

Impact of No-Till on physicochemical properties of Vertisols in Chaouia region of Morocco

Rachid Aboutayeb *, Brahim El Yousfi, Oussama El Gharras

National Institute for Agronomic Research (INRA), Settat, 26000, Morocco

Abstract

Conservation agriculture (CA) relies on low soil disturbance, mulching, and crop rotation, and these characteristics present CA as a good candidate to control soil degradation and preserve soil fertility. Therefore, agricultural scientists promote it as an efficient technique to sustain agricultural production. Conventional tillage (CT) dominates many semi-arid regions of Morocco, like Chaouia. However, crop/livestock management worsens degradation of soil organic matter and thus soil fertility. Since the eighties', controlled experimental trials tried to promote No-Till (NT) system in these regions. But it is still experiencing a low level of adoption. This on-farm research study aimed to evaluate NT effect on some Vertisols' physicochemical properties of this region. Analysis of variance only found a significant NT effect on soil organic matter (SOM), but factorial analysis provided evidence of a behavior of its effect on several physicochemical properties such as active limestone (CaCO_3), total nitrogen (TN), nitrate (NO_3^-), calcium (Ca^{2+}), potassium (K^+) and cation exchange capacity (CEC). Furthermore, pH, Electrical Conductivity (EC) and sodium (Na^+) did not show any significant difference between the two tillage treatments. This study also found that continuous cereal cropping with no mulching management mostly explains this low improvement in soil quality. This last approach, reduce CA to NT process. To promote CA in these regions, more efforts are still needed for a satisfactory up-scaling and a sustainable soil fertility conservation.

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Introduction

Thinking of soil as a natural resource drives attention to preserve it for future generations by protecting it from the harmful impact of climate change and intensive agricultural practices. Mismanagement such as frequent soil tillage enhances soil quality depletion. It leads to soil physical structure disturbance and reduces soil organic matter (SOM) content through its mineralization and carbon emission.

In semi-arid regions, plowing of Vertisols induces $4.99 \text{ gm}^{-2}\text{h}^{-1}$ emission of CO_2 (Moussadek et al., 2011). This burning effect lowers both soil physical properties and SOM, exposes soil profiles to water and wind erosion, and compaction when heavy machinery is used (Ryan et al., 2006).

Conservation Agriculture (CA) has been developed as a solution to soil quality depletion managed under conventional agriculture. It is promoted on three pillars: No-Till (NT) or minimum soil disturbance, plant cover or mulching and crop rotation (FAO, 2011). It addresses challenges related to natural resource degradation, sustainability of production systems, food security, climate change, and high-energy costs (Kassam et al., 2012). Agricultural scientists defined it as a method of managing agro-ecosystems for improved and sustained productivity and food security (Busari et al., 2015). In addition to its main role in restituting organic matter to agricultural lands, it also preserves soil and water resources (Hobbs, 2007;

* Corresponding author.

National Institute for Agronomic Research (INRA), Settat, 26000, Morocco

Tel.: +212618337961

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E-mail address: rachid.engineer@gmail.com

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Zheng et al., 2014). Worldwide, it gained attention through its optimization use of purchased inputs and its reduction of crop establishment costs (Kassam et al., 2012). Despite these useful advantages, the scale-up of its adoption, in North Africa regions, remains limited.

Soil organic matter (SOM) is one of the important indicators of soils quality (Larson and Pierce, 1991). It preserves soil water retention and improves its infiltration capacity (Gregorich et al., 1994), increases soil stability and reduces vulnerability to water and wind erosion. The increasing of SOM content reflects carbon sequestration which improves physicochemical properties of the soil profiles and activates biological life (fauna, flora and microflora). This improvement leads to enhance bioavailability of nutrients such as N, P, and K (Ashworth et al., 2017). In this regard, CA becomes a better candidate to improve soil quality, especially in semi-arid areas, where low levels of SOM prevail. Furthermore, maintaining crop residues is an attribute to enhance these pools of soil physical and biochemical attributes (Garcia et al., 2013). However, in the absence of residue management and crop rotations, the practice adopted in the region cannot be described as CA. Therefore, we will focus instead on NT.

