ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

REVIEW ARTICLE

Sensitivity of Moroccan semi-arid soil to structural degradation: Effect of rotation, tillage, and residue management

[1] **Belmekki. M.,** [2] **Mrabet. R.,** [3] **Moussadek. R.,** [4] **Iben Halima. O.,** [4] **El Gharous. M.,** [1] **Bouzidi. A and** [1] **Bencharki. B**

1. University Hassan 1, Faculty of Sciences and Techniques, Settat, Morocco.
2. National Institute of Agricultural Research, Scientific Division, Rabat, Morocco.
3. Regional Agricultural Research Center of Rabat, Morocco.
4. Regional Agricultural Research Center of Settat, Morocco.

Manuscript Info

Manuscript History:

Received: 25 October 2013
Final Accepted: 20 November 2013
Published Online: December 2013

Key words:
Soil aggregate stability, soil organic matter, no-tillage, residue management, Morocco.

Abstract

The actual uses of land based upon abusive tillage, overgrazing, over-intensification and inappropriate crop management are major contributors to breakdown of the soil structural stability in Morocco. The aim of this paper is to compare two aggregate stability measurement methods under wet sieving conditions: Kemper and Rosenau (1986) test and those of Le Bissonnais (1996), and relate test results of structural stability to soil organic matter, tillage practice and cropping systems. The influence of three tillage treatments was examined: (conventional tillage (CT) and no-tillage (NT) with two levels of residue: (NT50= half surface residue cover, NT100= full surface residue cover), and three rotations were considered: wheat–wheat; fallow–wheat; and fallow–wheat–barley. The Comparison of mean weight diameters (MWD) among the four tests showed the existence of Strong association between the first two tests of Le Bissonnais (fast and slow wetting) and between the fast wetting and the standard stability test for water-stable aggregate (WSA). However, there is no statistically significant correlation between this last test and mechanical breakdown treatment. Ours results showed significant correlation between organic matter content and aggregate stability confirmed that an increase in soil organic matter would lead to an increase in aggregate stability. Those results confirmed the lasting benefits of NT associated with the residue management on aggregate stability. The effect of crop rotation on soil structural stability was significant. In fact the continuous wheat in the first five centimeters under no till system has improved the structural aspects of the soil compared to the rotation including fallow.

1. Introduction

The alteration quality of the cultivated soils affects a considerable area of the semi-arid Moroccan zones (Mrabet et al., 2012; Abail et al., 2013). This degradation is due to both poor structural characteristics (Ryan et al., 2006), and directly or indirectly, to inadequate farming systems (abusive tillage, overgrazing, residues crop export and stubbles…) (Lahmar and Ruellan, 2007; Mrabet et al., 2008; Moussadek et al., 2011). This difficult and random situation grows worse by climate change with its impact on agricultural production (Balaghi et al., 2007; Esper et al., 2007).

These perturbations, affecting soil potentials, generate favourable conditions for its structural deterioration (Fikri et al., 2004), with the inflicted consequences: settlement, compaction and development of slaking crust that can be a major cause of low infiltration rate and increased water erosion (Le Bissonnais, 2000; Mabit et al., 2002). Soil susceptibility to water erosion is strongly controlled by the vegetation (Boukheir et al., 2001), in fact, bare soil is exposed to aggressive raindrops, which reduces its cohesion and subsequently increases the risk of erosion (Zuazo and Pleguezuelo, 2008). A comprehensive study conducted by the ministry of Agriculture concluded that 2.1 million hectares of agricultural lands suffer from water erosion (Dahan et al., 2012). Consequently, the modifications in the soil physical state are felt on the decline in fertility (Lal, 2002; Mrabet et al., 2001a), this situation has called into question of the use land mode in Morocco (Moussadek, 2012).

To fix this alarming situation, direct seeding (exclusive form of conservation agriculture) is a agronomic approach which aims to limit soil losses by erosion (Roose et al., 2008; Minnella et al., 2009 et Roger-Estrade et al., 2011) and restore the quality of this basic natural resource (Kassam and Brammer, 2013). In this sense, research conducted in semi-arid areas of Morocco have shown that this agronomic approach, less adopted in Morocco (about 4000 hectares (Kassam et al., 2012)), improves the profitability of soil production (Bouazza, 1990; Mrabet, 1997). This increase in profitability is mainly due to the evolution of the water soil state (Mrabet, 2000; Moussadek et al., 2008) and the restoration of its structural status (Bessam and Mrabet, 2001; Mrabet et al., 2001a; Moussadek et al., 2011).

Improvement of the structural state is felt in the evaluation of soil physical properties, such as structural stability, which can be defined as the resistance to disruption or breakage of the bonds within the aggregates by external forces of impact, shearing, and abrasion and internal forces arising from the escape of entrapped compressed air (slaking) and differential swelling (Angers et al., 2008). It is considered a good indicator of soil quality and its susceptibility to runoff and erosion (Barthès and Roose, 2001). It is also the most physical property influenced by the agricultural techniques (Bottinelli, 2010). An intensive tillage destroys the aggregates cohesion and weakens the structure, whereas direct seeding can limit interventions that contribute to the degradation of soil aggregation (Saroa and lal, 2003). The methodologies devised for measuring aggregate stability have been numerous and diverse (Yoder, 1936; Henin et al., 1958; Kemper and Rosenau, 1986; Le Bissonnais, 1996; Marquez et al., 2004). This multitude of methods shows both the interest in this concept and simultaneously prevents any quantitative synthesis of results (Cosentino, 2006). The choice between widely used, informally standardized methods novel ones often involves a substantial tradeoff between the need for consistency and the ultimate appropriateness of the methods facilitate comparability (Nimmo and Perkins, 2002). It must, however, indicate that the selection of the methods to be applied on the soil sample to measure aggregate breakdown and the interpretation of its results depends mostly on the purpose of the measurement (Rohoskova and Valla, 2004).

