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## Soil Organic Carbon Fractions and Aggregate Stability in Carbonated and No Carbonated Soils in Tunisia

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**Abstract:** This research aimed to study the relationship between different organic matter fractions and aggregate stability in carbonated and no carbonated soils in Tunisia. Samples of soil were taken from A or Ap horizon at twelve carbonated and ten no carbonated soils. Aggregate stability was tested by Le Bissonnais method. Total soil organic carbon (SOC), particulate organic carbon (POC), hot-water-extract-polysaccharides (HWEP) and humic compounds (HC: humic acids (HA) and fulvic acids (FA)) were analysed. Both carbonated and no carbonated horizons showed high SOC and POC contents, notably under forest. While, HWEP and HC (HA and FA) contents were greater in no carbonated soils. Across all horizons, positive correlation was found between SOC and POC. Soil stability test showed that horizons were affected by fast wetting rather than mechanical breakdowns ( $MWD_{FW} < MWD_{ME}$ ). The most stable horizon was a carbonated soil with important SOC content. However, there was a significant and positive relationship between SOC, POC and HC and aggregate stability only in no carbonated topsoil. Consequently, relationship between organic matter fractions and aggregate stability changes when soil properties vary. Accordingly, the present study may be useful to suggest practices that improve soil aggregate stability and organic matter sequestration to help retard soil loss and degradation.

**Key words:** Organic carbon, particulate organic carbon, polysaccharides, humic compounds, aggregate stability, calcium carbonate

### INTRODUCTION

Soil organic carbon (SOC) is one of the most important constituents of soils due to its capacity in affecting plant growth (Bongiovanni and Labartini, 2006). Organic matter improves soil aggregation or structure formation (Caravaca *et al.*, 2004; Pinheiro *et al.*, 2004; Tisdall and Oades, 1982) and it mediates many chemical and physical soil properties (Carter, 2002). Boyle *et al.* (1989) reviewed the influence of SOC on soil aggregation and water infiltration and concluded that SOC had a disproportionate effect on soil physical properties. In soil, where the SOC is the main binding agent, different size aggregates can be formed. This fact was essentially detected in soils with low contents of oxides and hydroxides of iron and aluminium (Le Bissonnais and Le Souder, 1995) and also in no carbonated soils. Consequently, causal relationships between management and soil quality are difficult to extrapolate among regions, because of differences in soil type, climate and management norms (Pikul *et al.*, 2007). On the other hands, the relations between the organic matter content

of soil and its aggregate stability are complex and not clearly understood (Puget *et al.*, 1995).

SOC improves aggregate stability by different mechanisms and different fractions. Indeed, Primary particles and clay microstructure are bound together with bacterial and fungal debris into extremely stable microaggregates. These latter may be bound together with fungal and plant debris giving a larger microaggregates. The humic matter, considered as a persistent cementing agent, is involved in stabilizing microaggregates (Bongiovanni and Lobartini, 2006). These microaggregates are bound into macroaggregates, due to the effect of transient binding agents (polysaccharides) and temporary binding factors (Oades, 1993; Tisdall and Oades, 1982). Particulate organic carbon (POC) improves soil aggregation since it can form an organic core surrounded by clay, silt particles and aggregates (Six *et al.*, 2000).

The macroaggregates are less stable than microaggregates to wetting or mechanical actions. Their destruction by different agents (rain, erosion, tillage) may result in exposure of the inner core of organic substances

(Six *et al.*, 2000), facilitating rapid oxidation and attack by micro-organisms of these binding agents (Elliott, 1986).

In Tunisia, carbonated rocks were the parent materials of most soils. However, in some cases decarbonation process decreases calcium carbonate amount in the subsurface horizon, especially in humid regions. On the other hands, soils in North of the country were developed on the sandstone rocks. The topsoil horizon (A) derived from the tow different substratum showed variable resistance degree to the erosion and land degradation. In addition, the extension of agriculture practices on hill slopes in the Mediterranean basin may be responsible for a loss of organic carbon from soil, as a result of increasing runoff and erosion (Le Bissonnais *et al.*, 2007). The loss of C makes soil aggregates less stable, which in turn increases erosion risks. Consequently, we should use indicators of these risks and so be able to identify the most threatened areas.

Decrease of soil stability in the studied area, was the cause of decreasing agriculture production and increasing soil erosion (Barthès and Roose, 2002; Cerdà, 1998). Subsequently, organic matter amendment forms the better solution to these problems. However, our knowledge of organic matter contribution in physical properties in Tunisia is not well understood.

This study aims to give further insights towards different organic matter fractions present in Tunisian soils and their involvement in structural stability improvement. The study focussed on carbonated and no carbonated subsurface horizons that support most of agriculture practices in this country.

## MATERIALS AND METHODS

**Soils:** The research was conducted in Tunisia along a South-North axis, characterized by a sharp South-to-North increase in rain amount. Along this axis twenty one soils were sampled. They were selected to represent a wide range of the principal soil types with large amount of organic carbon and carbonate calcium contents. Differences among the soils were due to the nature of their parent material (calcareous rock, sandstone and quaternary sediments) and land use (forestry or farming practices).