At the national level, studies that dealt with NT were carried out under controlled trials. Some in Chaouia region at Sidi El Aidi experimental station (Bessam and Mrabet, 2003). Others in Central Moroccan regions, Zaer-Rabat at Merchouch experimental station (Laghrou et al., 2014). Thus, all results and conclusions are, in general, confined to these controlled environments. In Morocco, on-farm NT research is still lacking. This study aimed to assess the effect of NT on some physicochemical properties of Vertisols.

Material and Methods

Description of sampled sites

The regional climate is semi-arid with a winter rainfall pattern characterized by hot summer (35°C to 45°C) and relatively cold winter (5°C to 15°C). Fluctuating from year to year, rainfall is low. The mean annual precipitation is around 350 mm (Bessam and Mrabet, 2003).

The studied soil is classified as Vertisols characterized by high content of clay minerals that shrink and swell as they change water content. Because of their high water-holding capacity, Vertisols are suited to dryland crop production in semi-arid environments with uncertain and heavy rainfall (Hess and Shoen, 1964; Icole, 1964; Coulombe et al., 1996).

Soil sampling was carried out during the first week of November 2016 before cereal crop establishment. This study concerned four rural counties reaching a total of 27 farmers' fields (Figure 1). All sampled soils were of a Vertisols type.

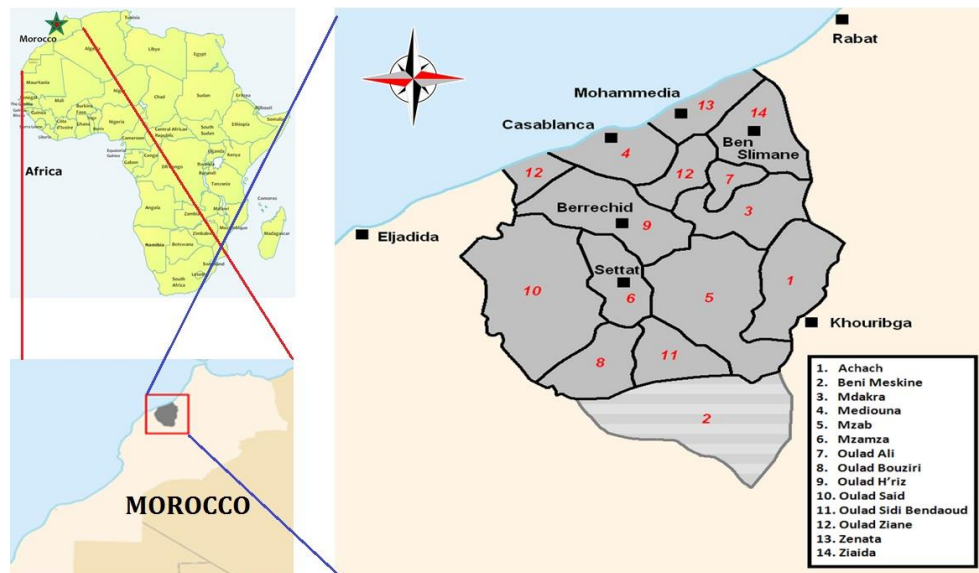


Figure 1. Map of Chaouia region.

(Note: Field trials where NT is adopted are in subregions number 6, 8, 10 and 11)

Table 1 presents their characteristics. Seventeen fields were managed under NT system, while the rest, ten fields, were of conventional one. In each county, a sampling of a conventional field was taken as a control. Within each field, soil samples were collected at 0 to 20 cm depth and taken from different locations. Collected samples were thoroughly mixed to constitute a composite sample of about half a kilogram which was bagged, labelled and taken to the laboratory. Before physical and chemical characterization, all samples were air-dried and sieved through 2 mm mesh.

Table 1. Characteristics of sampled soils field under NT and Conventional Tillage (CT).