In Morocco, the aggregation test developed by Kemper and Rosenau (1986) has been the basis of many works, and used as a technical reference for giving a judgment on the structural stability of soils. This approach, despite its merits (quick and easy) remains ill-suited for a wide range of soils (Mrabet et al., 2004). Another limitation of this test is its inability to examine the different desegregation processes generated by the constraints applied to the soil (Annabi, 2005). For this reason, we had to choose another method which takes into account various stressful conditions and to classify the behavior of soils under the effect of water, wind and management. Le Bissonnais (1996) proposed a unified method that combines prewetting with ethanol (Henin et al., 1958) and the use of slow wetting, rapid wetting, and mechanical breakdown to separate the effects of various bonding mechanisms.

This study provides a contribution to the research developed at the Agricultural Research Center of Settat on the aggregate stability of soils under different tillage systems and crop management. Hence, the main objectives of this study were to: i) compare two methods to measure aggregate stability under wet sieving conditions in order to identify those which seem most appropriate in these semi-arid areas and (ii) relate test results of structural stability to crop and soil management practices.

2. Materials and methods

2.1. Site description and treatments

The experimental site is located at the [2]National Institute of Agricultural Research agricultural research station, Sidi El Aydi, 50 km south of Casablanca, Morocco. Sidi El Aydi station is at 33°00'N, 09°22'W, elevation 230 m above sea level. The soil of the experimental area is classified as Vertic Calcixeroll (21 % sand; 28 % silt and 51 % clay) with a pH of 8,25and organic carbon content of 1,4 %. The regional climate is semiarid with a winter rainfall pattern. The long-term mean annual precipitation at the research station is 358mm with a maximum of 740mm and a minimum of 128 mm. The coldest month is January with an average minimum temperature of 6°C and the hottest month is July with an average maximum temperature of 34.4°C (Mrabet et al., 2001b).

At this site, a long-term experiment, which started in 1994, was carried out to study the effect of various rotation and tillage-residue management systems on wheat production and soil quality. The experiment design used random incomplete blocks with split-plots and three replications. Factors investigated were rotation assigned to the whole plots and tillage-residue management systems applied to the subplots. The rotations investigated were continuous wheat (WW), fallow–wheat (FW) and fallow–wheat–barley (FWB). In the subplots, we applied two tillage systems (conventional off-set disking, CT and no-tillage, NT); and two levels of residue in the NT system (NT50 = half surface residue cover, NT100 = full surface residue cover). The CT consisted of one or two passes with off-set disk for seedbed preparation and several passes for weed control in fallow phases. The only soil disturbance in NT occurred during seedbed and fertilizer banding operations. Wheat and barley were seeded with a double disk no-till drill. Glyphosate herbicide was used to control any weeds prior to planting and in fallow periods. Wheat and barley crops were sprayed with cholorosulfuron. Fertilizers were used according to soil test for each crop.

From each plot, sampling was done at the depths of 0 to 50, 50–100 and 100–150 mm. Air-dried and stored in rigid bags, the samples were pooled to elaborate the primary objective of comparing methods for the soil aggregate stability. Therefore, 27 samples were used for testing aggregate stability by four aggregate stability methods with three replicates. The samples of topsoil (0–50mm) were collected by shovel and near surface (50–100mm) and subsurface (100–150mm) by soil auger. Surface residues were removed before sampling.

2.2. Aggregate stability methods

Four different methodologies of assessing aggregate stability were used in this study have in common the contacting materials studied with a large excess of water and the result of dividing the aggregates will be evaluated by sieving (Le Bissonnais and le Souder, 1995). They are respectively denoted by KE, FW, SW and MB. KE was a wet sieving method using one single sieve (Kemper and Rosenau, 1986).The three tests (FW, SW , MB) were as suggested by Le Bissonnais (1996). The detailed description of the main followed steps in the methods is given below.

For the wet sieving with sieve method (Kemper and Rosenau, 1986), 4g of soil fraction between 1 and 2 mm were transferred to the sieving machine (Five star Cablegation and scientific supply, 303 Lake ST, Kimberly, ID 833341). The four grams were placed into the sieve and wetted with sufficient distilled water to cover the soil when the sieve was at the bottom of its stroke for 3 min. The soil that passed through the sieve was collected oven dried (105°C) and weighed to give a unstable aggregates mass (UAM). The soil that had not passed through the sieve was dispersed for 30min in a solution (containing 2 g sodium hexametaphosphate (SM) per liter). Sand particles that did not pass through the sieves were discarded, and the disperded soil that passed through the sieves oven dried and weighed to obtain the mass of stable aggregate (SAM). The water stable aggregates (WSA) percentage was calculated by

$$\% \text{WSA} = [\text{SAM} / (\text{SAM} + \text{UAM} - \text{SM})] \times 100$$

Where: UAM is the mass of unstable aggregates (g), SAM is the mass of stable aggregates (g) and SM is the mass of sodium hexametaphosphate used (g).