The study sites, representing Mediterranean humid, sub-humid and semi-arid climates along a climatic transect, running from the North to Central region. The mean annual rainfall was ranged from 400 to 1200 mm and annual mean temperature was ranged from 20 to 18°C (Fig. 1). The climatic parameters vary widely among the sites. The vegetation composition also differs among the sites. In general, annual species decrease from the arid to

Table 1: Sample denotation, soil classification, parent material and soil use for the twenty two sampled sites

Soil denotation	Soil classification (FAO terms)	Parent material	Soil use
A <sub>1</sub>	Humic Cambisols	Sandstones	Forest soil
A <sub>2</sub>	Eutric Fluvisols	Alluvium	Cultivated soil
B	Vertisol	Calcareous rocks	Forest soil
BMF	Calcaric Regosols	Calcareous rocks	Pasture lands
BR	Vertic Cambisols	Calcareous rocks	Cultivated soil
C	Vertisol	Calcareous rocks	Cultivated soil
L <sub>1</sub>	Luvic Kastanozems	Calcareous rocks	Pasture lands
L <sub>2</sub>	Luvic Xerosols	Calcareous rocks	Cultivated soil
L <sub>3</sub>	Humic Cambisols	Calcareous rocks	Forest soil
N	Podzoluvisols	Sandstones	Forest soil
S <sub>2</sub>	Eutric Fluvisols	Alluvium	Cultivated soil
T <sub>1</sub>	Humic Cambisols	Calcareous rocks	Forest soil
T <sub>2</sub>	Luvic Phaeozems	Calcareous rocks	Pasture lands
T <sub>3</sub>	Vertisol	Calcareous rocks	Cultivated soil
T <sub>4</sub>	Rendzinas	Calcareous rocks	Cultivated soil
Ta	Ferric Luvisols	Sandstones	Forest soil
TM	Albic Luvisols	Calcareous rocks	Forest soil
ZP <sub>1</sub>	Ferralic Cambisols	Calcareous rocks	Forest soil
ZP <sub>2</sub>	Orthic Greyzems	Calcareous rocks	Forest soil
ZP <sub>3</sub>	Calcic Cambisols	Calcareous rocks	Cultivated soil
ZP <sub>4</sub>	Calcic Cambisols	Calcareous rocks	Cultivated soil

the humid region with a parallel increase of perennial herbaceous and plant cover. Species richness and species diversity and number of species increased and the dominance factor decreased with the increase of rain.

Soil samples were collected from soil profiles located over landscapes and different management practices. Properties of the soils along with their sample denotation and classification are presented in Table 1.

- Eleven soils: BMF, Br, C, L<sub>1</sub>, L<sub>3</sub>, T<sub>2</sub>, T<sub>3</sub>, T<sub>4</sub>, ZP<sub>2</sub>, ZP<sub>3</sub> and ZP<sub>4</sub> were collected from carbonated horizons under different soil occupation.
- Ten soils: A<sub>1</sub>, A<sub>2</sub>, B, L<sub>2</sub>, N, S<sub>2</sub>, T<sub>1</sub>, Ta, TM and ZP<sub>1</sub> were collected from no carbonated horizons under different soil occupation.

**Soil sampling:** Undisturbed soil samples were collected for chemical and physical analysis at the same locations from the A horizons.

**Soil analysis:** Soil samples were air dried in the laboratory and passed through a 2 mm sieve prior to analysis. All the soil samples were analyzed for organic matter content with the dichromate oxidation method. The particle size fractions were determined using the pipette method. Soil pH was measured in 1:2 soil: water suspension (Nelson, 1982) and CaCO<sub>3</sub> content was determined with a pressure calcimeter (McLean, 1982).

### Organic matter analysis

**Particulate organic carbon:** Particulate organic matter was determined using the method of Cambardella and

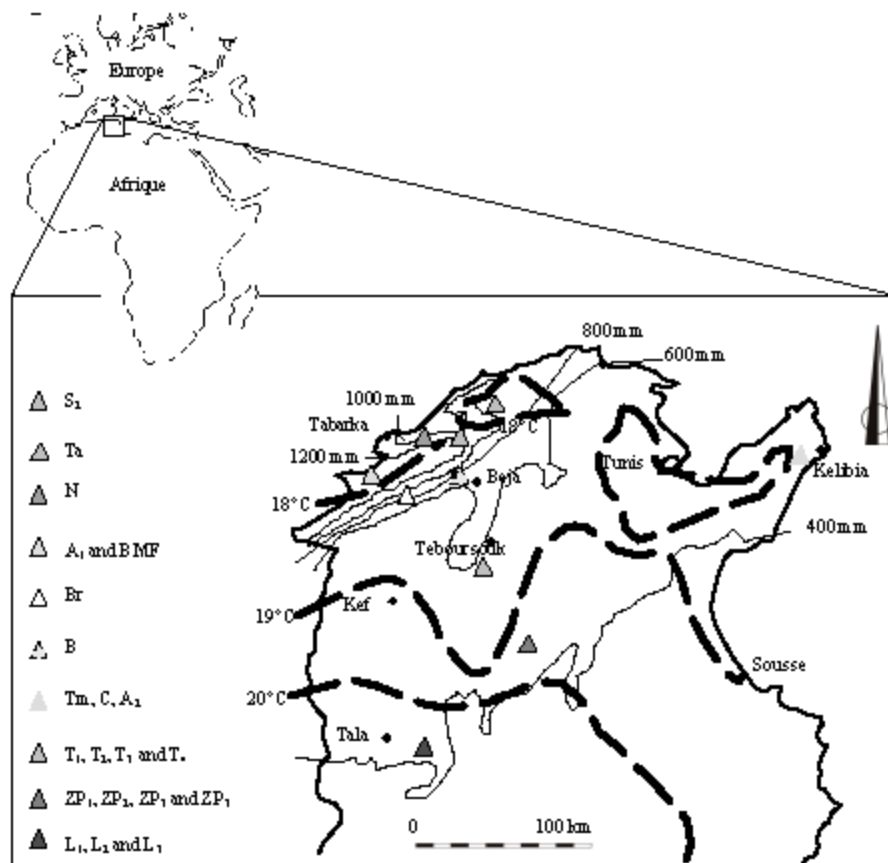


Fig. 1: Location of the sampling sites with isolines of mean annual temperature, in °C (dashed lines) and mean annual rainfall in mm (thin lines)

Elliott (1992) by dispersing the soil in 5 g L<sup>-1</sup> sodium hexametaphosphate. Particulate soil organic matter is a labile intermediate in the soil organic matter continuum from fresh organic materials to humified matter (Cambardella and Elliott, 1992). This material was separated from the soil by dispersion and sieving. The dispersed material was sieved through a 53 µm sieve and the suspended fraction was dried. Dried samples were ground and analyzed for organic carbon.