Sample Id	County	Cropping System	Previous crop	Current crop	Year of adoption	Number of NT adoption years
1	Ouledbouziri	NT	Lentils	Wheat	2010	6
2	Ouledbouziri	CT	Maize	Wheat	2016	0
3	Ouledbouziri	NT	Wheat	Wheat	2012	4
4	Ouledbouziri	NT	Wheat	Wheat	2012	4
5	Ouledbouziri	NT	Wheat	Lentils	2014	2
6	Ouledbouziri	NT	Forage	Wheat	2013	3
7	Ouledbouziri	NT	Maize	Barley	2012	4
8	Ouledbouziri	CT	Maize	Wheat	2016	0
9	Ouledbouziri	NT	Barley	Wheat	2012	4
10	Ouledbouziri	NT	Barley	Barley	2010	6
11	Ouledbouziri	NT	Wheat	Wheat	2012	4
12	Ouledbouziri	CT	Lentils	Wheat	2016	0
13	Ouled said 1	CT	-	Wheat	2016	0
14	Ouled said 1	NT	Barley	Barley	2014	2
15	Ouled said 1	CT	-	Wheat	2016	0
16	Ouled said 1	NT	Wheat	Barley	2014	2
17	Ouled said 1	NT	Wheat	Barley	2014	2
18	Gdana	NT	-	Wheat	2010	6
19	Gdana	CT	-	Wheat	2016	0
20	Gdana	NT	-	Wheat	2010	6
21	Gdana	CT	-	Wheat	2016	0
22	Gdana	NT	-	Wheat	2010	6
23	Gdana	CT	-	Wheat	2016	0
24	Ouled said 2	NT	Barley	Barley	2015	1
25	Ouled said 2	CT	Barley	Barley	2016	0
26	Ouled said 2	NT	Wheat	Wheat	2015	1
27	Ouled said 2	CT	Wheat	Wheat	2016	0

Note: - not available.

Soil analysis

For each soil sample, two measures were undertaken to assess chemical analysis reliability. A pH meter and a conductivimeter measured soil pH and electrical conductivity (1:2 w/v soil/water extracts) respectively (McLean, 1982). Walkey and Black method helped to determine SOM (Walkey and Black, 1934). This method is based on titration with potassium dichromate, and on this equation ($SOM=1.72 \times OC$). Kjeldahl method (Buchi, Switzerland) evaluated total nitrogen concentration (TN), and complexation with chromotropic acid helped to measure nitrate content by using absorbance in a spectrophotometer (Spectronic, USA) fixed at 410 nm (Hadjimetriou, 1982). Colorimetry method fixed at 882 nm determined phosphorus content (Olsen et al., 1954). Solutions of soil extract with ammonium acetate were processed in a flame photometer (Elico, Italy) to quantify potassium (K^+), sodium (Na^+), and calcium (Ca^{2+}) components (Knudsen et al., 1982). Soil cation exchange capacity (CEC) was determined by extraction with sodium and ammonium acetate and solutions were burned in a flame photometer. The active calcium carbonate ($CaCO_3$) was assessed by ammonium oxalates and titrated by potassium permanganate ($KMnO_4$) (Drouineau, 1942).

Data Analysis

First, an analysis of variance was carried out to assess the significance of the tillage effect on all measured soil characteristics and the mean differences were tested at a significance level of 5%. Solution of a mixed model analysis (Littell et al., 1996) estimated tillage effects of two levels, taken as fixed factors. Whereas, Farmers' field, nested within counties, as random factor. Second, a factorial analysis used CEC, Ca^{2+} , OM, TN, K^+ , active limestone and NO_3^- variables after their standardizing to a mean zero and a standard deviation of one. This last analysis used a varimax rotation option and a principal component analysis of the factor model (Johnson and Wichern, 2007). All the statistical analyses were performed by SPSS statistics software (IBM SPSS, 2011).

