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Land use effect on soil and particulate organic carbon, and aggregate stability in some soils in Tunisia

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Conversion of native forests to cultivation is usually accompanied by a decline in soil organic carbon and nutrients, and deterioration of soil structure. Our knowledge of this process must increase if we are to optimise the physical regeneration of degraded soils in semiarid areas. In this work we aim to (i) determine the relationship between aggregate stability and soil and particulate organic carbon (ii) to study the evolution of this relationship with land use. Samples were collected from a cropland cultivated and an adjacent natural forest and pasture from tree toposequence in North Tunisia. Change in land use from forest soil to pasture and cultivation induced significant losses of soil and particulate organic carbon. The soil organic carbon loss from forest soils to agriculture soils reached 83 and 74% from forest soils to pasture lands. However, the average of particulate organic carbon in forest ranged from 15 to 27 g kg^{-1} and 3 to 14 g kg^{-1} in agriculture soils. Across 13 sites, the average of mean weight diameter significantly decreased from (2.79 mm) natural forest soil to (2.10 mm) to pasture soil, being more significant in the cultivation soil (1.70 mm). Fast wetting treatment, causing aggregate slaking, was the process that decreased aggregate stability the most. Significant correlation was found between aggregate stability and soil organic carbon fraction. However, the greater association was observed between aggregate stability and particulate organic carbon. Soil where the organic matter was the principal aggregation agent (soil with sandy texture and zero carbonate calcium content) showed greater degradation sensitivity to soil organic carbon loss. Soil aggregate stability and soil organic carbon fraction could be used as indicators to apply the most appropriate management practices to increase soil sustainability or productivity.

Key words: Land use, soil organic carbon, particulate organic carbon, aggregate stability, North Tunisia.

INTRODUCTION

Interactions among crop and soil management practices and soil condition are often clouded by variability within a system. Further, causal relationships between management and soil quality are difficult to extrapolate among regions because of differences in soil type, climate, and management norms. The quantity and quality of soil organic matter provides an important diagnostic link between management and sustainability of soil function. Organic matter improves soil aggregation or structure formation (Caravaca et al., 2004; Pinheiro et al., 2004) and it mediates many chemical and physical soil properties (Dexter, 1988).

The soil organic carbon (SOC) content in soil was found to be one of the main factors controlling the aggregate stability of soils (Chaney and Swift, 1984; Elliot, 1986). Soil organic matter compounds bind the primary particles in the aggregate, physically and chemically, and this, in turn, increases the stability of the aggregates and limits their breakdown during the wetting process (Emerson, 1977). Tisdall and Oades (1982) classified these organic binding agents into (i) transient: mainly polysaccharides; (ii) particulate organic matter: roots and fungal hyphae; and (iii) persistent: resistant aromatic

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Abbreviations: SOC, soil organic carbon; **POC,** particulate organic carbon; **WSA,** water stable aggregate; **MWD,** mean weight diameter; **SW,** slow wetting; **FW,** fast wetting; **MB,** mechanical breakdowns; **PCA,** principal component analysis.

components associated with polyvalent metal cations, and strongly sorbed polymers. Particulate organic carbon (POC) is a labile intermediate in the soil organic matter conti-uum from fresh organic materials to humified SOC, and is more sensitive to changes in management than total SOC (Cambardella and Elliott, 1992, 1993; Cambardella et al., 2001). Aggregate formation was directly related to root-residue decomposition and POC dynamics under no-tillage practices (Gale et al., 2000a, 2000b) and in undisturbed soils (Gale et al., 2000a, 2000b).

New micro aggregates probably form around decomposing pieces of root-derived POC inside macro aggregates (Gale et al., 2000b). An aggregate “life cycle” was proposed by Six et al. (2000) in which aggregates form and stabilize around fine POC encrusted with microbial products, and eventually destabilize due to a cessation of microbial activity.