The method proposed by Le Bissonnais (1996) consists of determining the MWD (mean weight diameter) of the stable fractions remaining after three tests having various different wetting conditions and energies: fast wetting, slow wetting, and mechanical breakdown by raindrop impact. The tests were performed on the 3 - to 5 - mm aggregates recovered during the incubation. For the fast wetting test (FW), about 5 g of calibrated aggregates was rapidly immersed in 50 mL of deionized water for 10 min. For the slow wetting test (SW), similar amounts of aggregates were capillary rewetted with water on a tension table at a potential of 0.3 kPa for 30 min. For the mechanical breakdown test (MB), aggregates were gently immersed in ethanol. After 10 min, ethanol was eliminated and aggregates were hand agitated in 200 mL of deionized water 20 times in a fast end-over-end movement. The solution was adjusted to 250 mL and was left for 30 min for sedimentation, after which the water was eliminated. After each test, the residual aggregates were collected and transferred onto a 50 – µm sieve previously immersed in ethanol, which was gently moved five times with a Hénin apparatus, producing a helicoidal movement (4 cm). The remaining aggregates on the sieve were collected, dried at 105°C, and gently dry sieved using a column of six sieves: 2000, 1000, 500, 200, 100, and 50 µm. For each test, the aggregate stability was expressed by calculating the mean weight diameter (MWD, mm) of the six classes:

$$\text{MWD (mm)} = \sum X_I \times W_I$$

Where: X_I is the mean diameter of the size fraction and W_I is the proportion of the total sample retained on the sieve.

2.3. Statistical analysis

Analysis of variance was utilized to find significance of effects of rotation, tillage, and residue management on soil structural stability using the general linear model (GLM) procedure of the Statistical Analysis System (SAS, 2009) (*p* level of 5%). The relationships between SOC and aggregate stability were analyzed using the same procedure.

3. Results

3.1. Comparison of different aggregate stability approaches

The comparison of the standard method (Kemper and Rosenau, 1986) with the Le Bissonnais (1996) procedure highlights the advantage of the second because it determines stability for various conditions that may occur at the soil surface, and it helps to identify the mechanisms that cause aggregate breakdown, while the evaluation of the aggregation by the first method favors the bursting phenomenon related only to the fast wetting and therefore does not reflect all the mechanisms involved.
The linear correlation coefficients between the different structural stability tests (Table 1) are highly variable: it started with 0.42 between the third test of Le Bissonnais (mechanical breakdown) and standard method (Kemper and Rosenau, 1986), and reached a value of 0.87 between this last test and the fast wetting treatment (FW).

Table 1. Linear correlations values between mean weight diameter (MWD) calculated from tree tests: fast wetting (FW), slow wetting (SW), mechanical breakdown (MB) and water stable aggregates (WSA) (n=27)

	WSA	FW	SW	MB
WSA	1			
FW	0.87*	1		
SW	0.69	0.82	1	
MB	0.42	0.77	0.67	1

*Significant correlations at 5% according to Duncan's test are underlined

Several levels of correlations between different tests appear:
- Strong bonds between the first two tests of the Le Bissonnais despite that each treatment corresponds to specific conditions in terms of wetting conditions and applied destructive energy (Saygin et al., 2012): the FW treatment damaged aggregates by slaking average of MWD FW ranged from 0.33 to 0.55 mm, while Slow wetting (SW), second process induced aggregate destruction seemed less destructive than FW.
- Strong bonds between the first test of Le Bissonnais (FW) and that of Kemper showing similar behavior between the two tests, which allows to consider the use of these two treatments for estimating the structural stability, knowing that these tests generate a gain of material and time (Rohoskova and Valla, 2004).
- Average bonds between the second and third test of Le Bissonnais (Slow wetting and mechanical breakdown) indicating a sparsely marked relationship between these two tests. While, other researchers have shown that the second test (SW) is not significantly related with the other tests (Saidi et al., 1999).
- Weak bonds between the standard stability test for water-stable aggregate (test of Kemper) and mechanical breakdown by raindrop impact (The third treatment of Le Bissonnais, 1996), this shows that the standard test, causing aggregate slaking, was the process that decreased aggregate stability the most (figure 1).