Results and Discussion

NT impacts on physicochemical properties

SOM

NT system was found to affect only soil organic matter content (Table 2). Soils under this system had a SOM content of 2.6% compared to only 2.2% in plowed soils (Table 2). Over these years (1 to 6 years) of NT adoption (Table 1) and with an adequate crop rotation and mulching, this increase of 17% in SOM could have been higher (Table 1). In general, soils of semi-arid rainfed areas, such as those of the West-Asia and North-Africa regions have less than 1.5% SOM (Estefan et al. 2013). SOM improvement would help soil water retention and decreases the harmful impact of dry seasons. Indeed, in these regions, water is a main limiting factor for crop development under rainfed conditions (Moreno et al., 2006). Furthermore, Morocco was also impacted by climate change and thus experiences an increase in drought frequency that made yields of field crops variable and generally low (Karrou and Oweis, 2014). Which explains the enhance of crop yields in dry seasons. This claim is in agreement with Moreno et al. (2006) who pointed out that the efficiency of conservation tillage for reducing soil erosion and improving water storage is universally recognized.

Table 2. Soil mean characteristics for NT and CT systems.

Cropping System	pH	EC (dS m ⁻¹)	OM (%)	Active lime	TN	NO ₃ ⁻	P	K ⁺	Na ⁺	Ca ²⁺	CEC (meq 100g ⁻¹)
				(%)				(mg Kg ⁻¹)			
Conventional	7.23 (0.06)	0.21 (0.02)	2.25 (0.14)	4.95 (0.33)	0.12 (0.07)	27.63 (1.36)	29.24 (2.13)	241.26 (25.09)	90.80 (8.05)	7458.66 (211.98)	56.83 (1.78)
No-Till	7.28 (0.05)	0.16 (0.02)	2.63 (0.12)	5.39 (0.28)	0.12 (0.06)	25.02 (1.15)	29.99 (1.83)	264.31 (21.15)	86.03 (6.78)	7760.90 (178.74)	57.98 (1.50)
P _{value}	0.581	0.149	*0.043	0.311	0.741	0.816	0.788	0.478	0.647	0.274	0.619

Note: Values within parentheses are standard errors of the mean; * significant at P<0.05; TN=Total nitrogen.

Vegetation growth period of less than 180 days is prevalent in these regions along with a mixed crop-livestock farming system. The main constraint is the low primary productivity resulting from frequent low rainfall and the more severe this constraint is, the less important crops become. In this regard, livestock turns-out to be a primary source of income and subsistence. Therefore, the livestock consumes almost every bit of straw produced.

In the long run, NT as it is managed in this context (Table 1) could hardly affect SOM any further. NT performance may result from minimal soil disturbance, formation of soil aggregation and OM protection (Six et al., 2000). Furthermore, modification of soil properties might restrict SOM biodegradation (Mrabet et al., 2012). In this regard, Paustian et al. (1998) pointed out that the rate of SOM accumulation under NT was 300-800 kg carbon.ha⁻¹year⁻¹. Additionally, NT improves the quality of this component by increasing the level of organic matter at the soil surface (Table 2). But this latter characteristic is proportional to levels of residues left on the soil (Mrabet et al., 2003). The low SOM content of a 2.2% for soils under CT is probably due to higher mineralization or to soil structure deterioration according to Busari et al. (2015), and to the inversion of topsoil during plowing which shifts less fertile subsoil to the surface (Ali et al., 2006).

Active limestone (CaCO₃)

The mean active limestone (CaCO₃) content was found to vary around 5% for both NT and CT (Table 2). However, in the long run, NT would increase this soil property in this region (Figure 1). According to Neugschwandtner et al. (2014) and Fernández-Ugalde et al. (2009), soil CaCO₃ was not affected by soil tillage, whereas Moreno et al. (2006) observed that the loss of CaCO₃ was reduced by conservation tillage due to greater retention of water in soil profiles.

Exchangeable cations and CEC

Soil Na content was similar in both No-Till and conventional systems, and this is consistent with results of Mrabet et al. (2012). In contrast, on-farm NT, in these regions, has a behavior to increase exchangeable calcium content with 8661 mg kg⁻¹ and 7598 mg kg⁻¹ for NT and CT systems respectively. Busari et al. (2015) also conclude that exchangeable cations are often influenced by tillage systems. Likewise, Ismail et al. (1994) and Rahman et al. (2008) reported that exchangeable cations could be higher in the topsoil profiles managed under NT.