**Hot-water-extractable polysaccharides:** Hot-water-extractable polysaccharide carbon (HWPC) contents were determined on moist samples equivalent to 1 g dry weight and stored frozen at -20°C until analysis. The samples were extracted with 20 mL of deionized water at 80°C for 24 h (Puget *et al.*, 1999). The suspensions were centrifuged (20 min at 30,000 x g) and 10 mL of supernatant was recovered and stored frozen before analysis. The carbohydrate C content of the extracts was determined by a colorimetric method at 490 nm according

to the phenol-H<sub>2</sub>SO<sub>4</sub> method (Dubois *et al.*, 1956). Glucose was used as a standard.

**Humic substances: Fulvic acid and humic acid:** Total humic-like substances (fulvic-like and humic-like fractions) were extracted in triplicate by shaking 2 g soil samples with 100 mL of 0.1 M NaOH for 2 h on a rotative agitator. The alkali-soluble humic-like substances were then separated from the non-alkali-soluble humin by centrifugation (15 min at 8627 x g). Organic C in the extracts was measured using a TOC analyzer (Shimadzu TOC-5050A, Kyoto, Japan).

**Aggregate stability:** Aggregate stability was determined according to Le Bissonnais (1996). This method combines three disruptive tests having various different wetting conditions and energies: fast wetting, slow wetting and mechanical breakdown by shaking after prewetting. The tests were performed on the 3 to 5 mm aggregates recovered during the incubation. For the fast wetting test,

about 5 g of calibrated aggregates was rapidly immersed in 50 mL of deionized water for 10 min. For the slow wetting test, 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, aggregates were gently immersed in ethanol. After 30 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. The mass proportion of each fraction size of stable aggregates was calculated. Results were expressed as a mean weight diameter (MWD) corresponding to the sum of the mass fraction remaining on each sieve multiplied by the mean intersieve sizes. Mean weight diameters were calculated for each treatment (MWD<sub>FW</sub>, MWD<sub>MB</sub> and MWD<sub>SW</sub>, for fast wetting, mechanical breakdown and slow wetting, respectively). Calculated MWD ranged between 25 µm to 3.5 mm, with the larger MWD values representing greater aggregate stability.

**RESULTS AND DISCUSSION**

In this study, carbonated topsoil horizons, those with carbonate calcium amount greater than 10% (group 1: G1).

Eleven topsoil horizons showing different amount of carbonate calcium (CaCO<sub>3</sub>) (Table 2) were used in this study. In contrast ten no carbonated sub soils horizons with few (5 horizons) (<6%) or 0 carbonate calcium percentage were used (group 2: G2) (Table 2).

**Different organic matter fraction analysed:** We found significant differences among sites. The greater SOC content was 31.21 and 59.39 g kg<sup>-1</sup> of soil for horizons of groups 1 and 2, respectively. In the contrast, lower contents were calculated for G1 (9.09 g kg<sup>-1</sup>) and G2 (4.88 g kg<sup>-1</sup>). Across all sites, SOC contents decreased in the agriculture or pasture lands than forest soils. Consequently, the greater stock was associated with the forest soils ZP<sub>1</sub> (G2) and ZP<sub>2</sub> (G1). However, average of SOC content in cultivated soils was in some case lower than 10 g kg<sup>-1</sup> soils A2, L2 and S2 (G1) and Br (G1) (Table 1).

Because POC has been shown to be the labile fraction of SOC (Cambardella and Elliott, 1992) it can be expressed as a percentage of SOC. Particulate organic carbon in the carbonated soil reached 87.30% (ZP<sub>2</sub>) of total organic carbon and 27.23 g kg<sup>-1</sup> of soil (soil ZP<sub>2</sub>). The lower percentage (19%) was shown in the cultivated soil (T<sub>3</sub>). However, in no carbonated horizons the greater percentage of POC was 93% (soil L<sub>2</sub>) and the POC stock reached 27.44 g kg<sup>-1</sup> of soil. In both carbonated and no carbonated soils POC showed positive correlation with SOC (Table 3, Fig. 2).

Hot-Water-Extract-Polysaccharides (HWEP) did not have very significant presence across all twenty one horizons. The highest HWEP/SOC average was 1.1%

Table 2: pH, clay content, silt content, sand content, carbonate calcium content (CaCO<sub>3</sub>) and soil organic carbon (SOC), particulate organic carbon (POC), hot water extract polysaccharides (HWEP) and humic compounds (HC) content in carbonated and no carbonated sub soil horizons

