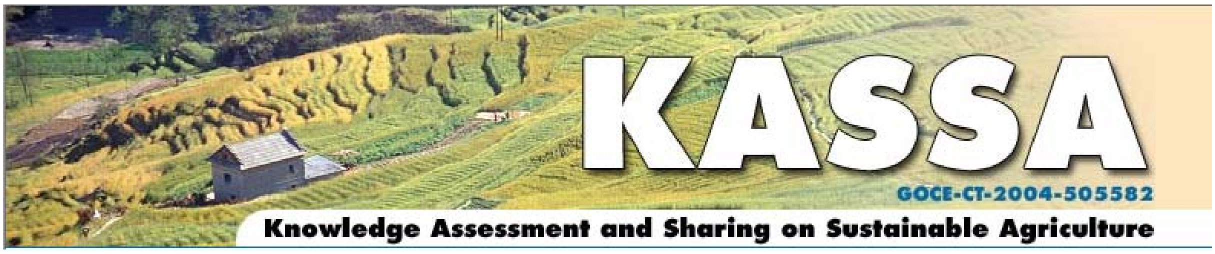

Deliverable 1.2 - Appendix A2

No-tillage research in rainfed areas of Morocco

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Table of Content

2. INTRODUCTION

1.1. General background

Agriculture represents between 15 to 20% of GDP depending on rainfall and employs 50% of active population. The cultivated area accounts for 12% of total land area, which is 9 millions hectares. It has varied from 8 millions in 1970s to 9 millions in 2000s as shown in Figure 1.

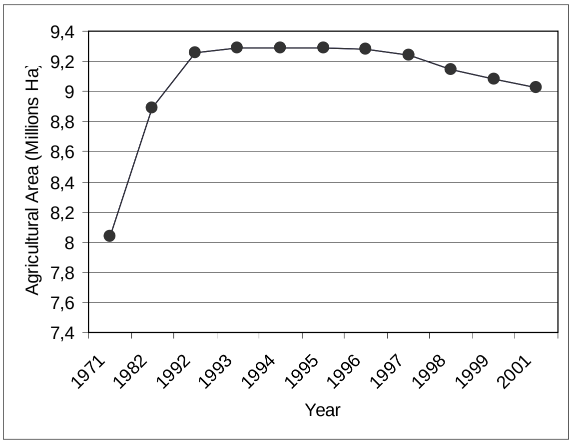

Figure 1: Cultivated Area Variation with Time

In semiarid Morocco, natural resources are unsustainably used and threatened by a myriad of environmental problems (erosion, compaction, contamination and greenhouse effects). Hence, food security is affected and spiral of poverty is reinforced. Tillage and grazing are integral parts of unsustainable conventional agriculture in Morocco. Residue/stubble exportation from lands is even maximizing these declines.

Over-grazing, intensive cropping and tillage systems have led to substantial soil quality deterioration of much of the country's farmlands. Soil fertility, structure and organic matter are declining as a result of widespread use of tillage and agricultural practices (i.e. grazing, straw exportation) that neglect to incorporate sufficient organic material into the soil. The persisting use of these soil management practices played a significant role in the durability of unsustainable agriculture.

At the farm, farmers are obliged to manage simultaneously water scarcity and crop failures through traditional soil, water and crop management practices. Quantitatively, farmers are seeing their production declining and loosing their harmony with natural resources (i.e. soils).

1.2. Dryland Agriculture: Features

Agriculture is a major and sensitive sector of the country’s economy, consuming most of the available water and energy resources. As can be expected from any dryland region, water availability is the main constraint for agriculture in Morocco. Irrigated lands account for 13% of total agricultural lands.

Agricultural production of major grain crops is strongly affected by precipitation fluctuations, and crop and livestock losses due to drought can have very severe repercussions on both the countries balance of payments and the livelihoods of individual farmers and producers. Land use is much diversified and a variety of crops are being grown. It is however interesting to note that cereals occupy 67% of cultivated area. An important percentage of lands is reserve to fallow (either weedy or tilled fallow) (13%). Livestock plays a key role; in most cases, it is characteristically interrelated with other land uses, through residue and stubble grazing or use of marginal lands.

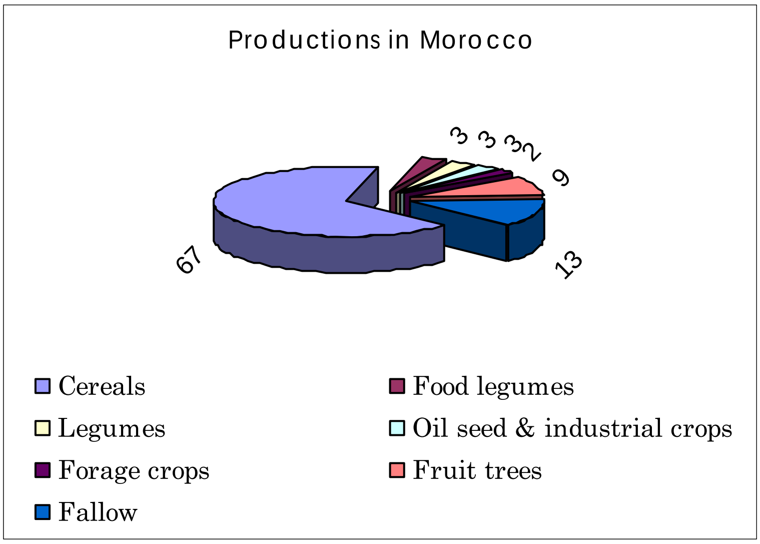

Figure 2: Importance of Agricultural Crops in Morocco

Morocco has a large region of dryland, which accounts for about 87% of the nation's total area. Dyland farming development in this region is constrained by adverse weather, topography and water resource conditions, low fertility soils, and poor soil management. Conventional farming practices with intensive cultivation, low fertilizer or manure input, and little use of crop residue cause an exacerbation of soil, water and nutrient losses.

The drylands can be subdivided in two important systems:

Sub-humid or Rainfed mixed: Highly diversified systems, with a wide range of rainfed crops, including tree crops (olives, fruits and nuts) and field crops (mainly wheat, barley, lentil, chickpea, potato, sugar beet and faba bean). Terracing is common in hilly areas. Seasonal interaction with livestock, mainly sheep and goats, and use of crop residues and other fodder are common features.