Vegetation cover is one of the key factors influencing soil erodibility. This is due to the positive feedback of the vegetation on soil quality due to the organic matter contribution by means of the litter. Also, vegetation increases weathering, enhances rainwater infiltration and favours a less contrasted microclimate beneath plants due to the shadow. These conditions should generate a more active fauna and flora and, as a consequence, stronger aggregates (Oades, 1993).

Generally, it is accepted that conversion to crop production practices has caused a decline in SOC compared with the original grassland levels throughout the Great Plains (Campbell and Souster, 1982; Monreal and Janzen, 1993; Allmaras et al., 2000). Tillage has caused SC losses from 28 to 77% depending on geographic location (climate) and soil type (Pikul et al., 2007). Changes in agricultural management from conventional tillage to NT and increased crop-rotation diversity can increase accumulation of SOC (West and Post, 2002). Tillage disrupts aggregates mechanically, changes the soil climate (temperature, moisture, aeration) and acelerates organic matter decomposition (Balesdent et al., 2000), reducing the proportion of stable aggregates >0.25 mm (Cambardella and Elliott, 1993; Puget et al., 1995; Six et al., 1999 Carter, 2002).

The annual input of residues in continuously cropped soils can increase the quantity of water stable aggregate (WSA) relative to soils with a fallow phase in the crop rotation. Chenu et al. (2000) found that SOC associated with clay minerals gave increased hydrophobicity, and that greater WSA could be ascribed to resistance of aggregates to slaking. Eynard et al. (2004) concluded that cultivation of Ustolls (prairie soils of central South Dakota) resulted in a decline of wettability compared with historically untilled grassland. The objectives of this study were to determine the relationship between aggregate stability and total and particulate organic carbon (ii) the effects of soil management on SOC, POC, and structural stability of A or Ap horizons in tree toposequences of soil in Tunisia.

MATERIALS AND METHODS

Sampling sites

We collected soil samples from three different regions showing some changes.

- The region of Ain Draham - Sedjnen: were the places from which we collected five sites. This region was characterized by humid climate (1000 mm/year) and a sandstone parent materiel of soil. The sites were called A_1, N, Ta, S_1 and S_2
- The region of Teboursouk, in the limit between central and north zones of Tunisia, was characterized by a sub humid climate (600 - 800 mm/year) and soil parent material consisting essentially in carbonated Rocks. In this sequence we sampled four sites T_1, T_2, T_3 and T_4.
- The last samples that were collected from Siliana, in the central region of Tunisia, were characterized by a semi arid condition (400 - 600 mm/year) and by carbonated rocks. The sites were called ZP_1, ZP_2, ZP_3 and ZP_4

In every sequence we collected forest soils, agriculture soils and pasture lands for the purpose of testing the effect of land use. Indeed, in Ain Draham - Sedjnen there are tree forest soils: A1, N and Ta, one agriculture soil S_2 and one pasture lands S_1. In Teboursouk sequence we noted one forest soil (T_1), one pasture land (T_2) and two agriculture soils (T_3 and T_4). Finally we collected two forest soils (ZP_1 and ZP_2), and two agriculture soils (ZP_3 and ZP_4) where sampled in Siliana. Soil characteristics are shown in Table 1.

Soil sampling and analysis

Undisturbed soil samples were collected for chemical and physical analysis at the same sites from the A or Ap horizons. 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 (Anne, 1945). The particle size fractions were determined using the pipette method. Soil pH was measured in 1:2 soil: water suspension (Nelson, 1982), and $CaCO_3$ content was determined with a pressure calcimeter (McLean, 1982).

Particulate organic carbon

Particulate organic matter was determined using the method of Cambardella and Elliott (1992) by dispersing the soil in 5 g l^{-1} 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 Eliott, 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.

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

Table 1. Sample denotation, soil classification, parent material and soil use for the 13 sampled soils.