	pH	Clay (g kg <sup>-1</sup> )	Silt (g kg <sup>-1</sup> )	Sand (g kg <sup>-1</sup> )	CaCO <sub>3</sub> (g kg <sup>-1</sup> )	SOC (g kg <sup>-1</sup> )	COP (g kg <sup>-1</sup> )	HWEP (g C kg <sup>-1</sup> )	HC (g C kg <sup>-1</sup> )
<b>Carbonated topsoil horizons (G1)</b>									
BMF	7.5	434.1	289.4	284.0	494.2	25.1	8.9	0.06	0.35
BR	7.0	546.7	244.5	192.9	125.0	9.1	5.9	0.05	0.42
C	7.3	333.6	249.0	403.3	113.6	26.0	15.4	0.07	0.42
L1	7.2	647.5	232.1	146.3	613.6	9.4	9.1	0.08	0.11
L3	6.9	294.1	234.0	490.2	181.0	29.2	9.4	0.05	0.09
T2	7.2	594.6	318.4	105.3	547.7	29.8	9.5	0.05	0.31
T3	7.1	578.7	391.9	53.5	419.3	10.4	2.0	0.07	0.34
T4	7.0	602.9	252.6	166.5	452.3	17.9	6.0	0.06	0.23
ZP2	7.4	649.6	166.4	207.6	638.1	31.2	27.2	0.08	0.46
ZP3	7.4	406.9	159.2	457.3	390.8	27.1	12.6	0.09	0.58
ZP4	7.7	463.6	201.7	315.5	322.5	27.6	16.1	0.08	0.08
<b>No carbonated topsoil horizons (G2)</b>									
A1	6.4	203.7	261.5	522.6	0.0	33.1	20.7	0.09	9.04
A2	6.9	270.2	161.1	561.2	22.0	9.0	4.3	0.09	0.14
B	6.7	785.2	150.1	52.5	90.0	21.1	5.6	0.05	0.45
L2	7.3	157.2	170.2	660.1	68.0	4.9	4.5	0.03	0.04
N	4.8	154.0	179.5	670.7	0.0	29.4	12.6	0.08	5.43
S2	6.3	126.4	190.1	669.9	0.0	5.5	3.6	0.06	0.03
T1	6.8	373.2	308.0	321.7	68.9	43.8	24.7	0.14	4.38
Ta	5.9	148.0	327.3	513.4	0.0	26.8	14.0	0.25	7.07
TM	7.0	238.4	180.5	575.5	45.0	16.0	12.8	0.10	0.20
ZP1	7.0	470.6	282.9	252.3	0.0	59.4	27.4	0.06	2.28

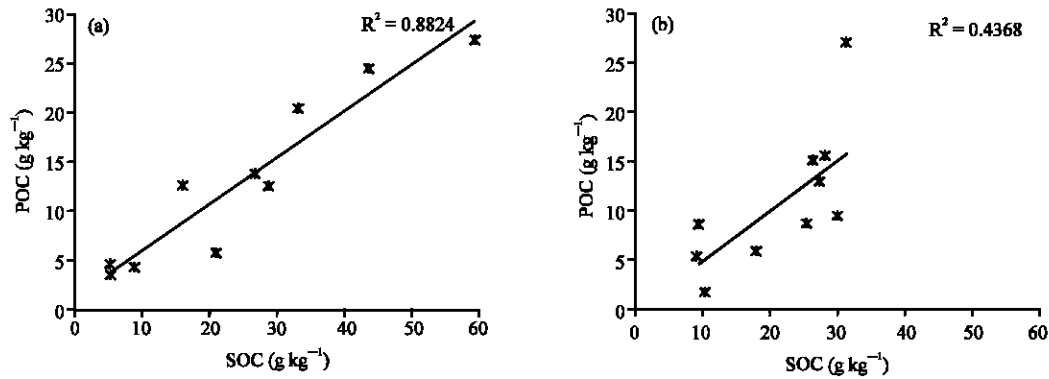


Fig. 2: Relationship between Soil organic carbon (SOC) and particulate organic carbon (POC) (a) no carbonated horizons (b) carbonated horizons

Table 3: Pearson correlation coefficients between carbonate calcium (CaCO<sub>3</sub>), soil organic carbon (SOC), particulate organic carbon (POC), hot water extract polysaccharides (HWEP) and humic compounds (HC) content

Variables	CaCO <sub>3</sub>	SOC	POC	HWEP	HC
<b>Carbonated sub soil horizons</b>					
CaCO <sub>3</sub>	1				
SOC	0.053	1			
COP	0.213	0.661*	1		
HWEP	0.284	0.044	0.399	1	
AH + AF	-0.014	0.100	0.214	0.270	1
<b>No carbonated sub soil horizons</b>					
CaCO <sub>3</sub>	1				
SOC	-0.205	1			
COP	-0.230	0.939*	1		
HWEP	-0.264	0.216	0.286	1	0.562
HC	-0.464	0.504	0.576	0.562	1

\*Significant correlation  $p \leq 0.05$

(soil S<sub>2</sub>). But their amount in no carbonated soil was larger than carbonated soils. Greater HWEP content under G1 was 0.09 g C kg<sup>-1</sup> in compared with 0.25 g C kg<sup>-1</sup> of soil under G2.

The results of humic compounds analysis showed low concentration in the carbonated soil. Values ranged from 0.08 to 0.58 g C kg<sup>-1</sup>. In contrast, in no carbonated soils the reserves on HA+FA reached 9.04 g kg<sup>-1</sup> of soils (Table 4). Consequently, the greater percentage of humic compounds related to the SOC content was 4.7% (sample Br) in the carbonated soils and 27.3% in no carbonated soils (sample A<sub>1</sub>).

**Aggregate stability:** Different MWD of different treatments (Fast Wetting, Slow Wetting and Mechanical Breakdown) related to the aggregate stability method used in this study showed a wide range of values. Consequently, there are different aggregate stability situations. In addition, we noted that across majority of horizons, MWD values decreased with increasing energies of treatment because the fact that  $MWD_{SW} > MWD_{FW}$ . On the other hands, mechanical breakdowns had lower effect on aggregate destruction

Table 4: Pearson correlation coefficients between different mean water diameters (MWD) related to the tree treatments fast wetting (MWD<sub>FW</sub>), mechanical breakdowns (MWD<sub>MB</sub>) and slow wetting (MWD<sub>SW</sub>) and soil organic carbon (SOC), particulate organic carbon (POC), hot water extract polysaccharides (HWEP) and humic compounds (HC) content in carbonated and no carbonated sub soil horizons

Variables	SOC	POC	HWEP g	HC
<b>Carbonated sub soil horizons</b>				
MWD <sub>FW</sub>	0.429	0.514	0.269	0.379
MWD <sub>MB</sub>	0.464	0.600	0.454	0.392
MWD <sub>SW</sub>	0.443	0.484	0.354	0.178
<b>No carbonated sub soil horizons</b>				
MWD <sub>FW</sub>	0.824*	0.911*	0.361	0.763*
MWD <sub>MB</sub>	0.756*	0.900*	0.509	0.736*
MWD <sub>SW</sub>	0.631	0.785*	0.455	0.709*

\*Significant correlation  $p \leq 0.05$

than the fast wetting. Thus, MWD<sub>MB</sub> was greater than MWD<sub>FW</sub> across most of all horizons.