An increase behavior was also observed for CEC, with values of 66.8 and 58.02 meq 100g⁻¹ for NT and CT systems respectively. These values define these soils in the high CEC group, and the behavior for an increase in CEC could be more pronounced if mulching was managed as needed. Retention of crop residues can

increase CEC in the 0-5 cm profile compared to bared soil. Similarly, the expressed SOM contents in NT soil in this region, may also stimulate CEC content (Duiker and Beegle, 2006; Verhulst et al. 2010).

Total Nitrogen (TN), Nitrates and Phosphorus

Within soil profiles, SOM accumulation induces changes in concentration and distribution of nitrogen where NT had significantly higher TN than in the CT (Mrabet et al., 2001, Govaerts et al., 2007; Verhulst et al., 2010). The observed increase in SOM also induced this behavior in increased of TN at farm levels of these regions. TN content was found to increase linearly with an increase in crop residues left on the soil (Ibnou-Namr, 2005). Organic matter revitalizes soil biological activity, which consequently activates mineralization of organic nitrogen. This study reveals that total and mineral nitrogen contents (in nitrate form) decreases with an increase in active limestone, Ca, and CEC. In this regard, lack of vegetal cover or mulching, and low restitution of organic matter to soil may explain this observed relationship.

Tillage systems had not a significant effect on soil phosphorus content; it is probably due to applying phosphorus fertilizers during crop establishment. NT management improves soil surface with low mobility nutrients (Bravo et al., 2006; Mrabet, 2012). It might be an advantage when P is a limiting nutrient especially under alkaline soil conditions like the study area, but could be a source of environmental concern with possibility of its losses by runoff water (Verhulst et al., 2010). It is also clear that progressive mineralization of SOM was the most important source of these nutrients under NT (Mrabet, 2012). However, these two cropping systems had similar quantities of nitrogen as NO_3^- , phosphorus and potassium. This is mostly due to limited restitution of organic matter due to low mulching level.

Exploratory Factor Analysis

In this study, exploratory factor analysis generated two factors that explain 73% of variability. Table 3 lists these factors with their loadings, and indicates how much each factor explains an independent variable. The first factor contrasted CEC, Ca^{2+} and active limestone with NO_3^- . While the second factor is characterized by SOM, TN and K^+ .

Table 3. Factor loadings after a varimax rotation

Soil variable	Factor 1	Factor 2
SOM (%)	0,053	0,924
Activelimestone (%)	0,777	0,405
TN (%)	-0,028	0,785
NO_3^- (mg Kg ⁻¹)	-0,704	0,517
K^+ (mg Kg ⁻¹)	-0,123	0,636
Ca^{2+} (mg Kg ⁻¹)	0,964	-0,084
CEC (meq100g ⁻¹)	0,928	-0,151

Data visualization of these two factors reveals that in each soil, two measurements were close together in Figure 2, and therefore reveals a good reliability in analysis of the soil chemical contents. Figure 2 also shows an increase's behavior of active lime, Ca^{2+} , CEC, SOM, TN and K^+ contents with a decrease in NO_3^- , when NT system is adopted. It is evident that the enrichment of soil with OM increases CEC and total nitrogen contents and by consequence, induced retention of cations such as calcium and potassium ions.

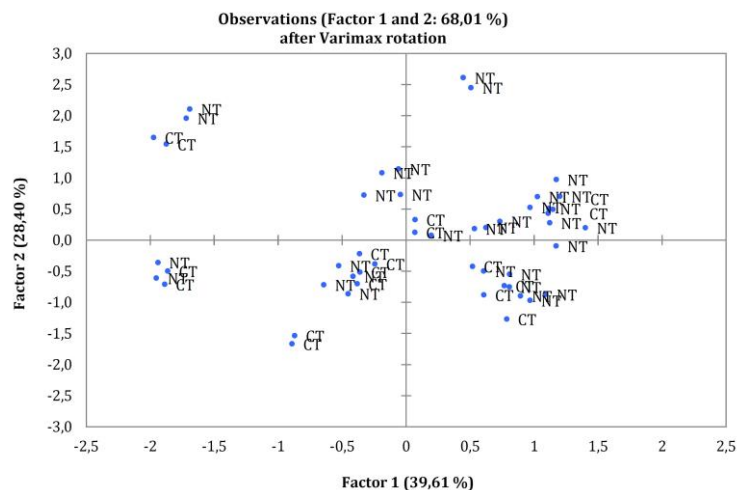


Figure 2. Exploratory Factor Analysis scattered plot representing soil characteristic behavior in NT and CT systems. Note: One soil under Conventional system is depicted in the upper right quadrant and refer to the sampled soil Id 8 (two repetitions) in Table 1.