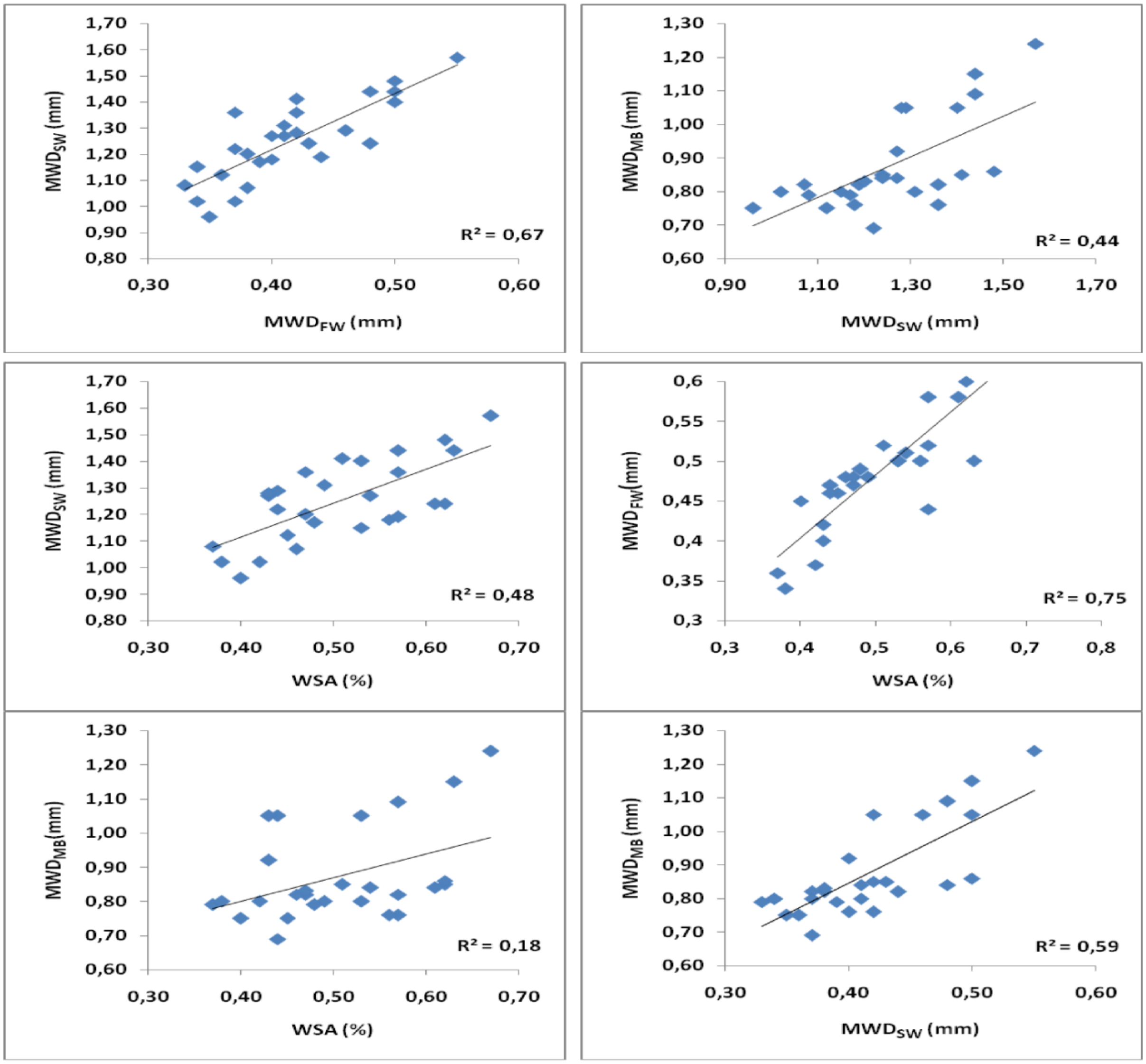

Fig 1. Relation between different structural stability tests: MWD_{SW} according to MWD_{Fw}, MWD_{MB} according to MWD_{SW}, MWD_{SW} according to WSA, MWD_{FW} according to WSA, MWD_{MB} according to WSA and MWD_{MB} according to MWD_{SW}.

3.2. Effect of tillage and cropping system on the wet aggregate stability (MWD and WSA)

The results presented in this section concerns only the samples of soil surface (0-50mm) from the three tillage methods (CT, NT50 and NT100).

3.2.1. Tillage effect (NT100, NT50 and CT)

The MWD indicated that aggregate stability decreased in the order slow wetting > stirring after prewetting > fast-wetting (table 2). In the same table the surface aggregates from the three agricultural techniques show weak resistance when subjected to fast-wetting treatment, The values of MWD (0.37 to 0.49 mm) presented by this destructive treatment is small compared to other tests. It appears that the organic matter accumulated in the soil under NT was not sufficient for the surface aggregates to resist strong intensity of rain (Belmekki et al., 2013b). For the slow wetting test that simulates the effect of moderate rainfall, the presence of residues (total or partial coverage) to the surface under NT has limited the speed of rewetting compared with LC. This allowed the aggregates under NT to have a more stable behavior (DMP> 1.43 mm) than those from tilled plots (WMD = 1.26 mm).The test of

mechanical breakdown shows that aggregate stability is greater under NT (WMD = 1.12 mm) compared to CT (WMD =0.79 mm), it turned out that the maintenance of residues on the surface of soil under NT improves soil resistance against the impact of drops rain and significantly reduces fragmentation (Roose et al., 2008).
With reference to the standards set by the Bissonnais (1996), plowed soil with DMP values <0.4 mm, is considered unstable to very unstable when subjected to fast wetting whatever agricultural practice adopted. For the slow wetting test, the soil under NT is considered stable with limited erosion risk (DMP> 1.30 mm). On the other side, plowed soils (MWD>1.30mm) have a moderately stable structure with a variable risk according climatic and topographic parameters. Our results are in some way consistent with results found by Moussadek et al (2011).
For the wet sieving with single sieve method (Kemper and Rosenau, 1986), Soil under NT showed greater overall improvement of its water stable aggregation compared to tilled system mainly with increased residue cover. In another long-term experiment and under the same soil, Lahlou (1999) found increased wet aggregation index with increased residue cover under NT, mainly at the soil surface (0–2.5 cm). These results confirmed that no-tillage helped to construct a good structure with time. While the soil subjected to conventional tillage suffers a deterioration of its structure as shown by a decrease in the stability of aggregate (Mrabet, 2008).

