availability because of greater immobilization by the residues left on the soil surface [41, 42].

After 7 years of experimentation at Sidi El Aidi and under continuous wheat, Mrabet et al [42] found that no-tillage sequesters more N than conventional and reduced tillage systems. It is also reported by Bessam and Mrabet [33, 36] that nitrogen in particulate organic matter (Npom) was higher under no-tillage than conventional tillage in the seed zone from 4 to 13 years of experimentation. However, the effect of these tillage systems was not significant in deeper soil layers (50–100 and 100–200mm). The same authors showed that Npom is more influenced by residue management than total nitrogen.

A positive effect of no-tillage has also been observed on the availability of P and K. According to Mrabet et al. [34], no-tilled soil had a higher concentration of P and K near the soil surface than tilled soil, whereas in deeper layers the reverse has been observed. The same authors suggest that P and K were probably higher in the surface of no-tilled soil due to higher soil organic matter. Progressive mineralization of organic matter was the most important source of these nutrients in this soil under no tillage. Franzluebbers et al. [43, 44] explain this fact by the accumulation of microbial biomass near the surface.

3) Soil pH

Numerous studies have reported that the pH of the top soil in no-tillage is lower than in conventional tillage. The results obtained by Ibno-Namr and Mrabet [45] and Ibno-Namr [46] confirmed these findings in the semi-arid area of Morocco for Vertic Calcixerol soil after 11 years of no-tillage. According to Franzluebbers and Hons [47], the pH decrease may be due to the decomposition of soil organic matter which has been accumulated with no-tillage. This lower pH could also be due to the acidifying effect of nitrogen and phosphorus fertilizers applied more superficially under no-tillage than under conventional tillage [48].

IV. CONCLUSION

In light of the above it is clear that CA can play a major role in improving soil quality in the semi-arid area, thus limiting the devastating consequences of drought and ensuring sustainable productivity while reducing threats to the environment. Research on tillage management systems in Morocco started in the early 1980s. Numerous studies have been conducted which have shown positive effects of CA in improving soil physical and chemical properties. However, the effect of this innovative management cropping system on soil biological properties has not been studied.

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