In G1, fast wetting treatment showed MWD<sub>FW</sub> values ranging from 0.34 mm (soil Br) to 3.30 mm (ZP<sub>2</sub>), however MWD<sub>SW</sub> varied from 0.80 mm (Br) to 3.43 mm (ZP<sub>2</sub>). As a result, the resistance of soil can decrease widely with increasing energies given by the treatment (case of soil Br). Aggregate destruction was also caused by Mechanical Breakdown but its effect was smaller than fast wetting, except for ZP<sub>2</sub> horizon. The values of MWD<sub>MB</sub> ranged from 0.67 to 3.21 mm.

Similar results were found for G2. Except for A<sub>1</sub>, T<sub>1</sub> and ZP<sub>1</sub> horizons, all soils were most affected by fast wetting than mechanical breakdowns. The data showed that MWD<sub>FW</sub> varied from 0.45 mm (sample A<sub>2</sub>) to 2.97 mm (sample A<sub>1</sub>); MWD<sub>SW</sub> ranged from 0.88 mm (sample L<sub>2</sub>) to 3.13 mm (sample A<sub>1</sub>) and MWD<sub>MB</sub> ranged from 0.85 mm (sample A<sub>2</sub>) to 2.82 mm (sample A<sub>1</sub>) (Fig. 3a, b).

**Effect of organic matter on aggregate stability:** The presence of calcium carbonate in the subsurface horizon affected organic matter dynamics and aggregate stability. Indeed, only no carbonated horizons showed evident

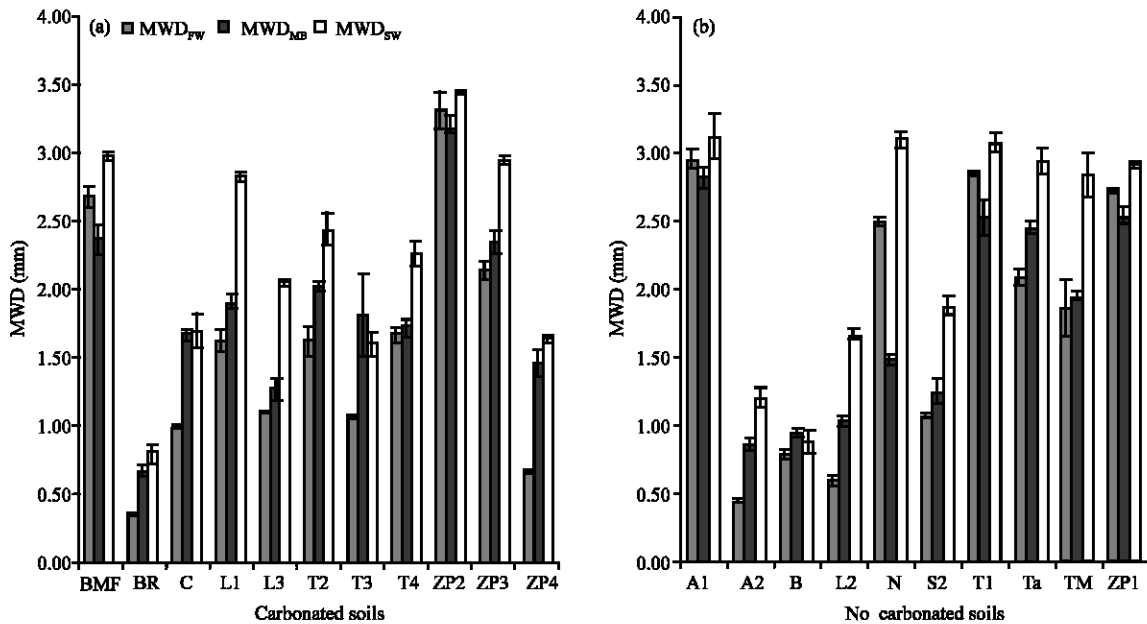


Fig. 3: Average of different mean water diameters (MWD) related to the tree treatments: fast wetting ( $MWD_{FW}$ ), mechanical breakdowns ( $MWD_{MB}$ ) and slow wetting ( $MWD_{SW}$ ) (a) carbonated soils (b) no carbonated sub soil horizons

relationship between organic matter fraction and aggregate stability indicators ( $MWD_{SW}$ ,  $MWD_{FW}$  and  $MWD_{MB}$ ). On the other hands, in no carbonated soils there was no directly relationship between organic matter and aggregate stability.

Consequently, in no carbonated soils (G2), different measured MWD were related to SOC, POC and humic compounds. In fact,  $MWD_{FW}$ ,  $MWD_{MB}$  and  $MWD_{SW}$  showed positive correlation with SOC contents (Fig. 4a-c) and coefficient of determination  $R^2$  was 0.67, 0.57 and 0.39, respectively. The same result was found between  $MWD_{FW}$ ,  $MWD_{MB}$  and  $MWD_{SW}$  POC content (Fig. 4d-f). However, in this case coefficients of determination  $R^2$  were greater than those obtained with SOC content. Therefore,  $R^2$  was 0.82, 0.80 and 0.61 for  $MWD_{FW}$ ,  $MWD_{MB}$  and  $MWD_{SW}$ , respectively. Data showed also that aggregate stability was associated to the HC since positive and significant correlation between different MWD values and HC was shown (Fig. 5a-c). In fact, calculated  $R^2$  was 0.54, 0.58 and 0.50 for  $MWD_{FW}$ ,  $MWD_{MB}$  and  $MWD_{SW}$ , respectively.