Semi-arid or Dryland mixed: Less diverse than the rainfed mixed systems, with barley and wheat as main crops grown in alternation with single or double-season fallows or with legumes (lentil, chickpea). Interactions with small livestock systems mainly take the form of barley and stubble-grazing and are stronger than in the previous system.

Crops suitable for the region therefore have to be adapted to stresses related to temperate regions (cold) and arid zones (heat and drought). Depending on the extent of rainfall variability, intra-seasonal dry spells can be an important risk to dryland agriculture. Early-season, mid-season and late-season dry spells are all possible (Yacoubi et al., 2000).

Dryland cropping in most cultivated areas with winter rainfall is dominated by cereals, i.e., wheat (*Triticum* spp) and barley (*Hordeum vulgare* L.); cereal production and livestock are combined enterprises. The relative importance of bread wheat (T. *aestivum* L.) and durum wheat (T. *turgidum* var *durum* L.) depends on rainfall; bread wheat tends to occupy the more favorable rainfall areas. In general, barley tends to dominate the lower end of the rainfall range. Continuous wheat occupies 30% of the arable lands in Morocco, even though it is grown in a permanently stressed environment. Mean cereal yields are low, even after adoption of fertilizers and appropriate crop cultivars.

Associated with cereal production are food legumes, i.e., chickpea (*Cicer arietinum* L.), lentil, faba bean (*Vicia faba*), and pea (*Pisum sativus* L.). Forage legumes ‘vetch (*Viscia sativa*)) and Oilseed crops (sunflower (*Helianthus annus))* are also common but of minor importance. As all rainfed crops are invariably limited by drought to some degree in most years, the cropping “strategy” that has evolved to mitigate this constraint is the use of rotations, i.e., growing of crops in a particular sequence.

For several millennia, Moroccan farmers were aware of the value of legumes and fallow for improving cereal yields vis-à-vis climatic variations. This perception has provided the basis for the cropping systems common in the region today. In the wetter part of the rainfall spectrum (> 350 mm), wheat, both bread and durum, is alternated with faba bean, lentil, and chickpea as winter-sown species, or sunflower, and vegetables sown in spring or summer. Barley replaces wheat in drier areas with a more limited range of alternative crops. While fallowing was common, especially for barley, land-use pressure is now such that continuous cereal cropping is more common. Notwithstanding such cropping changes, the rationale for, and the benefits of, rotational cropping systems are as valid as ever.

Since the 1970s, soil tillage systems have been greatly improved with the development and the introduction of mechanized farming technologies. In sub-humid region, a common practice was, and still is, to use a moldboard plow to a depth of 20–30 cm and then follow with seedbed preparation with a harrow implements. In semi-arid region, a tractor-drawn offset disc harrow is used for both primary and secondary tillage. The use of tillage is dependant on various factors, i.e. time availability, livestock grazing, rainfall occurrence, tillage tools, and economy. In livestock-grain production systems, primary tillage takes place in early fall, usually October-November, after the onset of the first seasonal rains which make the soil friable. Where the stubble residues have been grazed heavily, with animal trampling pressure following the previous cropping season, some soils are prone to “hard setting” which reduces infiltration and promotes runoff of the initial rains. Prior to early-season rain, most soils are too hard and unworkable and can only be tilled with the most powerful machinery.

The use of tractors for tillage and cultivation is still in a developmental stage in most semi-arid and sub-humid Morocco. More than 50% of farmers use the off-set disk for seedbed preparation and other cultivations. We can see in table 1 that 80% of farmers used powered tillage. Only 28% of the cultivated land undergoes deep tillage (Moldboard, disk plow and chisels). Chisel plows are getting more frequently used for primary tillage or for wheat seedbed preparation on sloping lands. Other types of tillage implements are lacking or not widely used.

Table 1: Importance of tillage implements use by Moroccan farmers (Mrabet, 1997)

Tillage implements	Percent of total area
Off-set disk	51
Mouldboard and disk plow	18
Chisel	10
Stubble plow	1
Rotavator and sweep	0
Animal drawn implements	20

Natural resources are at present weakly resilient to degradation enforcing economical failure of most agricultural systems. Particularly, Moroccan dryland wheat cropping systems are productively erratic and time-stability is needed. Hence, it is crucial, that these effects be reversed through developed soil carbon sequestration options (ie no-tillage systems).

1.3. Development of no-tillage[1] practices

Agronomic research has for many years faced the need to maintain favorable `soil tilth' in order to sustain productive agriculture (Mrabet et al., 1993; Kacemi et al., 1995). Water conservation research starting in the early 1970s, has focused on the effects of tillage systems, row spacing, seeding rate, rotation (including fallow type) and variety on yields of wheat. All of the early studies either removed residue by grazing and/or incorporated residue with clean tillage. The burning of residues in place is rare because of low residue production.

Due to climate insecurity characterizing drylands, researchers at INRA developed in early 1980 a water conservation project to see opportunities for both storing scarce rainfall and increasing its efficient use by crops. Pertinent opportunity was no-tillage system with crop residue cover. High and stable wheat productions were allowed by the no-tillage system vis à vis climatic variability. At the same time, conventional systems, in their myriad forms of soil manipulation and perturbation, were either responsible of crop failure or reduced productivity. Twenty two years of research on No-tillage in semiarid Morocco was accompanied by several years of trials at other agricultural institutions (Institut Agronomique et Vétérinaire Hassan II (Rabat) and Ecole Nationale d'Agriculture (Meknes)) in sub-humid zones, which also agreed on superiority of no-tillage system over other traditional and conventional tillage practices.
Bouzza (1990) and Kacemi (1992) agreed that the wheat-fallow system is obligatory in areas receiving less than 300 mm rainfall with profile-stored water contributing significantly to the later stages of wheat growth and grain filling. In water-deficient areas, like Morocco, where the potential for increasing crop water supply is limited, small increases in available water can result in large relative increases in yields. In areas receiving more than 300 mm rainfall, fallowing may be restricted due to: a need for continuous grain production to sustain population needs, a required protection against erosion, restrictions in herbicide usage, and a limited water storage capacity of soils.

[1] No-tillage system means elimination of any soil manipulation prior and during crop growth and development, chemical weed control, crop residue and stubble maintenance at level at least higher than 30% cover and seeding with a no-till drill.