Table 2. Influence of tillage and residue management on mean weight diameter (mm) (MWD_{FW}, MWD_{SW} and MWD_{MB}) and water stable index WSA (%) at depth of 0-50 mm

	NT100	NT50	CT
MWD_{FW}	0.49 A*	0.46 A	0.37 B
MWD_{SW}	1.43 A	1.37 A	1.26 B
MWD_{MB}	1.12 A	1.04 A	0.79 B
WSA	0.56 A	0.53 A	0.46 B
Average	0,90	0,85	0,72

*The values followed by the same letter within the same column are not significantly different at 5% according to Duncan's test.

3.2.2. Cropping system effect

In the surface horizon (0-50mm), rotations FWB and continuous wheat do not differ significantly but have improved aggregate stability (MWD and WSA) as compared to FW (table 3).
The same table shows that the soil under continuous wheat rotation presents a more stable structure (WMD=1.45mm) compared to the rotation including fallow, when subjected to the slow wetting treatment. This result is justified by the fact that continuous wheat accumulated more soil organic matter than the other rotations at (0-50mm) (Belmekki et al., 2013a).

Table 3. Influence of Cropping system on mean weight diameter (mm): (MWD_{FW}, MWD_{SW} and MWD_{MB}) and water stable index WSA (%) at depth of 0-50 mm

	WW	FW	FWB
MWD_{FW}	0.42 A*	0.45A	0.39 B
MWD_{SW}	1.45 A	1.40 A	1.21 B
MWD_{MB}	1,05 A	0.98 A	0.92 B
WSA	0.62A	0.52 A	0.41B
Average	0,89	0,84	0,73

*The values followed by the same letter within the same column are not significantly different at 5% according to Duncan's test.

3.3. Relationship between soil aggregate stability and organic matter.

Soil organic matter (SOM) is the most reported soil attribute from tillage experiment, since it is the main soil quality indicator, being inextricably linked to other soil properties (Mrabet, 2007). Many authors demonstrated that SOM content is one of the most important factors determining aggregate stability (Tisdall and Oades, 1982; Cerda, 2000;

Le Bissonnais et al., 2007). However, several studies showed that the relationship between aggregate stability and organic matter varies with change in soil use and management (Mrabet, 1997; Moussadek et al., 2011, Belmekki et al., 2013c).
Figure 2 shows that the SOM had a more positive effect on aggregate stability in the tree tests and a lower association with standard method test (r=0.46), which involves a weaker disruptive energy than the fast wetting test. A significant positive linear relationship existed between MWD MB and SOM (r=0.84), which shows that the organic matter content was involved, as evidenced by increases in aggregate cohesion against the impact of drops rain. This same finding is reported by Bouajila and Gallali, (2010). Large Association with slow wetting test and SOM (r=0.82) is yet observed in the same Figure, this result indicates that the increase in SOM is generally associated with increase in the resistance level of aggregates against the process by capillarity wetting.

