Supplementary Material
Effects of Tillage Systems on the Physical Properties of Soils in a Semi-Arid Region of Morocco

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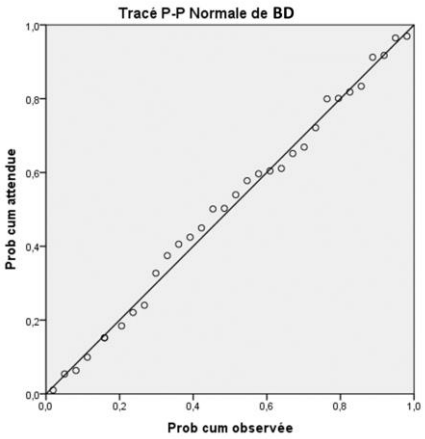
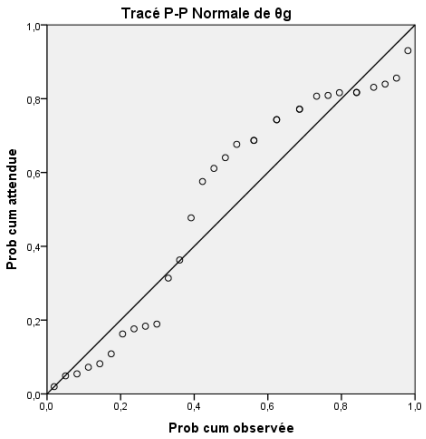
Figure S1. PP-Plot normal

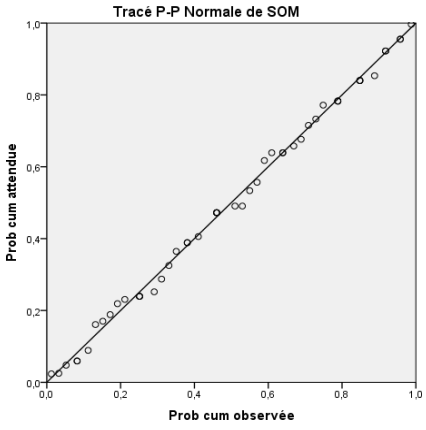
To verify our analysis hypotheses (the dependency test, ...), several methods will be implemented, mainly the ANOVA analysis. The latter requires the verification of the normality of some variables, in particular the use of the P-P Plot normal diagram, which allows the comparison of the distribution of the data for a variable to the so-called normal or Gaussian distribution. For our case, we compare the distribution of the variables related to the physical study for the two sites, AS7 and M13. The graphs below summarize the results of this analysis:



(**a**)



(**b**)



(**c**)

Figure S1. P-P Plot normal to check the normality of: (**a**) BD; (**b**) θg (**c**) SOM.

To verify the normality of the variables, we must observe the distribution of the points of each variable with respect to the diagonal line. In the case of the BD, we can see that all the points follow the diagonal line, so we can conclude that the residual value is normally distributed. This is the case for the rest of the variables. Therefore, we can conclude that all the graphs have verified the hypothesis of normality and constant variances through a straight line which means normality and points close to the line which implies very minimal outliers.

Text S1. Measurements and methods.

Composite samples were taken to determine the following physical properties: Particle size analysis, bulk density (BD), gravimetric moisture (θg), and aggregate stability (SS) and soil organic matter (SOM). Thus, at each sampling site, the following determinations were made:

(i) Soil bulk density (BD) was measured by the calibrated cylinder method using cylinders with a volume of 1140 cm3 following the procedure described by Grossman and Reinsch (2002) [1], The measurements are made at two soil depths (0-13 and 13-26 cm) with five replicates for the two treatments (CT and NT). The principle of the cylinder method is based on the determination of the apparent specific weight of a volume of soil sampled, using a metal cylinder, so the weight sampled is evaluated by weighing before and after passage in the oven at 105°C for 24 hours, using a precision balance [2]. Knowing the total volume as well as the mass of the soil, the bulk density is determined in g·cm-3 by the following relationship [3] :

$$BD\ (\rho_b) = Ms / VT \quad (1)$$

(ρ_b : Bulk density (g/cm3) ; Ms : Mass of dry soil (g) ; VT : Total soil volume (cm^3));

(ii) Gravimetric moisture was determined by weight difference (Gardner, 1986) [4].

$$\theta g = \frac{m\ water}{m\ soil} = \frac{mwet - mdry}{mdry} \quad (2)$$

with **θg**: gravimetric humidity (g/g), $\mathbf{m_{wet}}$: the wet weight (g) and $\mathbf{m_{dry}}$: weight of the dry soil obtained after drying (g)