In late 1990, research was fostered by on-farm experimentation and evaluation of no-tillage and conservation cropping systems in several locations by INRA in semi-arid areas and by IAV and ENA in more favorable zones. Results from these trials recognized that no-tillage system could halt or reverse decreased production and land degradation. With No-tillage, Moroccan farmers, like their counterparts worldwide, can improve their production with eliminating tillage while adapting to changes (climate, prices). Reduced costs, labor and energy use are also possible with appropriate management of soils without tillage.

Both adaptive research and adoption/extension efforts of no-tillage should be reinforced by economic and social studies with full participation of farmers. However, a common problem in dry areas is that the impact of these technologies on the livelihood of the rural poor and natural resource sustainability has often been limited. Available contribution of INRA to field demonstration of No-tillage is not sufficient for wide recognition of benefits of no-tillage systems by farmers.

2. NO-TILLAGE RESEARCH

2.1. Conditions of obtaining of results

Research groups

Recognizing the need to recover soil quality and production decline, INRA scientists began, in the early 1980s, research on the effects of crop rotations, tillage and residue management on the productivity and quality of cropped soils. Twenty two years of no-tillage research were confined to two soils of INRA experiment stations in semiarid Morocco. In subhumid areas, research on no tillage was carried by IAV Hassan II and ENA Meknes but it is discontinued. In Meknès, NT research was focused on improving the wheat-sunflower rotation with a combination of direct seeding and fertilization.

The main research teams are INRA at Settat, IAV Hassan II at Rabat and ENA at Meknes. The researchers involved in no-tillage are very few, not exceeding 12. INRA at Settat was involved with no-tillage in semi-arid and arid regions (200-400 mm) and IAV and ENA were interested in more favorable areas (400 – 600 mm), which is Gharb, Zaer and Saïs.

Research approach used

The first years' research was confined to experiment stations, either at INRA, IAV or ENA. Lately, research on no-tillage was performed in farmer's fields as on-farm studies or research & development. In the development of trials at farmer fields, the various regional and local agricultural authorities were involved.

The experimental sites are located at the Institut National de la Recherche Agronomique (INRA) agricultural research stations at Sidi El Aydi and Jemaa Shaim, at IAV and ENA research Stations (Table 2).

Table 2: Summary information on no-tillage experiments[2]

Experiment	Site	Treatments	Duration	References
Water Conservation	Jemaa shaim, 40 km de Safi, Chromoxerert, Average rainfall 270mm	Tillage systems Fallow Management Wheat Rotations	1983-long term	Mrabet & Bouzza (1999)
Water Conservation	Sidi el aydi, 40km au sud de Casablanca, Entic Chromoxeret, Average rainfall 380mm	Tillage systems Fallow Management Wheat Rotations	1983-1993	Bouzza (1990)
Tillage, Weed Control and Cropping Systems	Sidi el aydi, Vertic Calcixerol, Average rainfall 380mm	Tillage systems, Herbicide strategies, Wheat Rotations	1987-long-term	Kacemi (1992) Kacemi et al. (1995) El-Brahli et al. (1997) Saber (2002), Mrabet et al. (2001a,b).
Tillage, Residue Management and Cropping Systems	Sidi el aydi, Vertic Calcixerol, Average rainfall 380mm	Tillage systems Crop residue management Wheat Rotation	1994-long-term	Ibno-namr & Mrabet (2004),
Tillage systems for continuous wheat intensification	Sidi el aydi	Tillage systems Crop residue management Continuous wheat	1994-2004	Mrabet (1997, 2000, 2002), Tab (2003)
Optimizing Tillage systems in rainfed cereal production areas	Ain el Aouda (zaer), 30 km au sud-est de rabat, 350-400mm, Sidi allal tazi, near kenitra (gharb) Vertisol	Cereal-cereal-food legumes, Tillage systems	1984-1988	Bourarach (1989); Dycker & Bourarach (1992)
Intensification of wheat-sunflower rotation	Meknes, vertisol soil, 570 mm	Fallow management, Tillage systems	1994-98	Aboudrare et al. (2003)
Soil behaviour under tillage systems and climate	Meknes, Vertisol, 570 mm	Tillage systems	1985-88	Chekli (1991)

[2] Table summarizes documented no-tillage research experiments. More information can be gathered later.

Biophysical conditions

The semi-arid and sub-humid regions of Morocco (200 – 600 mm), where research on no-tillage was carried, are characterized by some of the most variable climates in the world, in which drought is endemic. These climates are typical Mediterranean types in the sense that they have warm and dry summers and mild and rainy winters. Within this overall Mediterranean setting, the climates of the region show great diversity.

The dryness of the summer is typical for this region. The seasonal distribution of precipitation is characterized by an overall predominance of winter precipitation; however, autumn rains can be as important as the winter rains, especially in sub-humid region.

Irrespective of the degree of aridity, precipitation variability is considerable throughout the country. The large variations in rainfall between different years are typical for the country as a whole, and are not confined to a particular sub-region. Drought is a natural consequence of pronounced rainfall variability and therefore an inherent feature; rainfall variability has a higher impact on agricultural production with point to mid-season drought.

An additional characteristic is a greater tendency towards higher-volume, higher-intensity storms as compared to temperate climates. This entails a greater concentration of precipitation into single precipitation events, with implications for the regional hydrology, such as higher runoff, increased flood risk and erosion hazard. In addition, these regions have diverse landforms and soils; however, most research trials were carried out in soils of high clay contents (ie vertisols and mollisols).

2.2. Significance and impact of the results obtained

Much of the research that forms the foundation for understanding the influence of no-tillage on soil quality, water conservation and wheat productivity has been conducted in two experimental stations (Sidi El Aydi with an average rainfall of 358 mm and a Vertic Calcixeroll and Jemaat Shaim with an average rainfall of 270 mm and a Typic Chromoxerert).

Main research lines and topics identified

The main research lines for arid and semi-arid regions (200-450mm):

- Water conservation & Use,
- Soil quality and fertility,
- Wheat productivity and performances,
- Weed control and herbicide use,
- No-till Wheat drill
- Nitrogen fertilisation,
- Cropping systems,
- Crop residue management,
- Disease,
- Socio-economy of adopting no-tillage systems.

The main research lines for semiarid to subhumid regions (400-600 mm):

- No-till drill & tillage performances,

– Water conservation & Use,
– Soil structure,
– Soil erosion and runoff,
– Crop productivity,
– Disease,
– Time & Energy consumption.