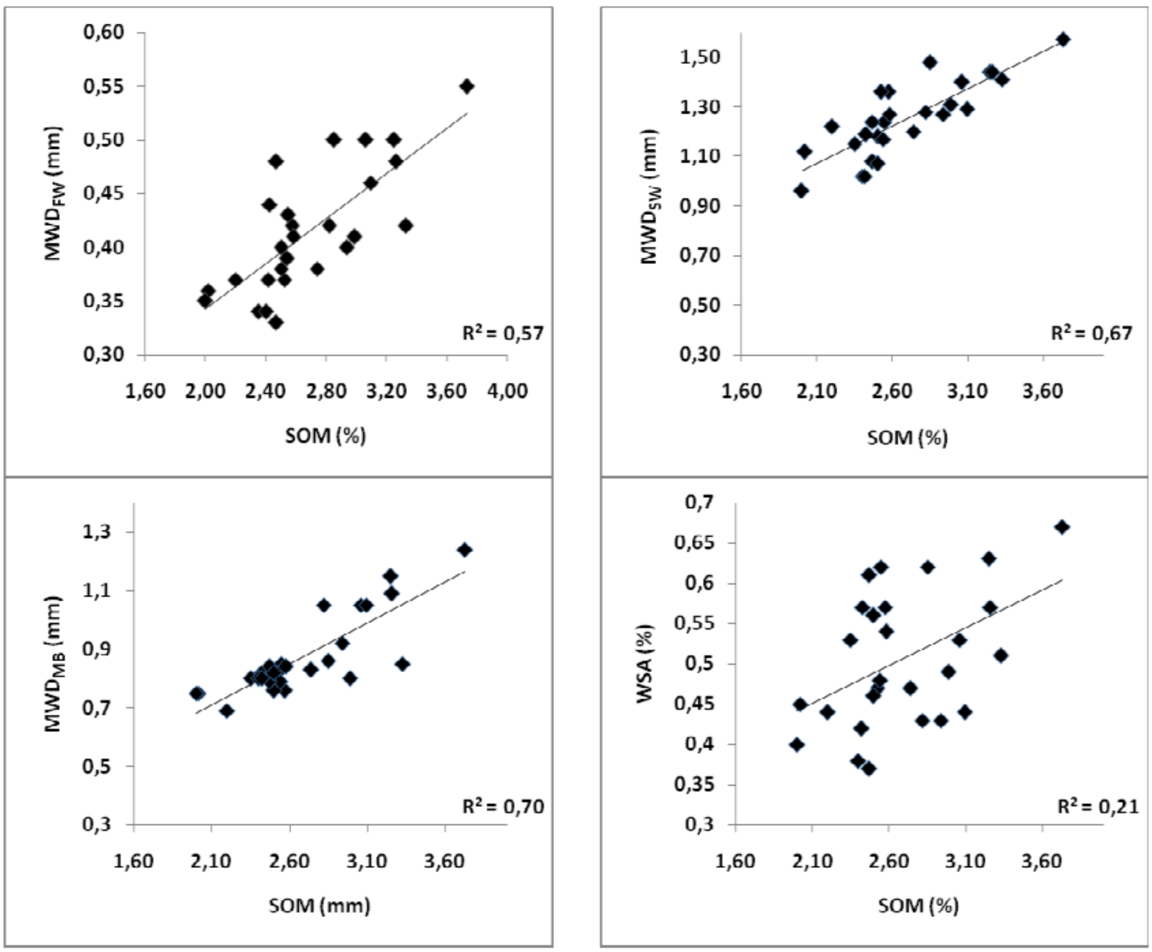

Fig 2. Relationship between mean weight diameters of different tests: fast wetting (FW), slow wetting (SW), mechanical breakdown (MB) and water stable aggregates (WSA) and SOM content across all 27 samples tested.

Conclusion

Soil aggregation is a complex attribute and methods of its quantification are diverse (Amézketa, 1999). In fact, the major objectives of stability tests are to give a reliable description and to classify the behavior of soils under the effect of water and management. Comparison of MWD among the four treatments have shown the existence of Strong association between the first two tests of Le Bissonnais (fast and slow wetting) and between the FW and the standard stability test for water-stable aggregate (WSA).However, there is no statistically significant correlation between this last test and mechanical breakdown treatment. We conclude that both methods have their advantages and disadvantages. The main disadvantage of the method proposed by Le Bissonnais (1996) is time consuming than the standard method (Kemper and Rosenau, 1986). On the other hand, a major advantage of the first method is distinguishing the particular mechanisms of aggregate breakdown. While the evaluation of the aggregate stability by the standard method related only to the fast wetting and therefore does not reflect all the mechanisms involved. We recommend that a consistent approach be used in bringing effectively the aggregates out of the water so that comparisons are more likely to be possible even among diverse soils. Ours results showed significant correlation between organic matter content and aggregate stability confirmed that an increase in organic matter in the soil would lead to an increase in aggregate stability. Increased aggregate stability under the no-tillage treatment indicates its beneficial effects on soil conservation in Morocco; through in organic matter accumulation with time. We can conclude that soil structural stability is improved with the maintenance of residue at the soil surface under no-tillage system and that it is significantly higher compared to conventional tillage. It was found also that the continuous wheat rotation has improved the structural aspects of the soil compared to the rotation including fallow.

References

Abail, Z., Belmekki, M., El Gharous, M, and Ibenhalima, O. (2013): Conservation agriculture and its impact on soil quality: Highlights of Moroccan research results in semi-arid areas. An International Journal ESTIJ., 3 (4): 699-703.

Amezketa, E. (1999): Soil aggregate stability: a review. Journal of sustainable Agriculture., 14: 83-151.

Angers, D.A., Bullock, M.S. and Mehuys, G.R. (2008): Aggregate Stability to Water. IN: Carter MR, Gregorich EG (eds) Soil Sampling and Methods of Analysis. 2nd Edition, USA: CRC Press Taylor & Francis, Boca Raton, FL, Chapitre 62.

Annabi, M. (2005): Stabilisation de la structure d'un sol limoneux par des apports de composts d'origine urbaine: relation avec les caractéristiques de leur matière organique Thèse de doctorat d'INA, Paris, France. 268p.

Balaghi, R., Jlibene, M., Tychon, B. and Mrabet, R. (2007): Gestion du risque de sécheresse agricole au Maroc. Sécheresse., 18:1-8.

Barthés, B. and Roose, E. (2001). La stabilité de l'agrégation, un indicateur de la sensibilité des sols au ruissellement et à l'érosion: validation à plusieurs échelles. Cah. Agric.,10: 185-193.

Belmekki, M., Mrabet, R., Moussadek, R., Ibenhalima, O., Boughlala, M., El Gharous, M. and Bencharki, B. (2013a). Effects of tillage and cropping systems on the structural stability and soil organic matter in semi-arid areas of Morocco. International Journal of Innovation and Applied Studies., 4: 322-333.

Belmekki, M., Mrabet, R., Moussadek, R., El Gharous, M., **O**, Ibenhalima.,Z, Abail. and B, Bencharki. (2013b). Etude de l'effet des systèmes de labour de conservation sur la qualité physique et chimique d'un Vertisol de la Chaouia. 7ème Edition des Journées Internationales des Géosciences de l'Environnement (JIGE7). 13-15 Novembre, FST Beni-Mellal, Maroc. Recueil des résumés, pp. 60-61.

Belmekki, M., El Gharous, M, Ibenhalima, O., Boughlala, M., Abail, Z. and Bencharki, B. (2013c): Conservation agriculture as a mean of CC adaptation in the semiarid zones of Morocco: Long-term effects on soil quality and water conservation. 17th International Symposium on Environmental Pollution and its Impact on Life in the Mediterranean Region, September 28th to October 1st, 2013. Istanbul. Turkey.