Soil denotation	Soil classification (FAO terms)	Parent material	Soil use
Toposequence of Ain Draham Sedjnan			
A_1	Humic cambisols	Sandstones	Forest soil
N	Podzoluvisols	Sandstones	Forest soil
Ta	Ferric luvisols	Sandstones	Forest soil
S_1	Albic luvisols	Sandstones	Pasture lands
S_2	Eutric fluvisols	Sandstones	Cultivated soil
Toposequence of Teboursouk			
T_1	Humic cambisols	Calcareous rocks	Forest soil
T_2	Luvic phaeozems	Calcareous rocks	Pasture lands
T_3	Vertisol	Calcareous rocks	Cultivated soil
T_4	Rendzinas	Calcareous rocks	Cultivated soil
Toposequence of Siliana			
ZP_1	Ferralic cambisols	Calcareous rocks	Forest soil
ZP_2	Orthic greyzems	Calcareous rocks	Forest soil
ZP_3	Calcic cambisols	Calcareous rocks	Cultivated soil
ZP_4	Calcic cambisols	Calcareous rocks	Cultivated soil

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_{FW}, MWD_{MB}, and MWD_{SW}, 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

Statistical analysis

The relationships between POC, SOC and aggregate stability were analyzed with principal component analysis (ACP).

RESULTS

Soils analysis and organic carbon fraction

Across all soils two major differences were noticed. It concerns soil pH and soil texture. Indeed, soils of Ain Draham – Sedjnen showed acid pH ranging from 4.8 to 6.9; sandy texture (sand content > 51%) and zero $CaCO_3$ content (Table 2). In contrast, soils of the two other regions: Teboursouk and Siliana, showed neutral pH, fine texture and important $CaCO_3$ content in the majority of samples (Table 2).

Soil organic carbon (SOC)

For all sites, the greatest concentration of SOC was found in forest top soil horizons. The SOC content decreased in pasture lands and agriculture soils compared with forest soils in the same region.

- In soil sequence of Ain Draham - Sedjene : the most SOC content was detected in the A_1 sample (33.13 g kg^{-1} of dry soil) and the smallest SOC concentration derived from S_1 sample (5.47 g.kg^{-1} of dry soil) (Table 2). The loss in SOC after deforestation and change in soil management from forest soils to agriculture soils reached 83 and 74% from forest soils to pasture lands.
- In the region of Teboursouk, differences between SOC content in the soils were related to the soil occupation. Indeed, the greatest difference in SOC was calculated between forest (T_1) A horizons (43.76 g.kg^{-1}) and agriculture soil T_3 (10.41 g.kg^{-1}) (Average SOC T_3 / SOC T_1 was 23.8 %).
- Similar results were found in the soil sequence of Siliana. Forest top soil horizons, ZP_1 and ZP_2 sampled in this region showed the important SOC content with 59.39 g.kg^{-1} and 31.2 of dry soil, respectively (Table 2).

Table 2. Soil properties: pH, clay, silt, sand, carbonate calcium ($CaCO_3$), soil organic carbon (SOC), particulate organic carbon (POC) content in all soils.

Soil	pH	Clay (%)	Silt (%)	Sand (%)	$CaCO_3$ (%)	SOC (g kg^{-1})	POC (g kg^{-1})
sequence of Ain Draham-Sedjnan							
A_1	6.4	20.37	26.15	52.26	0	33.13	20.72
N	4.8	15.40	17.95	67.07	0	29.36	12.62
S_1	6.9	25.95	23.66	49.05	0	26.83	14.04
S_2	6.3	12.64	19.01	66.99	0	8.53	3.63
Ta	5.9	14.80	32.73	51.34	0	5.47	3.62
sequence of Teboursouk							
T_1	6.8	37.32	30.80	32.17	6.89	43.76	24.67
T_2	7.2	59.46	31.84	10.53	54.77	29.81	9.53
T_3	7.1	57.87	39.19	5.35	41.93	10.41	1.99
T_4	7	60.29	25.26	16.65	45.23	17.85	6.03
sequence of Siliana							
ZP_1	7	47.06	28.29	25.23	0	59.39	27.44
ZP_2	7.4	64.96	16.64	20.76	63.81	31.21	27.23
ZP_3	7.4	40.69	15.92	45.73	39.08	27.06	12.65
ZP_4	7.7	46.36	20.17	31.55	32.25	27.64	16.12