2.3. Main scientific and practical results obtained[3]

2.3.1. Environmental impact

Much of the pioneering work on conservation tillage was done in Morocco at the Dryland Center of the Institut National de la Recherche Agronomique, Settat, Morocco. The fundamentals of this research were reported in the doctoral theses of Bouzza (1990), Kacemi (1992), and Mrabet (1997), and subsequently reported in various proceedings and journal articles. The work grew out of need to improve the efficiency of fallowed land in Morocco, especially in the 200-400 mm zone. Theoretically, residual moisture from the fallow year should increase the available moisture and therefore crop yields in the subsequent cropped year. However, in practice at the farm, fallows are kept "weedy" and grazed. At the end of the fallow season, there is little stored moisture and the soil is bare and prone to erosion. With increasing cultivation, any perceived advantage of fallow is eliminated.

Soil moisture is a critical environmental variable, as it significantly affects infiltration, evapotranspiration and surface and subsurface runoff processes. In semiarid region, insufficiency of soil moisture caused by tillage is more significant and has much short-term negative influence on crop production than water erosion. There is a plethora of research supporting the general positive relationship between No-Tillage and water storage and conservation. Thus, the work of Bouzza (1990, Table 3) assessed various cultivation implements under different fallow systems. These initial results highlighted the potential of no-tillage to conserve moisture. The work of Kacemi (1992) showed that where weeds were controlled exclusively by chemicals with evaporation being negligible in the absence of conventional tillage, the no-till system increased stored soil water by 85 mm and promoted increased wheat yields and consequently better water-use efficiency. Mrabet (1997) found that residues on the soil surface reduced evaporation. To reach soil moisture at wilting point, a non-tilled surface needed on average 32 days, while moldboard plow, chisel plow, rotavator and disking needed only 8, 21, 17 and 18 days, respectively (Table 4).

Table 3. Fallow storage efficiency (Bouzza, 1990)[4].

Type of Fallow	Fallow Storage Efficiency (%)[5]	Amount of stored water (mm)[6]
Chemical	28	85
Clean	18	54
Stubble Mulch	21	63
Weedy	10	30

[3] The results presented herein are those published in reports, papers and seminars. More results are available but not yet published.
[4] Five years' average (1986-90) at Sidi El-Aydi station near Settat (Entic Chromoxerert). Stubble mulch fallow in which weeds are controlled by a V blade sweep, but without inverting the soil, Tilled or clean fallow in which weeds are controlled with inverting equipment such as an offset disk
[5] Calculated as the ratio of stored water and the amount of rainfall received during the fallow
[6] Amount of stored water in a 1.2 m profile

Table 4: Time to wilting point for different tillage systems at Sidi el Aydi station (Mrabet, 1997).

Tillage	Wet regime Irrigation (77 mm)	Dry regime Irrigation (35 mm)
No-tillage	39	25
Chiseling	31	11
Rotavator	24	10
Off-set disk harrow	26	9
Sweep	17	8
Moldboard plow	16	0

Soil moisture at wilting point is 0.16 g/g

A crucial aspect of soil water management under semi-arid tillage systems is the extent of crop residues left on the soil surface (Mrabet, 1997), with 70% soil cover having a significant effect on reducing soil water loss when cultivation implements were compared with no-till plus residues. The chisel was superior to the rotary cultivator offset disk or stubble mulching with the "sweep". Based on Bouzza's (1990) and Mrabet's (1997; 2000) work, pre-plant tillage was not considered necessary in self-mulching clay soils, as represented by Sidi El-Aydi station in Morocco.

An additional side-benefit from no-tillage-reduced-tillage systems is a positive impact on soil organic matter. While soil organic matter levels in Morocco are low. i.e., < 1–2%, some cropping systems managed under no-tillage technology, notably with forage legumes in rotation with cereals, can cause sustainable increases in soil organic matter (Mrabet et al., 2001a,b). Mrabet et al. (2001b) showed increases of 13.6% with no-till, and 3.3% with conventional tillage over an 11-year period, with differences being greater in the top 25 cm layer. Generally, there is a trend towards a stratification of Soil organic carbon at the surface under NT, without any effect on lower horizons (Mrabet, 2002c). At 0-25 mm, Soil organic carbon increased from 5.62 to 7.21 t ha^{-1} under NT, after 4 and 11 years. At the same horizon, Soil organic carbon level did not change under conventional tillage after the same periods (Bessam & Mrabet, 2001, 2003). These authors reported that NT soil has sequestered 3.5 and 3.4 t ha-1 of SOC more than conventional tillage in the 0-200 mm horizon, after 4 and 11 years, respectively. These findings are illustrated in Figure 3.

More recent studies have recognized the importance of residue covers. Retention of crop residues and lack of soil disturbance under NT affect nutrient cycling and availability. Consequently, fertilizer requirements of wheat grown with NT have also received attention (Mrabet *et al.*, 2001b). These authors found that NT helped to conserve more nitrogen, and resulted in increased extractable phosphorus and exchangeable potassium concentrations in the upper root-zone. There is also a slight acidification of the soil at the surface, which can increase availability of nutrients to wheat (Table 5). Saber & Mrabet (2002) reported an increase in the labile fraction of soil organic matter (particulate organic matter) under NT compared to conventional tillage. This soil organic matter fraction also contributes to nutrient cycling and availability.

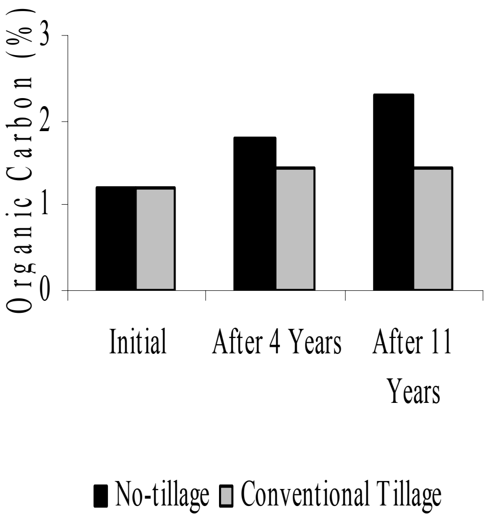

Figure 3. Soil Organic Carbon in the 0-200 mm horizon as affected by tillage system and time (Bessam and Mrabet, 2003)

Elimination of tillage prevents and eventually reverses soil organic matter decline, due largely to the accumulation of plant residues on the soil surface. Therefore, NT provides more favorable conditions than mechanical tillage for sequestering carbon and tapping the soil's potential to serve as a sink for atmospheric C (Mrabet et al., 2001a,b). This build-up of organic matter in surface horizon (generally the seed-zone) improves seedling establishment, sometimes an important factor in crop growth under no-tillage (El-Maataoui, 2002). Figure 4 shows that the increase in residue level helped sequester the greatest amount of C in the top 50 mm of soil, a lesser amount in the 50-100 mm depth and no significant amount in the 100-200 mm and below. Ibno-Namr & Mrabet (2004) reported an increased level of organic carbon, nitrogen, particulate organic matter with increase in residue level at the soil surface (0-5 cm). In other terms, the NT improvement of soil organic carbon and other chemical soil properties can proportional to residue level (Fig. 5).