(iii) Structural stability represents the ability of a soil to maintain its solid phase and porosity arrangement when exposed to stresses [5]. It allows to determine the susceptibility of soils to degradation processes and their vulnerability to ramming and erosion[6,7]. This is an important characteristic that accounts for the cohesion of soil aggregates. It is determined by the method proposed by Le Bissonnais [8]. This method is applied to sieve-separated, air-dried and dry-stored aggregates of 3.15 to 5 mm. Three tests are applied to these aggregates under the different climatic, hydric, and structural conditions that can be encountered at the soil surface:

- Treatment 1: Fast wetting by immersion (FW),
- Treatment 2: Slow wetting by capillary action (SW),
- Treatment 3: Mechanical disaggregation by agitation after rewetting (WS).

After each of these tests, the proportions of the aggregate size classes are evaluated by sieving on a column of 6 sieves and the results are expressed in terms of weight average diameter after disaggregation (MWD) calculated using the following formula [9] :

$$MWD\ (mm) = \Sigma \bar{X}i * Wi \quad (3)$$

With $\bar{\mathbf{X}}\mathbf{i}$: average diameter of two successive sieve classes and **Wi** : proportion of total residual aggregate mass in each sieve (2, 1, 0,5, 0,2, 0,1 et 0,05 mm).

This becomes, for the sieves used:

MWD = ((3,5× [%>2 mm]) +(1,5× [% 1 à 2 mm]) +(0,75× [% 0,5 à 1 mm]) +(0,35× [% 0,2 à 0,5 mm]) +(0,15× [% 0,1 à 0,2 mm]) +(0,075× [% 0,05 à 0,1 mm]) +(0,025× [%<0,05mm])) /100 (4)

(iv) Percentages of clay, silt and sand, according to the USDA Soil Taxonomy [10] and the Meriaux method or granulometric analysis by densimetry [11].

(v) SOC content was determined indirectly by oxidation of organic carbon using the classical method of Walkley & Black [12]. The organic matter content is estimated by multiplying the SOC content by a correction factor of 1.724.

$$SOM\ (\%) = SOC\ (\%) * 1.724 \quad (5)$$

Table S1. Effect of the two cultivation practices over time on bulk density.

Depth (cm)	NT (0-13 cm)	CT (0-13 cm)	NT (13-26 cm)	CT (13-26 cm)
2011 Moussadek et al. [13]	1.51a (NT50)	1.45b		
2015 Laghrour et al. [14]	1.33a	1.12a		
2016 Laghrour et al. [15]	1.29a	1.15a		
2018 EL Mekkaoui et al. [9]	1.46a	1.45a	1.66a	1.64a
Present study	1.44a	1.40a	1.60a	1.60a

[1] Values followed with diffente withing letters are a significantly different ($p<0.05$)

The table shows that the bulk density decreased by 1% from 2011 (1.51 g/cm3) to May 2018 (1.44 g/cm3). This surface (0-13 cm) improvement in bulk density could only be seen after 13 years of the NT system installation at site M13. According to Table S1, BD was high under SD (>1.4 g cm-3) and it reached the value of 1.60 g cm^{-3} under NT in 13-26 cm, knowing that for vertisols used in agriculture, the BD can reach 2 g cm^{-3} due to their swelling clay content [17]. In fact, the BD of the soil surface (0-13 cm), was slightly higher under no-till (1.45 g cm-3) than that obtained with conventional tillage (1.40 g cm-3). This is consistent with the work of several authors [18,19] which showed that under NT, bulk density is higher on 75 cm of the soil profile compared to CT.