Table 3. Pearson correlation between soil organic carbon (SOC) and particulate organic carbon (POC) content and mean weight diameter (MWD) calculated from tree tests: fast wetting (MWD_{FW}), mechanical breakdowns (MWD_{MB}) and slow wetting (MWD_{SW}).

	SOC (g kg^{-1})	POC (g kg^{-1})	MWD_{FW} (mm)	MWD_{MB} (mm)	MWD_{SW} (mm)	MWD_{AV} (mm)
SOC g kg^{-1}	1.00					
POC g kg^{-1}	0.88**	1.00				
MWD_{FW} mm	0.60*	0.72**	1.00			
MWD_{MB} mm	0.60*	0.77**	0.81**	1.00		
MWD_{SW} mm	0.55	0.65*	0.96**	0.74**	1.00	
MWD_{AV} mm	0.62*	0.76**	0.98**	0.89**	0.96**	1.00

* Significant correlation $P \leq 0.05$
** Significant correlation $P \leq 0.01$

Compared with agriculture soils, ZP_2 and ZP_3, the loss in SOC content reached 45%.

Particulate organic carbon (POC)

Since POC content was correlated (Table 3 and Figure 1) to soil organic carbon, this parameter has the same trend. Indeed, particulate soil organic matter consists of insoluble plant debris and this material was separated from the soil by dispersion and sieving of soil fraction (> 50 µm). Considering all 13 soil samples average of POC in forest soil across tree toposequences ranged from 15 to 27 g kg^{-1} of dry soil. However, in agriculture Ap horizons the average ranged from 3 to 14 g kg^{-1} and 8 in pasture lands.

Globally, results of SOC and POC content analysed from tree sequence of soil showed that horizons of the soil sequence of Ain Draham – Sedjnen showed great sensibility on SOC and POC when soil occupation changed compared with other soil sequences (Teboursouk and Siliana).

Aggregate stability

All samples were tested in order to evaluate their resistance to destruction by water applied at different wetting conditions and energies. Wetting significantly caused aggregates destruction with the large effect of fast

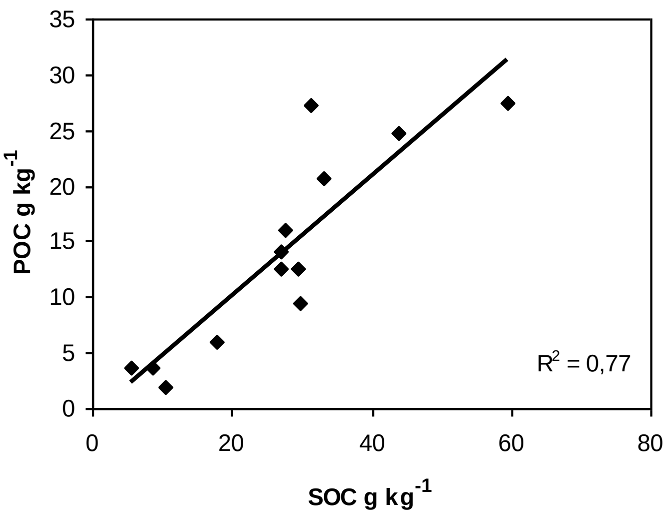

Figure 1. Relationship between soil organic carbon (SOC) and particulate organic carbon (POC).