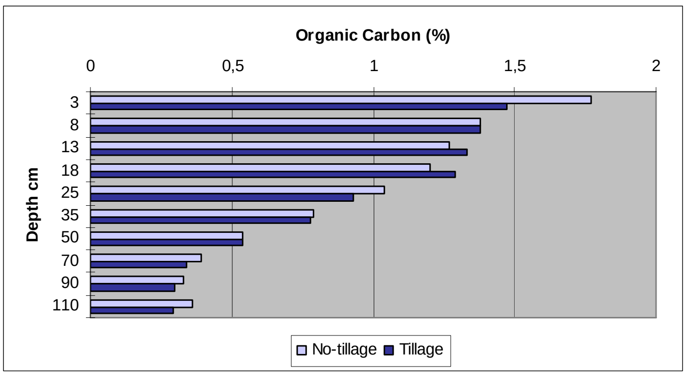

Figure 4: Impact of tillage on organic matter distribution in a soil profile (Sidi El Aydi)

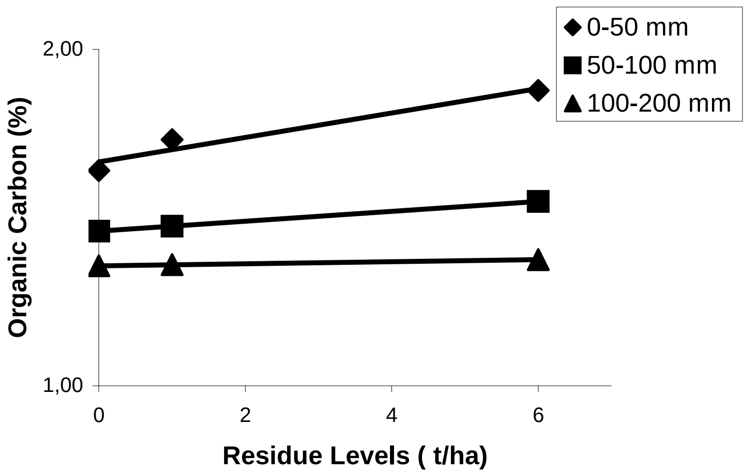

Figure 5: Residue level effect on organic carbon at three surface horizons under No-tillage system (Mrabet et al., 2003, Ibno-Namr & Mrabet, 2004).

Table 5 : Effect of rotation and tillage[7] on soil pH (Saber & Mrabet, 2002).

Horizon depth	0-25 mm	25-70 mm	70-200 mm
Rotation			
WW	7.6B[a]	7.9B	8.1B
WF	7.7B	8.0B	8.1B
WFoF	8.0A	8.1A	8.3A
WCF	8.0A	8.2A	8.2A
WLF	8.0A	8.1A	8.2A
Tillage System			
No-tillage	7.8B	8.1A	8.2A
Conventional Tillage	8.0A	8.0A	8.2A
Average	7.9	8.1	8.2

[a] In each column, values followed by the same letter are not significantly different at $P \leq 0.05$ using LSD test.

In a semiarid soil of Morocco, Table 6 shows clearly that NT is improving POM in the surface compared to conventional tillage. The benefits of improving soil quality and hence reducing degradation are cumulative. This cumulative effect of NT is a reflection on short or long-term gain in production.

[7] WW = Continuous wheat, WF = Wheat Fallow, WFoF = Wheat-forage-fallow, WCF = Wheat-corn-fallow, WLF=Wheat-Lentils-Fallow; CT = off-set disking.

Table 6. Carbon content in particulate organic matter (Mg ha^{-1}) as affected by tillage system over time in semiarid Morocco (Bessam & Mrabet, 2003).

Time Years	Horizon (mm)					
	0-50		50-100		100-200	
	NT	CT	NT	CT	NT	CT
5	10.62 A	9.75 B	9.45 A	9.32 A	17.23 A	16.81 A
13	11.88 A	8.94 B	8.53 A	9.07 A	14.80 B	16.28 A

In each raw and for each horizon, values followed by same letter are not significantly different at p=0.05 using LSD test; NT = No-tillage and CT = Conventional tillage with disk harrows.

The surface of Moroccan soils is vulnerable to erosion by water and wind due to its low aggregation and organic matter content. Independently of the season, results showed that the proportion of more stable aggregates in the soil surface (seed-zone) is greater in NT than conventional tillage (Fig. 6). It was also found that aggregate stability increases with depth as residue cover increases in NT (Fig. 7). The development of a good structure at the surface improves water entry, movement and distribution and has positive effects on evaporation and erosion control. The aggregation also reflects that SOC is conserved and protected and allows soil organic matter to function as a reservoir of plant nutrients and energy. Soil aggregation is increased under No-tillage which generates positive effects (sediment control, wind erosion reduction, elimination of crusting). No-Tillage acreage will increase where erosion and surface crusting are limiting farming. In favorable areas of Morocco (like sub-humid region), No-tillage economical and ecological positive influences will certainly render the system the favored approach.