References

1. Grossman, R.B.; Reinsch, T.G. 2.1 Bulk Density and Linear Extensibility. *Methods of soil analysis: Part 4 physical methods* **2002**, *5*, 201–228.
2. Blake, G.R.; Hartge, K.H. Bulk Density. *Methods of soil analysis: Part 1 Physical and mineralogical methods* **1986**, *5*, 363–375.
3. Blake, G.R. Bulk Density. *Methods of Soil Analysis: Part 1 Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling* **1965**, *9*, 374–390.
4. Gardner, W.H. Water Content. *Methods of Soil Analysis: Part 1 Physical and Mineralogical Methods* **1986**, *5*, 493–544.
5. Pojasok, T.; Kay, B.D. Assessment of a Combination of Wet Sieving and Turbidimetry to Characterize the Structural Stability of Moist Aggregates. *Canadian Journal of Soil Science* **1990**, *70*, 33–42.
6. Chenu, C.; Abiven, S.; Annabi, M.; Barray, S.; Bertrand, M.; Bureau, F.; Cosentino, D.J.; Darboux, F.; Duval, O.; Fourrié, L. Mise Au Point d'outils de Prévision de l'évolution de La Stabilité de La Structure de Sols Sous l'effet de La Gestion Organique Des Sols. *Etude et Gestion des sols* **2011**, *18*, 161–174.
7. Moussadek, R.; Mrabet, R.; Dahan, R. Effet de l'agriculture de Conservation Sur La Qualité Des Sols Au Maroc. *Revue HT E* **2011**, *149*, 25–28.
8. Le Bissonnais, Y. Aggregate Stability and Assessment of Soil Crustability and Erodibility: I. Theory and Methodology. *European Journal of Soil Science* **1996**, *47*, 425–437, doi:10.1111/j.1365-2389.1996.tb01843.x.
9. Mekkaoui, A.E.; Moussadek, R.; Mrabet, R.; Chakiri, S.; Douaik, A.; Ghanimi, A.; Zouahri, A. The Conservation Agriculture in Northwest of Morocco (Merchouch Area): The Impact of No-till Systems on Physical Properties of Soils in Semi-Arid Climate. *E3S Web Conf.* **2021**, *234*, 00037, doi:10.1051/e3sconf/202123400037.
10. KEYS, T.S.T. By Soil Survey Staff. *United States Department of Agriculture Natural Resources Conservation Service, Tenth Edition, USA* **2006**.
11. Mériaux, S. Contribution à l'etude de l'Analyse Granulometrique: Theses Présentées à La Faculté Des Sciences de L'Université de Paris Pour Obtenir Le Titre de Docteur d'Université de Paris (Mention Sciences). PhD Thesis, Institut National de la Recherche Agronomique, 1954.
12. Walkley, A.; Black, I.A. An Examination of the Degtjareff Method for Determining Soil Organic Matter, and a Proposed Modification of the Chromic Acid Titration Method. *Soil science* **1934**, *37*, 29–38.
13. Moussadek, R.; Mrabet, R.; Dahan, R. Effet de l'agriculture de Conservation Sur La Qualité Des Sols Au Maroc. *Revue HT E* **2011**, *149*, 25–28.
14. Laghrour, M.; Moussadek, R.; Mekkaoui, M.; Zouahri, A.; Dahan, R.; El Mourid, M. Impact Du Semis Direct Sur

Les Propriétés Physiques d'un Sol Argileux Au Maroc Central (Impact of No Tillage on Physical Proprieties of a Clay Soil in Central Morocco). *J. Mater. Environ. Sci* **2015**, *6*, 391–396.
15. Laghrour, M.; Moussadek, R.; Mrabet, R.; Dahan, R.; El-Mourid, M.; Zouahri, A.; Mekkaoui, M. Long and Midterm Effect of Conservation Agriculture on Soil Properties in Dry Areas of Morocco. *Applied and Environmental Soil Science* **2016**, *2016*, e6345765, doi:10.1155/2016/6345765.
16. El Mekkaoui, A.; Moussadek, R.; Mrabet, R.; Chakiri, S.; Douaik, A.; Ghanimi, A.; Zouahri, A. The Conservation Agriculture in Northwest of Morocco (Merchouch Area): The Impact of No-till Systems on Physical Properties of Soils in Semi-Arid Climate. In Proceedings of the E3S Web of Conferences; EDP Sciences, 2021; Vol. 234, p. 00037.
17. Murthy, R.S.; Bhattacharjee, J.C.; Landey, R.J.; Pofali, R.M. Distribution, Characteristics and Classification of Vertisols. In Proceedings of the Vertisols and rice soils of the tropics. Symposia papers; 1982; Vol. 2, pp. 3–22.
18. Bruce, R.R.; Langdale, G.W.; Dillard, A.L. Tillage and Crop Rotation Effect on Characteristics of a Sandy Surface Soil. *Soil Science Society of America Journal* **1990**, *54*, 1744–1747.
19. Cassel, D.K.; Raczkowski, C.W.; Denton, H.P. Tillage Effects on Corn Production and Soil Physical Conditions. *Soil Science Society of America Journal* **1995**, *59*, 1436–1443.