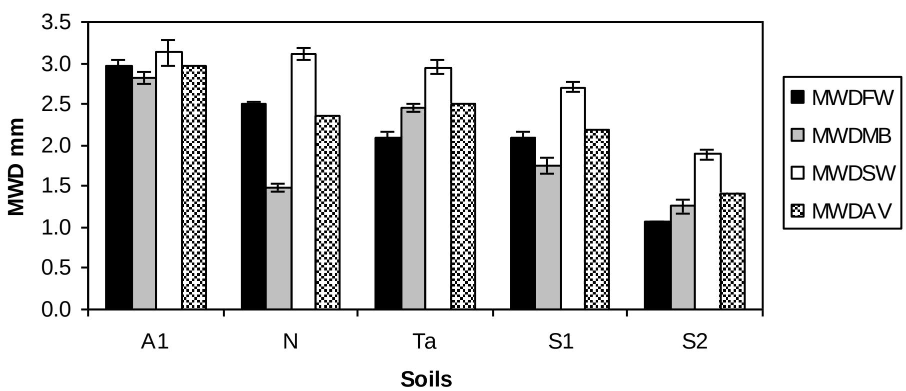

Figure 2. Different mean weight diameter (MWD) of tree tests: fast wetting (MWD_{FW}), mechanical breakdowns (MWD_{MB}) and slow wetting (MWD_{SW}), and MWD_{AV} for Ain Draham - Sedjnen soil sequence.

wetting (FW) when compared with slow wetting (SW). The FW treatment damaged aggregates by slaking. Average of MWD_{FW} ranged from 0.66 to 3.30 mm. However, MWD_{SW} average ranged from 1.60 to 3.43 mm. Mechanical breakdowns (MB), the second process induced aggregate destruction seemed less destructive than FW (Figures 2, 3 and 4). Results of aggregate stability of the tree sequence showed:

- In the soil sequence of Ain Draham-Sedjnen (Figure 2), the greater MWD_{AV} (Average of tree tests FW, SW and MB) was observed in forest soil sample A_1 (2.97 mm) and the smaller MWD_{AV} in agriculture soil sample S_2 (1.40 mm). Globally, lower MWD characterized by fast wetting treatment.
- In the soil sequence of Teboursouk (Figure 3), the forest soil T_1 was the most stable sample (MWD_{AV} = 2.83 mm), in contrast the smaller MWD_{AV} was related to the agriculture soil sample T_3 (MWD_{AV} = 1.48 mm). Greater MWD resulted from slow wetting treatment.
- In the soil sequence of Siliana (Figure 4), compared with the other sites similar results were found because the smaller MWD_{AV} (1.25 mm) characterized by agriculture soil sample (ZP_4). However, the largest MWD_{AV} was related to the forest soil sample ZP_2 (MWD_{AV} = 3.31 mm).

In summary, aggregate stability was more influenced by soil occupation in the soil sequence of Ain Draham – Sedjnen compared to other soil sequences.

Relationship between SOC, POC and aggregate stability

Our results showed that presence of organic matter

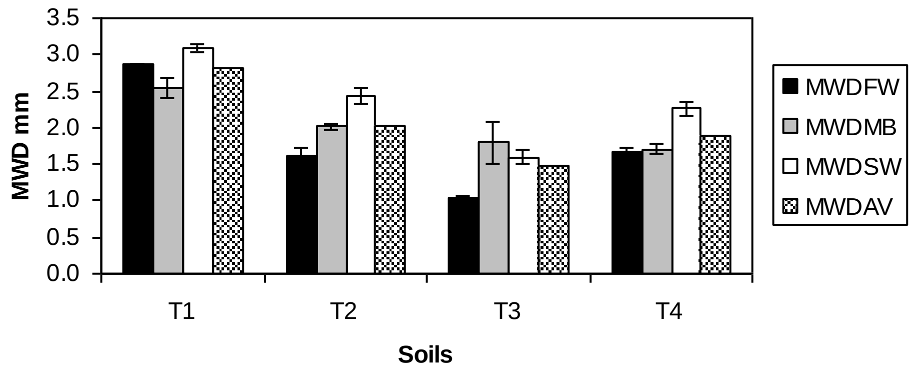

Figure 3. Different mean weight diameter (MWD) of tree tests: fast wetting (MWD_{FW}), mechanical breakdowns (MWD_{MB}) and slow wetting (MWD_{SW}), and MWD_{AV} for Teboursouk soil sequence.