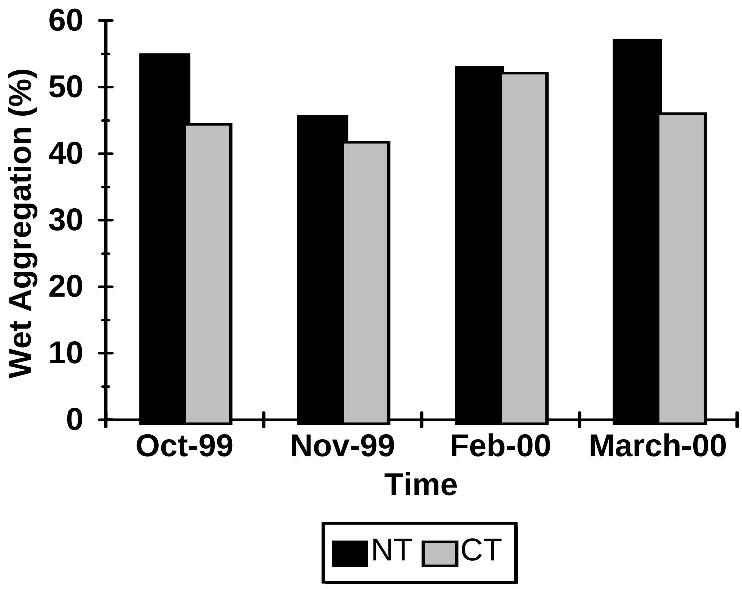

Figure 6: Aggregate stability as a function of tillage and season (Mrabet, 2002c). NT = No-tillage and CT = Off-set disking.

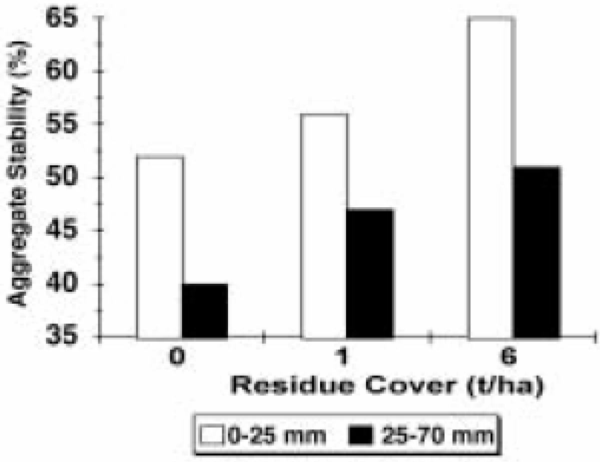

Figure 7: No-tillage residue cover effect on aggregate stability at two surface horizon of a calcixeroll soil (Lahlou and Mrabet, 2001).

In sub-humid site with a soil of 60% clay (Meknes region), Aboudrare et al. (2003), in a wheat-sunflower, were not able to find significance in terms of infiltration and water storage between several conventional tillage systems (chisel, mouldboard, paraplow, disk harrow) and no-tillage systems in a period from 1994 to 1998. Accumulated evaporation was lower under no-tillage systems when residue cover is maintained.

2.3.2. Agronomic impact

The assessment of any tillage system hinges around crop yields. Thus, under continuous wheat or wheat fallow, mean yields with no-tillage, over a 10-year period at two stations (Sidi El-Aydi, 370 mm, and Jemma Shaim, 270 mm) were higher or equal to minimum tillage (sweep), with both being significantly better than conventional tillage (Table 7). Differences between tillage systems in terms of crop yields and water-use efficiency were less pronounced under continuous wheat. The Moroccan research identified depth of seeding as an important factor in crop establishment and the need for an appropriate grain drill for direct seeding. Given the precariousness of the region's rainfall, shallow seeding runs the risk of crop failure if post germinating rains are poor, while deep planting causes poor germination. The Dryland Research Center's researchers have now developed a no-till drill which is commercially available to farmers.

Table 7: Wheat grain yield (Mg/ha) as affected by tillage and cropping systems (Mrabet, 2002b).

Tillage system	Continuous Wheat	Wheat-Fallow
Sidi El Aydi[1]		
No-Tillage	1.9A	3.7A
Conventional Tillage	1.4B	2.6B
Jemaa Shaim[2]		
No-Tillage	1.6A	3.1A
Conventional Tillage	1.6A	2.4B

[1] Average annual rainfall 358mm, Clay Soil, Flat Topography, this experiment started in 1983 and ended in 1993.

[2] Average annual rainfall 270 mm, Clay Soil, Flat Topography, this experiment started in 1983, is at its 18th years. In a column, values with the same letter do not differ significantly at $P \leq 0.05$ (LSD Test).

As a result of long-term trials at the research stations, It has been found that average wheat yields with use of no-tillage systems are higher than those observed with other tillage systems (Bouzza, 1990; Mrabet, 2000). Mrabet (2002a) stated that in spite of a somewhat slower rate of growth of wheat in the early growing season, final yields were higher under NT. These data were supported by those found in a farmer's field over a five-year period (Mrabet, 2002b; Fig. 8). Mrabet (2002a) reported that 30% of straw produced under no-tillage could be removed without jeopardising wheat performances. Taking into account the potential savings in machinery, labour and fuel, No-tillage will give a net economic benefit (Table 9).

2.3.3. Socio-economic impact

Agriculture is an important part of the livelihoods of Moroccan farmers in semi-arid and sub-humid regions, and it is frequently argued that agricultural growth is a fundamental pre-requisite for widespread poverty reduction. The no-tillage system is seen as an agriculture moving technology to improve economically and socially farmer's being.

According to Bourarach (1989) and Dycker & Bourarach (1992) the direct seeding has the least fuel and time consumption as compared to intensive or surface tillage practices (Table 8). No-tillage fuel consumption is several times lower than the least intensive tillage. This is a clear justification of no-tillage systems as low cost and less energy dependant technologies. Table shows that no-tillage profit is 5 times higher than conventional tillage for a farmer in Chaouia region.

Table 8: Energy requirement and fuel consumption per hectar of different tillage systems (Decker & Bourarach, 1991).

Tillage	Gharb region		Zaer region	
	Energy requirement kWh/ha	Fuel consumption l/ha	Energy requirement kWh/ha	Fuel consumption l/ha
Chiseling & rototiller	68.4	28.8	37.5	20.3
Deep plow & rototiller	92.1	46.7		
Disk harrow (twice)	37.9	21.37	28.8	17.6
Rotavator & rototiller	59.2	18.65	55.9	19.9
Direct seeding	6.0	3.1	5.9	3.2

Table 9: Wheat Yield (Grain Yg and Straw Ys, t/ha), operating cost C (dh/ha) and profit P (dh/ha) as a function of tillage at a farmer field (Mrabet & Lahlou, 2002)

	Direct Seeding				Disk plow & Heavy disking			
	Yg	Ys	C	P	Yg	Ys	C	P
1997-98	3.0	1.7	1600	7000	1.9	1.3	1900	3750
1998-99	3.3	1.4	1600	7550	1.0	0.9	1900	1200
1999-00	1.2	0.8	1600	2150	0.0	0.0	1700	-1700
2000-01	1.4	1.1	1600	2950	0.8	0.5	1900	550
Average	2.2	1.3	1600	4912	1.2	0.9	1850	950

1Euro = 11 dh

3. ADOPTION OF CONSERVATION AGRICULTURE PRACTICES and CRITICAL FACTORS AND FUTURE REQUIREMENTS

There is a plenty of evidence that NT is technically feasible:

- Efficient use of water,
- Efficient use of inputs (seeds, fertilizers, pesticides, energy, and manpower),
- Flexible/early times for seeding and fertilizer application,
- Diversification of cropping systems,
- Integration of livestock and agriculture.