EC, sodium contents and pH level were not included in Exploratory Factor Analysis because of their low loadings in both factors, and NT had not any significant effect on these soil characteristics. According to Mrabet et al. (2012), tillage system did not affect exchangeable cations contents. However, results of Busari et al. (2015) supported that tillage effect on pH depends on climatic conditions, soil type and on-farm management. But contrasting results reveal that tillage practices affect soil pH and salinity (Verhulst et al. 2010).

Conclusion

Long term NT adoption should be effective in enhancing SOM depth of 0-20 cm depth under semi-arid condition of Chaouia. This performance was evident in the evolution of active limestone, Ca²⁺, CEC, TN and K⁺ soil contents. But, non-adoption of a suitable rotation and lack of mulching may be among factors that hamper the scale-up of this technique in this region. Results herein infer that CA adoption should also concern suitable crop rotations and residues management. Otherwise, this adoption will be reduced to a simple NT practice. Furthermore, more efforts are needed to properly manage CA because Moroccan smallholder farmers have very limited understanding of soil chemical properties, impact of tillage practices on soil components, and are not aware of the negative impact of plowing on soil properties.

Adoption of CA is recommended, worldwide, and especially for arid and semi-arid regions where SOM is generally low. It is presented as a good strategy for soil quality improvement (Bessam and Mrabet, 2003). But this study revealed that this system when it is not applied properly has only induced small improvements in soil quality in the studied region. Despite decades of ongoing promotion efforts under the present agronomic practices, CA still needs large-scale implementation because of limited access to critical inputs such as fertilizers, herbicides, pesticides along with specialized machinery. Finally, and for sustainable adoption, research in large farms should be targeted to expand adoption of CA.