Bessam, F. and Mrabet, R. (2001): Time influence of no tillage on organic matter and its quality of a vertic calcixeroll in semiarid area of Morocco. In: Garcia T and al (eds): Proceeding of 1 World congress on Conservation Agriculture (2), Madrid. Spain, pp. 281-286.

Bottinelli, N. (2010): Evolution de la structure et de la perméabilité d'un sol en contexte de non labour associé à l'apport d'effluent d'élevage : rôle de l'activité lombricienne. Thèse de doctorat .Sciences de l'environnement, Rennes, France. 152p.

Bouajila, A. and Gallali, T. (2010): Land use effect on soil and particulate organic carbon, and aggregate stability in some soils in Tunisia. African Journal of Agricultural Research., 5(8): 764-74.

Boukheir, R., Girard, M. C., Khawlie, M. and Abadallah, C. (2001): Erosion hydrique des sols dans les milieux méditerranéens: une revue bibliographique. Etud. Gest. Sols., 8: 231-245.

Bouzza, A. (1990): Water conservation in wheat rotations under several management and tillage systems in semi-arid areas. PhD. Dissertation univ. Nebraska, Lincoln, USA. 200p.

Cerda, A. (2000): Aggregate stability against water forces under different climates on agriculture land and scrubland in southern Bolivia.57 (3):159-166.

Cosentino, D. J. (2006): Contribution des matières organiques à la stabilité de la structure des sols limoneux cultivés. Effet des apports organiques à court terme. Thèse de doctorat d'INA, Abies, France. 186p.

Dahan, R., Bouglala, M., Mrabet, R., Laamari, A., Balaghi, R. and Lajouad, L. (2012): A review of Available Knowledge on land Degradation in Morocco. In: ICARDA (eds). Morocco. OASIS Contry, Report 2, 38p.

Esper, J., Frank, D., Buntgen, U., Verstege, A., Luterbacher, J. and Xoplaki, E. (2007): Longterm drought severity variations in Morocco. Geophysical Research Letters., 34: L17702.

Fikri, B. K., Ismaili, M., Fikri, B. S. and Tribak, A. (2004): Problèmes de dégradation de l'environnement par la désertification et la déforestation. Impact du phénomène au Maroc. Science et changements planétaires. Sécheresse., 15: 307-320.

Henin, S., Monnier, G. and Combeau, A. (1958): Méthode pour l'étude de la stabilité structurale des sols. Ann. Agron., 9: 73–92.

Kassam, A., Friedrich, T., Derpsch, R., Lahmar, L., Mrabet, R., Basch, G., Sánchez, E.J. G. And Serraj, R. (2012): Conservation agriculture in the dry Mediterranean climate. Field Crops Research., 132: 7-17.

Kassam, A. and Brammer, H. (2013): Combining sustainable agricultural production with economic and environmental benefits. The Geographical. J., 179:11-18.

Kemper, W. D. and Rosenau, R. C. (1986): Aggregate stability and size distribution. In: Klute A (eds) Methods of Soil Analysis, Part 1. Agronomy Monographs. Madison, Wisconsin: American Society of Agronomy, pp. 425-442.

Lahlou, S. (1999):La qualité physique du sol sous différents systèmes de travail du sol et de management des cultures en zones semi-arides Marocaines. Mémoire présenté pour l'obtention du diplôme des études approfondies, UFR: Instrumentation de Mesure et de Contrôle. Faculté des Sciences El Jadida, Maroc. 62p.

Lahmar, R. and Ruellah, A. (2007): Dégradation des sols et stratégies coopératives en Méditerranée. La pression sur les ressources naturelles et les stratégies de développement durable. Cah. Agric., 16: 318-323.

Lal, R. (2002): Carbon sequestration in dry land ecosystems of West Asia and North Africa. Land degradation & development., 13:45-59.

Le Bissonnais, Y. and Le Souder, C. (1995): Mesurer la stabilité structurale des sols pour évaluer leur sensibilité à la battance et à l'érosion. Etud. Gest. Sols. 2: 43-56.

Le Bissonnais, Y. (1996): Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology. Europ. J. soil. Sci., 47: 425-437.

Le Bissonnais, Y. (2000): La dégradation structurale superficielle et le détachement des particules des sols cultivés. Ingénieries. EAT., 22: 27-36.

Le Bissonnais, Y., Blavet, D., De Noni, G., Laurent, J.Y., Asseline, J. and Chenu, C. (2007): Erodibility of Mediterranean vineyard soils: relevant aggregate stability methods and significant soil variables. European Journal of Soil Science., 58: 188–195.

Mabit, L., Laverdière R. M. and Bernard, C. (2002): L'érosion hydrique. Méthodes et études de cas dans le Nord de la France. Cah. Agric., 11: 195-206.

Marquez, C.O., Garcia, V.P., Cambardella, C.A.,Schultz,R.C. and Isenhart, T.M.(2004): Aggregate-size stability distribution and soil stability. Soil Sci. Soc. Am. J., 68: 725–735.

Minella, J.P.G., Merten, G.H., Walling, D.E. and Reichert, J.M. (2009): Changing sediment yield as an indicator of improved soil management practices in southern Brazil. Catena, 79: 228-236.

Moussadek, R., Mrabet, R., Verdoodt, A., Ye, L. and Ranst, E. V. (2008): Effect of no tillage on Vertisol hydrodynamic properties. In: Winfried HBMH Gerzabek, Vodrazka M (eds): Proceedings of the EUROSOIL 2008 Congress, Austria. Vienna: Book of Abstracts, P 49.