No-tillage research/development (on-farm trials) started in 1994 in several regions including Meknes, Settat, Khouribga and Rabat regions. Figure 8 shows results from one of these field trials. It is clear from Figure 6, that NT is more durable and less risky than conventional tillage for Moroccan farmers. In this figure, wheat production under NT in a drought year like 1999 expresses the stabilising effects of favourable conditions of soil properties and microclimate when applying no-tillage and residue cover. However, crop failure under conventional tillage means that conditions for degradation are prevalent.

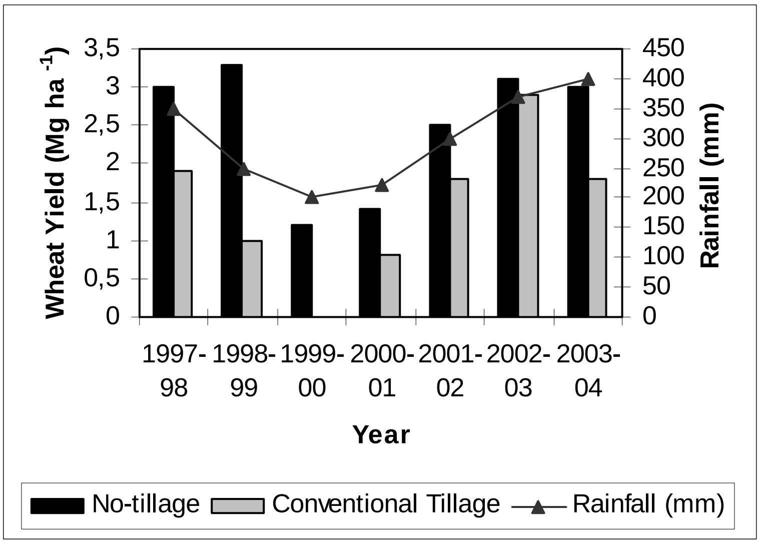

Figure 8: Tillage effect on wheat grain yield in a semi-arid Moroccan Farm (Mrabet, 2002b, Farmer, Personal Communication).

To be adopted readily, No-tillage technologies have to be in harmony with the existing farming systems and be consistent with farmers' objectives. Despite these undoubted agro-economic returns, the adoption of 'no-tillage' technologies has not fuelled its promise and a wider diffusion has not taken place yet.

NT adoption is still at early stage. Several concerns have stymied the ability to deal with the adoption of no-tillage systems in semiarid Morocco. Among these concerns is residue (stubble) use for animal nutrition and as farm returns. Two questions were raised: Are crop residues (and stubble) of good feed (forage) quality to express animal performance? Are residues durable sources of income? A paradigm shift is needed in which the yield and monetary profits are added to environmental benefit. Among interesting solutions is to control straw exportation and animal grazing, and include forage crops in wheat rotations.

The other major challenges are weed infestation, higher management requirements, insufficient advices and experience with the technology, fear for low yield and seed equipment. To avoid problems associated with seeding through a thick residue cover and hard soil surfaces, special attention to seeding conditions and equipment is required. Due to proper characteristics of soil and moisture conditions at time of seeding and the need for early sowing, no-tillage seeding machines need to be build by industrials in Morocco. Intensive research was conducted in this aspect and requirements of a versatile direct seeding machine were set and need only financial support. For hard soils, Bourarach et al. (1998) recommended hoe type no-till drill for seeding winter cereals and several food legumes. However, researchers need to investigate in developing or experimenting no-till drills for row crops (faba bean, sunflower, corn, chick pea, pea, etc), not yet available.

The big change facing farmers when shifting to no-tillage is weed control. Small farmers consider weeds as an important source of nutrients for their livestock. Great variety of herbicides is available and was tested for no-tillage conditions (ElBrahli & Mrabet, 2000). Concept about fertilization has been revisited under no-tillage due to residue recycling and nutrient release (Tab, 2004).

The major barriers traditional land tenure, grazing, lack of sufficient mulch and missing income alternatives. Considerable changes in mentality, attitude, and conviction should be done. In fact, government rigidity and farmer's attitudes vis-à-vis changes, if not modified, may slow no-tillage adoption in Morocco (Mrabet, 2001b).

4. CONCLUSIONS AND PROPOSALS

The trend towards research and development of no-tillage systems are gaining momentum due to international collaborations and mediated effort by several institutions. Consequently, substantial efforts and appropriate policies are needed to increase adoption and growth of no-tillage at large scale during the next years. Conditions for assuring prolonged adoption of no-tillage and hence implementing conservation agriculture should be satisfied through partnership building, subsidies to and participation of farmers (Mrabet, 2001b). Finally, No-tillage as a system of documented benefits in preventing desertification should be included in the United Nation Convention to Combat Desertification text, mechanisms and agenda.

Future research needs include:

- Crop and cover crop performance,
- Cropping systems and Crop diversification,
- Soil erosion, and biological soil quality,
- Water dynamics,
- Weed and Herbicides,
- Residue management/livestock integration,
- Crop Variety development for no-tillage systems,
- Fertilizer use and management,
- Row crop no-till drill,
- Animal-drawn no-tillage systems,
- Technology Transfer Approach development,
- Sociology and economy of adoption,
- Externalities.

5. REFERENCES

Aboudrare, A., A. Bouaziz, P. Debaeke & H. Chekli. 2003. Effect of soil tillage and fallow management on soil water reserves at the time of sunflower sowing in a semi-arid Mediterranean climate. ISTRO Conference, p: 1-6.

Bessam, F. & R. Mrabet. 2001. Time influence of no tillage on organic matter and its quality of a vertic Calcixeroll in a semiarid area of Morocco. In proceedings of I World Congress on Conservation Agriculture. Garcia-Torres et al. (eds). Madrid, Spain. October 1-5, 2001. pp: 281-286.