References

- Ali, A., Ayuba, S.A., Ojeniyi S.O., 2006. Effect of tillage and fertilizer on soil chemical properties, leaf nutrient content and yield of soyabean in the Guinea Savanna zone of Nigeria. *Nigerian Journal of Soil Science* 16(1): 126-130.
- Ashworth, A.J., Allen, F.L., Tyler, D.D., Pote, D.H., Shipitalo, M.J., 2017. Earthworm populations are affected from long-term crop sequences and bio-covers under no-tillage. *Pedobiologia* 60: 27-33.
- Bessam, F. Mrabet R., 2003. Long-term changes in soil organic matter under conventional tillage and no-tillage systems in semiarid Morocco. *Soil Use and Management* 19(2): 139-143.
- Bravo, C., Torrent, J., Giráldez, J.V., González, P., Ordóñez, R., 2006. Long-term effect of tillage on phosphorus forms and sorption in a Vertisol of southern Spain. *European Journal of Agronomy* 25(3): 264-269.
- Busari, M.A., Kukal, S.S., Kaur, A., Bhatt R., Dulazi, A.A., 2015. Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research* 3(2): 119-129.
- Coulombe, C.E., Wilding, L.P., Dixon, J.B., 1996. Overview of Vertisols: Characteristics and Impacts on Society, *Advances in Agronomy* 57: 289-375.
- Drouineau, G., 1942. Dosage rapide du calcaire actif des sols. *Annales of Agronomy* 12: 441-450.
- Duiker, S.W. Beegle, D.B., 2006. Soil fertility distributions in long-term no-till, chisel/disk and moldboard plow/disk systems. *Soil and Tillage Research* 88(1-2): 30-41.
- Estefan, G., Sommer R., Ryan, J., 2013. Methods of Soil, Plant, and Water Analysis: A manual for the West Asia and North Africa region. International Center for Agricultural Research in the Dry Areas (ICARDA). 3rd Edition. Lebanon. 244p.
- FAO, 2011. What is Conservation Agriculture? FAO Conservation Agriculture. Available at [Access date: 19.02.2018]: <http://www.fao.org/conservation-agriculture/overview/what-is-conservation-agriculture/en/>
- Fernández-Ugalde, O., Virto, I., Bescansa, P., Imaz, M.J., Enrique, A., Karlen, D.L., 2009. No-tillage improvement of soil physical quality in calcareous, degradation-prone, semiarid soils. *Soil and Tillage Research* 106(1): 29-35.
- García, R.A., Li Y. Rosolem, C.A., 2013. Soil organic matter and physical attributes affected by crop rotation under no-till. *Soil Science Society of America Journal* 77(5): 1724-1731.
- Govaerts, B., Fuentes, M., Mezzalama, M., Nicol, J.M., Deckers, J., Etchevers, J.D., Figueroa-Sandoval, B., Sayre, K.D., 2007. Infiltration, soil moisture, root rot and nematode populations after 12 years of different tillage, residue and crop rotation managements. *Soil and Tillage Research* 94(1): 209-219.
- Gregorich, E.G., Carter, M.R., Angers, D.A., Monreal, C.M. Ellert, B.H., 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. *Canadian Journal of Soil Science* 74(4): 367- 385.
- Hadjidemetriou, D.G., 1982. Comparative study of the determination of nitrates in calcareous soils by the ion-selective electrode, chromotropic acid and phenoldisulphonic acid methods. *Analyst* 107: 25-29.
- Hess, C. Shoen, U., 1964. Tirsification et classification des Vertisols : Apport de l'analyse minéralogique des argiles à la connaissance des Tirs. *Al Awamia* 13: 42-119.
- Hobbs, P.R., 2007. Conservation agriculture: what is it and why is it important for future sustainable food production? *Journal of Agricultural Science* 145(2): 127-137.
- IBM SPSS Statistics for Windows, Rel. 20. 2011. Chicago: SPSSInc.