**Organic matter in soils:** In both carbonated and no carbonated soils, SOC content vary widely. Therefore, the differences in SOC properties studied were related to (i) soil use or cultivation (ii) the subsurface horizon characteristics (amount of calcium carbonate). We noted that samples collected from forest soils showed high

SOC content. Under forest soils, the presence of litter recycles continuously SOC storage in topsoil horizons (Garcia-Pausas *et al.*, 2004). However, in the pasture lands and specially cultivated soils, perennial herbaceous or crop residues were the main carbon resources. Cultivation decreases amount of carbon by the following processes: (1) accelerated mineralization, (2) leaching and translocation as dissolved or particulate organic C and (3) accelerated erosion (Bongiovanni and Lobartini, 2006; Li *et al.*, 2007). The SOC content in the no carbonated soils was higher than in carbonated soils. This fact can be attributed to the sampling sites from where derived no carbonated soils. Because sampling were selected in the north of Tunisia, where the important forest ecosystems are installed. Consequently, in these sites we observed thick layer of litter recycling continuously SOC content in the subsoil horizon. Also, in carbonated soils neutral acidity improves biodegradation activity of organic matter and the presence of calcium carbonate influenced organic mineralization and humification (Jacquin and Chouliaras, 1976).

Similar results were found in particulate organic carbon (POC) analysis. The data showed also considerable differences in POC contents between soils in different sub soils horizons used in this study. Thought, cultivated soils appear to have harmfully affected the POC content (Bongiovanni and Lobartini, 2006). Indeed, destruction of macroaggregates by tillage

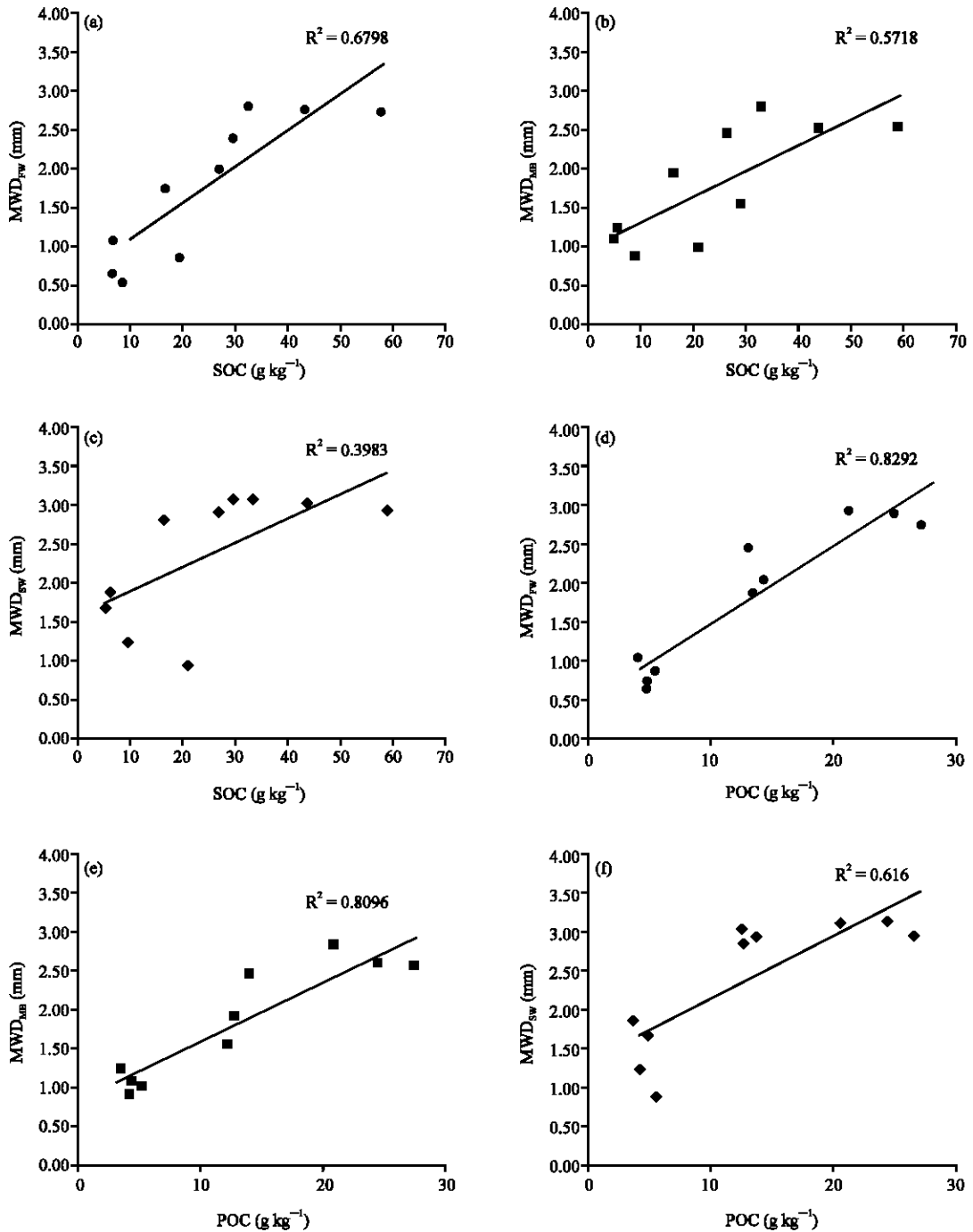


Fig. 4: Relationship between (i) (a) mean weight diameter fast wetting MWD<sub>FW</sub>, (b) mean weight diameter mechanical breakdowns MWD<sub>MB</sub> and (c) mean weight diameter slow wetting (MWD<sub>SW</sub>) and SOC content (ii) (d) mean weight diameter fast wetting MWD<sub>FW</sub> (e) mean weight diameter mechanical breakdowns MWD<sub>MB</sub> (f) mean weight diameter slow wetting (MWD<sub>SW</sub>) and POC content in no carbonated sub surface horizons

may result in exposure of the inner core of POC facilitating rapid decomposition by microorganisms of this important organic carbon reserve in the soil (Six *et al.*, 1999, 2004).