Moussadek, R., Mrabet, R., Zante, P., Lamachere, J. M., Pénin, Y., Le Bissonnais, Y., Liming, Y., Verdoot, A. n. and Van Ranst, E. (2011):Effets du travail du sol et de la gestion des résidus sur les propriétés du sol et sur l'érosion hydrique d'un Vertisol Méditerranéen. Canad. J. Soil. Sci., 91: 627-635.

Moussadek, R. (2012). Impacts de l'agriculture de conservation sur les propriétés et la productivité des vertisols du Maroc Central. Afrika focus., 25: 147-151.

Mrabet, R. (1997): Crop residue management and tillage systems for water conservation in a semi-arid area of Morocco. PhD. Dissertation. Colorado State Univ. Fort Collins, USA. 220p.

Mrabet ,R. (2000): Differential response of wheat to tillage management systems under continuous cropping in a semiarid area of Morocco. Field Crops Research., 66:165-174.

Mrabet, R., Saber, N., ElBrahli, A., Lahlou, S. and Bessam, F. (2001a): 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 Till. Res., 57: 225-235.

Mrabet, R., Ibno-Namr, K., Bessam, F. and Saber, N. (2001b): Soil chemical quality changes organic matter and structural stability of a Calcixeroll soil under different wheat rotations and tillage systems in a semiarid area of Morocco. Land Degradation & Development., 12 (6): 505 -517.

Mrabet, R., Lahlou S., Le Bissonnais, Y. and Duval, O. (2004): Estimation de la stabilité structurale des sols semi-arides marocains: Influence des techniques culturales simplifiées. Bulle. Résea. Erosion., 23: 405- 415.

Mrabet, R. (2007): Conservation Agriculture in Morocco: A Research Review. International Workshop on Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas, 7-9 May, Damascus: ACSAD, FAO, GTZ, AAAAID & UNEP, pp. 183-208.

Mrabet, R. (2008): No-tillage Systems for Sustainable Dry land Agriculture in Morocco. INRA Publication, Rabat. Morocco. 153p.

Mrabet, R., Essahat, A. and Moussadek, R. (2008): Influence des systèmes de travail du sol sur les propriétés des sols en zones semi-arides du Maroc. In: Roose. et al (eds). Efficacité de la lutte anti-érosive / GCES. Morocco. Congrès ISCO, 12p.

Mrabet, R., Moussadek, R., Fadlaoui, A. and Van Ranst, E. (2012): Conservation agriculture in dry areas of Morocco. Field Crops Research., 132: 84-94.

Nimmo, J.R. and Perkins, K.S. (2002): Aggregate stability and size distribution. In: Dane JH, Topp GC (eds) Methods of Soil Analysis, Part 4—Physical Methods, USA. Madison, WI: Soil Science Society of America, pp. 317–328.

Roger, E. J., Labreuche, J. and Richard, G. (2011): Effets de l'adoption des techniques culturales sans labour (TCSL) sur l'état physique des sols. Conséquences sur la protection contre l'érosion hydrique en milieu tempéré. Cah. Agric., 20: 186-193.

Rohoskova, M. and Valla, M. (2004): Comparison of two methods for aggregate stability measurement. A review. Plant. Soil. Environ., 8: 379-382.

Roose, E., Blavet, D., Sabir, M., Ouagga, T., Cheggour, A., Simonneaux, V., Oliver, R., Ferrer, H., Louri, J. and Chotte, J. L. (2008): Influence de l'utilisation d'un sol brun vertique sur les stocks de carbone du sol, les risques de ruissellement et d'érosion et le devenir du carbone érodé (bassin de l'oued Rheraya, Haut-Atlas, Maroc).In : Roose E, Albergel J (eds) Efficacité de la GCES en milieux semi-arides, France. Paris: AUF, EAC et IRD éditeurs, pp. 317-324.

Ryan, J., Depauw, E., Gomez, H. and Mrabet, R. (2006): Drylands of the Mediterranean Zone: Biophysical Resources and Cropping systems. In: Peterson GA. and al (eds). Ameri. Agron. Monograph, USA: Dry land Agriculture, 23: 577-624.

Saidi,D., Douaoui,A ., Le Bissonnais,Y. and Walter,C. (1999): Sensibilité de la surface des sols des plaines du Chélif à la dégradation structurale. Etude et Gestion des Sols., 6(1): 15-25.

Saroa, G. S. and Lal, R. (2003): Soil restorative effects of mulching on aggregation and carbon sequestration in a Miamian Soil in Central Ohio. Land Degradation & Development., 14: 481- 493.

Saygın, S. D., Cornelis, W. M., Erpul, G. and Gabriels, D. (2012): Comparison of different aggregate stability approaches for loamy sand soils. Applied Soil Ecology., 54:1-6.

Tisdal, J. M. and Oades, J. M. (1982): Organic matter and water stable aggregates in a soils. J. Soil. Sci., 33:141-164.

Yoder, R.A. (1936): A direct method of aggregate analysis of soils and a study of the physical ature of erosion losses. J. Am. Soc. Agron., 28: 337–351.

Zuazo, V. H. D. and Pleguezuelo, C. R. (2008): Soil-erosion and runoff prevention by plant covers. A review. Agronomy for Sustainable Development., 28: 65-86.