Bessam, F. & R. Mrabet. 2003. Long-term changes in soil organic matter under conventional and no-tillage systems in semiarid Morocco. Soil Use & Management. (19):139-143.

Bouzza, A., 1990. Water conservation in wheat rotations under several management and tillage systems in semiarid areas. PhD. Diss. University of Nebraska, Lincoln, USA. 200p.

Bourarach, EH. 1989. Mécanisation du travail du sol en cerealiculture pluviale : performances techniques et aspects economiques dans une région semi-aride au Maroc. Thèse de Doctorat Es-Agronomiques, IAV Hassan II, Rabat.

Chekli, H. 1991. Eléments de choix des séquences d'installation de la culture de blé dans la région de Meknès : modification des états structuraux et aspects énergétiques. Thèse de Doctorat Es-Agronomiques, IAV Hassan II, Rabat.

Dycker, J. & Bourarach, EH. 1992. Energy requirements and performances of different tillage systems in the Gharb and Zaer regions. In. Proceedings of International Seminar on Tillage in arid and semi-arid areas, Bourarch et al. (edts). Rabat, April, 1992.

El-Maataoui, H. 2000. Comportement et performances du blé sous différents systèmes de travail du sol et rotation céréalières. Diplôme des Etudes Supérieures Approfondies en Amélioration de la Production Agricole. Faculté des Sciences et Techniques, Settat, Maroc. 74p.

El-Brahli. A., A. Bouzza, & R. Mrabet. 1997. Stratégies de lutte contre les mauvaises herbes dans plusieurs rotations céréalières en conditions de labour et de non- labour. Ann. Report. Aridoculture Center.

El-Brahli. A., & R. Mrabet. 2001. La jachère chimique: Pour relancer la céréaliculture non-irriguée en milieu semi-aride Marocain. Proceedings of Journée nationale sur le désherbage des céréales. INRA Settat, 23 Novembre 2000. pp :133-145.

Ibno Namr, K. & R. Mrabet. 2004. Influence of agricultural management on chemical quality of a clay soil of semi-arid Morocco. Journal of African Earth Sciences 39(3-5): 485-489.

Kacemi, M., 1992. Water conservation, crop rotations, and tillage systems in semiarid Morocco. PhD Dissertation. Colorado State University. Fort Collins, CO. USA. 200p.

Kacemi, M., G.A. Peterson, and R. Mrabet. 1995. Water conservation, wheat-crop rotations and conservation tillage systems in a turbulent Moroccan semiarid agriculture. p. 83-91. *In* El Gharrous et al. (ed.). Conference on Challenges in Moroccan Dryland Agriculture. INRA, Rabat, Morocco.

Lahlou, S. & Mrabet, R. 2001. Tillage Influence on Aggregate Stability of a Calcixeroll Soil in Semiarid Morocco. In Proc. I World Congress on Conservation Agriculture. Garcia-Torres *et al.* (eds). Madrid, Spain. October 1-5, 2001. pp. 249-254.

Mrabet, R., A. Bouzza, & G.A. Peterson. 1993. Potential reduction of soil erosion in Morocco using no-till systems. Agron. abstract p. 323, ASA. Madison, WI.

Mrabet, R. & Bouzza, A. 1994. Conservation de l’eau sous différentes rotations céréalières et systèmes de gestion des résidus de récolte en semi-aride. Ann. Report. Aridoculture Center.
Mrabet, R., 1997. Crop residue management and tillage systems for water conservation in a semiarid area of Morocco. PhD Diss. Colorado State Univ. Fort Collins, CO. USA. 220p.

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. 2001a. No-tillage Farming: Renewing Harmony Between Soils and Crops in Semiarid Morocco. In proceedings of the Third International Conference on Land Degradation (ICLD3) and Meeting of the IUSS Subcommission C – Soil and Water Conservation. Rio de Janeiro, Brazil, September 17-21, 2001. http://www.cnps.embrapa.br/icld3.

Mrabet, R. 2001b. No-Tillage System: Research Findings, Needed Developments and Future Challenges for Moroccan Dryland Agriculture. In. proceedings of I World Congress on Conservation Agriculture. Garcia-Torres *et al* (eds). II: 737-741.

Mrabet, R., K. Ibno-Namr, F. Bessam, & N. Saber. 2001a. Soil chemical quality changes and implications for fertilizer management after 11 years of no-tillage wheat production systems in semiarid Morocco. Land Degrad. & Develop. 21:1–13.

Mrabet, R., N. Saber, A. El-Brahli, S. Lahlou, & F. Bessam. 2001b. 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 Tillage Res.* 57: 225–235.

Mrabet, R. 2002a. 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. 2002b. Conservation agriculture: for boosting semiarid soil’s productivity and reversing production decline in Morocco. In Proc. Int. Workshop on Conservation agriculture for sustainable wheat production in rotation with cotton in limited water resource areas. 14-18 October, 2002, Tashkent, Uzbekistan. pp. 56-61.

Mrabet, R. 2002c. Stratification of soil aggregation and organic matter under conservation tillage systems in Africa. Soil Till. Res., 66: 119-128.

Mrabet, R. & S. Lahlou. 2002. Conservation Agriculture in Morocco: Present status, development and future perspectives. African Conservation Tillage Network ACT-Year Book. 10p.

Saber, N. & Mrabet, R. 2002. Impact of no-tillage and crop sequence on selected soil quality attributes of a vertic calcixeroll soil in Morocco. Agronomie 22: 451-459.

Tab, N. 2003. Contribution à l’étude de l’influence des systèmes de travaux du sol et de la fertilisation azotée sur le comportement du blé et la qualité chimique d’un sol argileux du semi-aride Marocain. Diplôme des Etudes Supérieures Approfondies en Amélioration de la Production Agricole. Faculté des Sciences et Techniques, Settat, Maroc. 103p.

Mrabet, R., A. El-Brahli, F. Bessam & I. Anibat. 2003. No-Tillage Technology: Research review of impacts on soil quality and wheat production in semiarid Morocco. Options Méditerranéennes 60:133-138.

Yacoubi, M., M. El Mourid, N. Chbouki, & C.O. Stockle. 1998. Typologie de la sécheresse et recherche d'indicateurs d'alerte en climat semi-aride Marocain. Secheresse. 4:269-276.