Important POC contents were measured in carbonated and no carbonated horizons. This result, which may be expected, can be attributed to the presence of litter and to



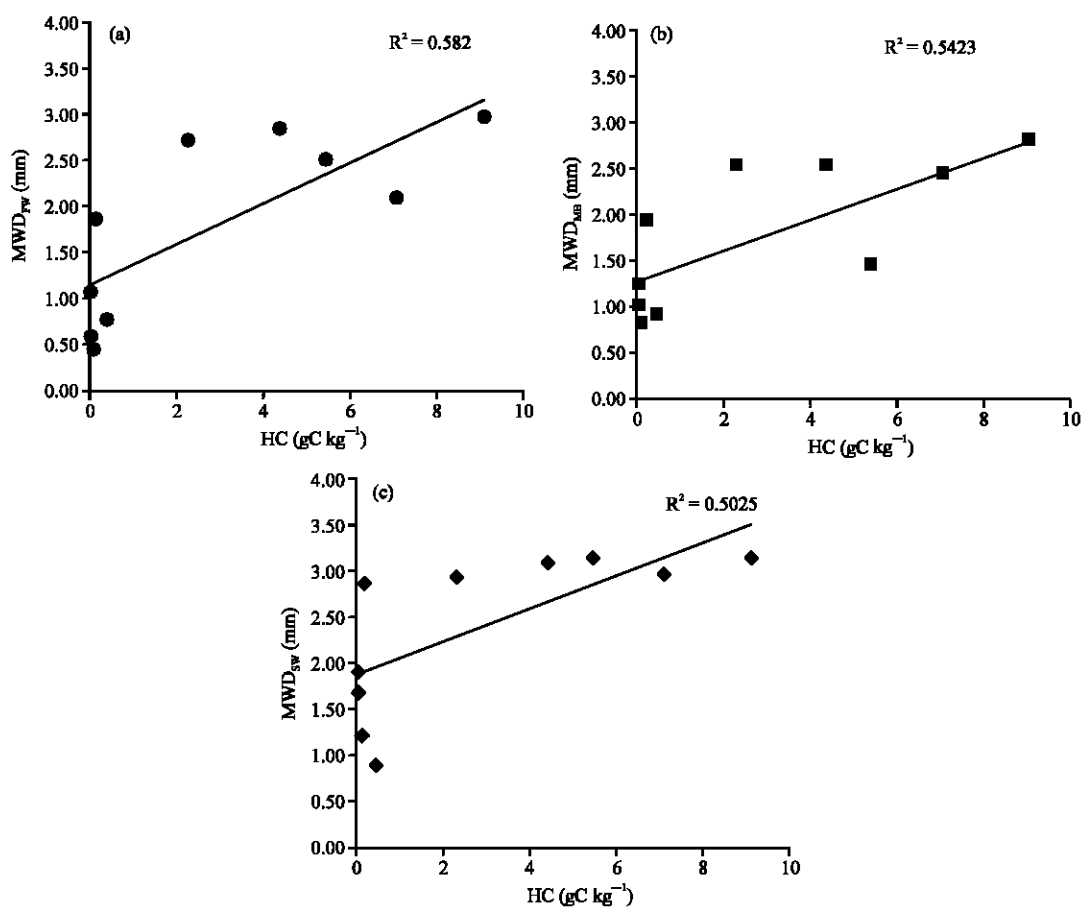


Fig. 5: Relationship between (a) mean weight diameter fast wetting MWD<sub>FW</sub>, (b) mean weight diameter mechanical breakdowns MWD<sub>MB</sub> and (c) mean weight diameter slow wetting (MWD<sub>SW</sub>) and HC content in no carbonated sub surface horizons

the effect of calcium carbonate calcium. Because, organic residues was surrounded by a mineral enclosing matrix of CaCO<sub>3</sub> limiting microorganisms attack (Jacquin and Chouliaras, 1976).

The positive correlation between SOC and POC in all soils was considerable. This is the case was to the role played by POC as an important fraction of SOC and a source of other organic matter fractions obtained after its mineralization and humification.

On the other hands, data indicated that the HWEF concentration was not important in whole soils. The reason of this situation was the labile nature of these compounds, vulnerable to decomposition by microorganisms. However, HWEF was greater in no carbonated than in carbonated horizons, because degradation activity in carbonated horizons was more important than in the other horizons. Also fungal activity observed in sandy horizon of no carbonated soils, produces more polysaccharides substances in sub surface horizons.

Humic compounds (HA+FA) were low in carbonated soils due to the presence of CaCO<sub>3</sub> that stopped organic matter maturation. In addition, in most no carbonated soils sampled, low pH values results from the increasing occurrence of humic and fulvic acids whose eluviate from the humus layers (Seeber and Seeber, 2005). This soil acidity reduces microbial and faunal activities leading to an accumulation of organic material and thus organic matter increases in the topsoil (Seeber and Seeber, 2005).

**Aggregate stability:** The most stable sample was derived from a carbonated horizon. In carbonated soils, in addition to organic matter and clay, CaCO<sub>3</sub> was considered an important agent of aggregation. But in no carbonated horizon, the sandy texture decreased aggregate formation and stabilisation (Bouajila and Gallali, 2007).