- Ibno-Namr, K., 2005. Effet à moyenterme du travail du sol, de la gestion des résidus de récolte et de la rotation céréalière sur la qualité chimique d'un sol calcimagnésique à caractère vertique dans le semi-aride Marocain. Thèse de Doctorat d'Etat, Faculté des Sciences, El Jadida, Maroc, 143p.
- Icole, M., 1964. Pédogenèse des Vertisols en Chaouia. Rapport technique. *Al Awamia* 11: 71-87.
- Ismail, L., Blevins, R.L., Frye, W.W., 1994. Long-term no-tillage effects on soil properties and continuous corn yields. *Soil Science Society of America Journal* 58(1): 193-198.
- Johnson, R.A. Wichern, D.W., 2007. Applied Multivariate Statistical Analysis. Sixth Edition. Prentice-Hall edition. Upper Saddle River, New Jersey, USA. 794p.
- Karrou, M., Oweis, T., 2014. Assessment of the severity and impact of drought spells on rainfed cereals in Morocco. *African Journal of Agricultural Research* 9(49): 3519-3530.
- Kassam, A., Friedrich, T., Derpsch, R., Lahmar, R., Mrabet, R., Basch, G., González-Sánchez, E.J., Serraj, R., 2012. Conservation agriculture in the dry Mediterranean climate. *Field Crops Research* 132: 7-17.
- Knudsen, D., Peterson, G.A., Pratt, P.F., 1982. Lithium, sodium and potassium, In: Methods of soil analysis. Part 2 Chemical and microbiological properties. 2nd edition. Page, A.L., Miller, R.H., Keeney, D.R., (Eds.) American Society of Agronomy Inc., Madison, WI, USA. pp.225-246.
- Laghrou, M., Moussadek, R., A. Zouahri, A., Mekkaoui, M., Dahan, R., El Mourid, M., 2015. Impact of No Tillage on physical proprieties of a clay soil in Central Morocco. *Journal of Materials and Environmental Science* 6: 391-396.
- Larson, W.E., Pierce, F.J., 1991. Conservation and enhancement of soil quality. In: Proceeding of the Evaluation for sustainable land management in the developing world. International Board for Soil Research and Management. 15-21 September 1991. Bangkok, Thailand. pp. 175-203.
- Littell, R.C., Milliken, G.A., Stroup, W.W. Wolfinger, R.D., 1996. SAS system for mixed models. SAS Institute, Inc., Cary, NC.
- McLean, E.O., 1982. Soil pH and Lime Requirement. In: Methods of soil analysis. Part 2 Chemical and microbiological properties. 2nd edition. Page, A.L., Miller, R.H., Keeney, D.R., (Eds.) American Society of Agronomy Inc., Madison, WI, USA. pp. 199-224.
- Moreno, F., Murillo, J.M., Pelegrín, F., Girón, I.F., 2006. Long-term impact of conservation tillage on stratification ratio of soil organic carbon and loss of total and active CaCO₃. *Soil and Tillage Research* 85(1-2): 86-93.
- Moussadek, R., Mrabet, R., Dahan, R., Douaik, A., Verdoodt, A., Van Ranst, E., Corbeels, M., 2011. Effect of tillage practices on the soil carbon dioxide flux during fall and spring seasons in a Mediterranean Vertisol. *Journal of Soil Science and Environmental Management* 2(11): 362-369.
- Mrabet, R., El-Brahli, A., Bessam, F., Anibat, I., 2003. No-tillage technology: Research review of impacts on soil quality and wheat production in semi-arid Morocco. *Options Méditerranéennes* 60: 133-138.
- Mrabet, R., Ibno-Namr, K., Bessam, F., Saber, N., 2001. Soil chemical quality changes and implications for fertilizer management after 11 years of no-tillage wheat production systems in semiarid Morocco. *Land Degradation and Development* 21(6): 505-517.
- Mrabet, R., Moussadek, R., Fadlaoui, A., van Ranst, E., 2012. Conservation agriculture in dry areas of Morocco. *Field Crops Research* 132: 84-94.
- Neugschwandtner, R.W., Liebhard, P., Kaul, H.P., Wagentrist, H., 2014. Soil chemical properties as affected by tillage and crop rotation in a long-term field experiment. *Plant, Soil and Environment* 60(2): 57-62.
- Olsen, S.R, Cole, C.V., Watanabe, F.S., Dean, L.A., 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate, US Dept. of Agric, Circ. 939. Washington DC, USA.
- Paustian, K., Cole, C.V., Sauerbeck, D., Sampson, N., 1998. CO₂ mitigation by agriculture: An overview. *Climatic Change* 40(1): 135-162.
- Rahman, M.H., Okubo, A., Sugiyama, S., Mayland, H.F., 2008. Physical, chemical and microbiological properties of an Andisol as related to land use and tillage practice. *Soil and Tillage Research* 101(1-2): 10-19.
- Ryan J., De Pauw E., Gomez H., Mrabet, R., 2006. Drylands of the Mediterranean zone: biophysical resources and cropping systems. In: Dryland Agriculture. Peterson, G.A., (Ed.). ASA Monograph No. 23, Wisconsin, pp. 577-624.
- Six J., Elliott E.T., Paustian K., 2000. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. *Soil Biology and Biochemistry* 32(14): 2099-2103.
- Verhulst, N., Govaerts, B., Verachtert, E., Castellanos-Navarrete, A., Mezzalama, M., Wall, P., Deckers, J., Sayre, K.D., 2010. Conservation Agriculture, Improving Soil Quality for Sustainable Production Systems? In: Advances in Soil Science: Food Security and Soil Quality. Lal, R., B.A. Stewart (Eds.). CRC Press, Boca Raton, FL, USA, pp. 137-208.
- Walkey, A., Black, I.A., 1934. An examination of the Degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. *Soil Science* 63(4): 251-263.
- Zheng, C., Jiang Y., Chen, C., Sun, Y., Feng, J., Deng, A., Song, Z., Zhang, W., 2014. The impacts of conservation agriculture on crop yield in China depend on specific practices, crops and cropping regions. *The Crop Journal* 2(5): 289-296.