Considering all MWD related to the different treatments (FW, SW and MB), aggregate stability was most affected by fast wetting (FW). Indeed, the later can mimic a strong rain that destroys macroaggregates by

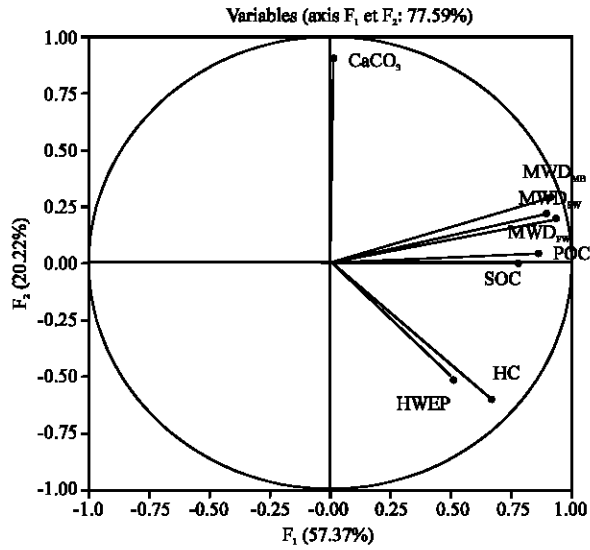


Fig. 6: Principal component analysis between different mean water diameters (MWD) related to the tree treatments fast wetting (MWD<sub>FW</sub>), mechanical breakdowns (MWD<sub>MB</sub>) and slow wetting (MWD<sub>SW</sub>) and soil organic carbon (SOC), particulate organic carbon (POC), hot water extract polysaccharides (HWEP) and humic compounds (HC) content in all horizons Soil Correlation circle and variables axis, first and second components

burst, which produces microaggregates (Annabi *et al.*, 2007). However, slow wetting affected soil aggregation lower than fast wetting. The reason was the differences of treatment energies between fast and slow wetting. On the other hands, mechanical breakdown, in more than 80% of studied horizons, affected aggregates lower than fast wetting. Soils with MWD<sub>MB</sub> < MWD<sub>FW</sub> indicated that their macroaggregates was more resistant to burst than to breakdown.

Generally, aggregate stability of no carbonated soils and carbonated soils was almost the same between soils in the same conditions.

**Organic matter effect on aggregate stability:** The considerable effect of organic matter on aggregate stability of the soils was discussed in literature. However, several studies showed that relationship between organic matter and aggregate stability varies widely between soils. In addition, this relationship can be affected by the method used to evaluate structural stability (Chenu *et al.*, 2000; Le Bissonnais and Arrouays, 1997).

Results obtained in the present study showed two different relationships between organic matter fractions and aggregates stability (i) not clear or indirectly

association G1 soils and (ii) directly association G2 soils. In fact, in the soils with low CaCO<sub>3</sub> content (G2), aggregate stability was associated to the organic matter (significant correlations). In these soils, we can suggest that organic compounds are the principal binding agents of aggregate and the most factors influencing their stability.

In summary, SOC content in the no carbonated sub soil horizons improves aggregate stability. Also, the data indicated that this influence was insured essentially by two fractions: COP and Humic compounds (HA+FA). Similar results were found by Ashagrie *et al.* (2007), Annabi *et al.* (2007) and Piccolo and Mbagwu (1999). However, many studies showed significant relationship between polysaccharides and aggregate formation and stability (Haynes and Francis, 1993; Annabi *et al.*, 2007). In contrast, there was no significant role of hot water extract polysaccharides in aggregate stability in this study. This is the case due to nature of this organic matter compounds. In addition, acid extract polysaccharides content was greater in soil than HWEP and then play more important role in aggregates stability (Puget *et al.*, 1999).

Relationship between organic carbon fractions and aggregate stability in topsoil horizons, with important CaCO<sub>3</sub> content, showed no correlation. This fact can be attributed to (i) the presence of CaCO<sub>3</sub> causing no organic matter maturation (ii) its aggregation role and (iii) effect of the interaction between clay, organic matter and CaCO<sub>3</sub> in this case of soils, which can influence aggregate stability.

For evaluating and to summarise relationships between several variables analysed in this study, we use Principal Component Analysis (PCA) representation (Fig. 6). In this representation, data of twenty one sampling soils were used. Results showed that aggregate stability was mostly associated to the SOC and POC contents rather than HC and HWEP. However, we hypothesized trough PCA analysis that, in the presence of CaCO<sub>3</sub>, HC and HWEP improves structural stability. Ladd *et al.* (1993) and Munneer and Oades (1989) suggested that the presence of CaCO<sub>3</sub> in the soils caused clay flocculation and stabilization of organic matter compounds which improves soil aggregate organisation and stability.

**CONCLUSION**

The present results showed that organic matter dynamics and evolution were not the same in carbonated and no carbonated soils. The presence of important CaCO<sub>3</sub> content in carbonated horizons affects significantly different organic matter compounds

concentrations. On the other hands, Tunisian soils showed different aggregate stability situations. In general, soils with sandy texture and low content of organic matter showed the lowest MWD values.

In addition, results above indicate that the organic matter improves aggregate stability. However, this role can not be clear in all soils. It was more important in the no carbonated soils where the organic matter was the most aggregate agent. Also, present results suggested that both particulate organic carbon and humic compounds were the important fractions of total organic matter that improve aggregate stability.

These findings will be useful for the management of organic amendments with the purpose of improving soil structure stability. In Tunisian subhumid and semi arid regions, wind and water erosion are persistent problems. Soil conservation practices that improve soil aggregate stability also help retard soil loss by maintaining soil structure and surface conditions resistant to erosion. Because the predominance of carbonated horizons in Tunisian soils, we must integrate the effect of CaCO<sub>3</sub> content when we discuss evolution of soil physical properties. Furthermore, CaCO<sub>3</sub> particles properties (nature and size) affect differently aggregate stability (Le Bissonnais, 1996).

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