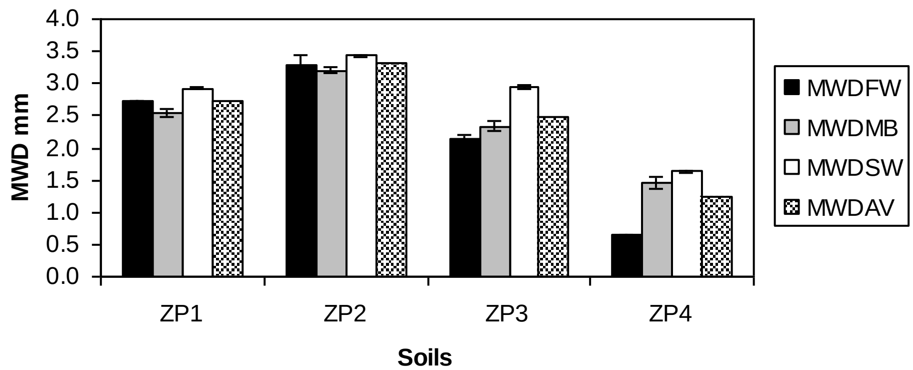

Figure 4. Different mean weight diameter (MWD) of tree tests: fast wetting (MWD_{FW}), mechanical breakdowns (MWD_{MB}) and slow wetting (MWD_{SW}), and MWD_{AV} for Siliana soil sequence.

improves aggregate stability, considering all 13 soil samples. Particulate fraction of organic carbon (POC) had a significantly larger effect on the MWD_{AV} than SOC (Table 3). Moreover, both MWD_{FW} and MWD_{MB} were more associated to POC compared to SOC (Figure 5 and 6). Indeed, MWD_{FW} were significantly correlated with POC ($r = 0.72$, $P < 0.01$), but with SOC significant correlation was detected when $P < 0.05$ ($r = 0.60$). The same results were found for MWD_{MB}, MWD_{SW} (Table 3 and Figures 5 and 6). To summarize this relationship between indicators of aggregate stability and POC and SOC, principal component analysis (PCA) was used. The first factor in the PCA representation included 80.78 % of the total variability, the second factor 12.46% and the two factors together 93.25% (Figure 7A). PCA showed that indicators of aggregate stability of all soils (different MWD) and POC and SOC were closely associated.

The factorial map of sites (Figure 7B) showed two sets of soil. The first represents forest sites with a high amount of SOC and POC content and important aggregate stability. In contrast the second corresponds to pasture and agriculture sites with low SOC and POC content and small aggregate stability. Average MWD and organic carbon fractions (SOC and POC) across all tree sites presented similar evolution (Figure 8). As soon as soil occupation changes, both structural stability and organic fraction concentrations, change. Furthermore, decrease of SOC and POC from forest soil to pasture and agriculture soil caused a decrease in aggregate stability. The loss of 2.7% of SOC produced a decrease of 1.57 mm on MWD_{AV} in the soil sequence of Ain Draham - Sedjnen. However, in the two other sequences more loss of organic carbon (3.3 %) compared with the first sequence, caused smaller decrease on MWD_{AV} (1.34 mm in Teboursouk soil sequence and 0.26 mm in Siliana soil sequence).

DISCUSSION

Soils analysis and organic carbon content

Differences between the three sites (Ain Draham-Sedjnen, Teboursouk, Silianana) studied in this work

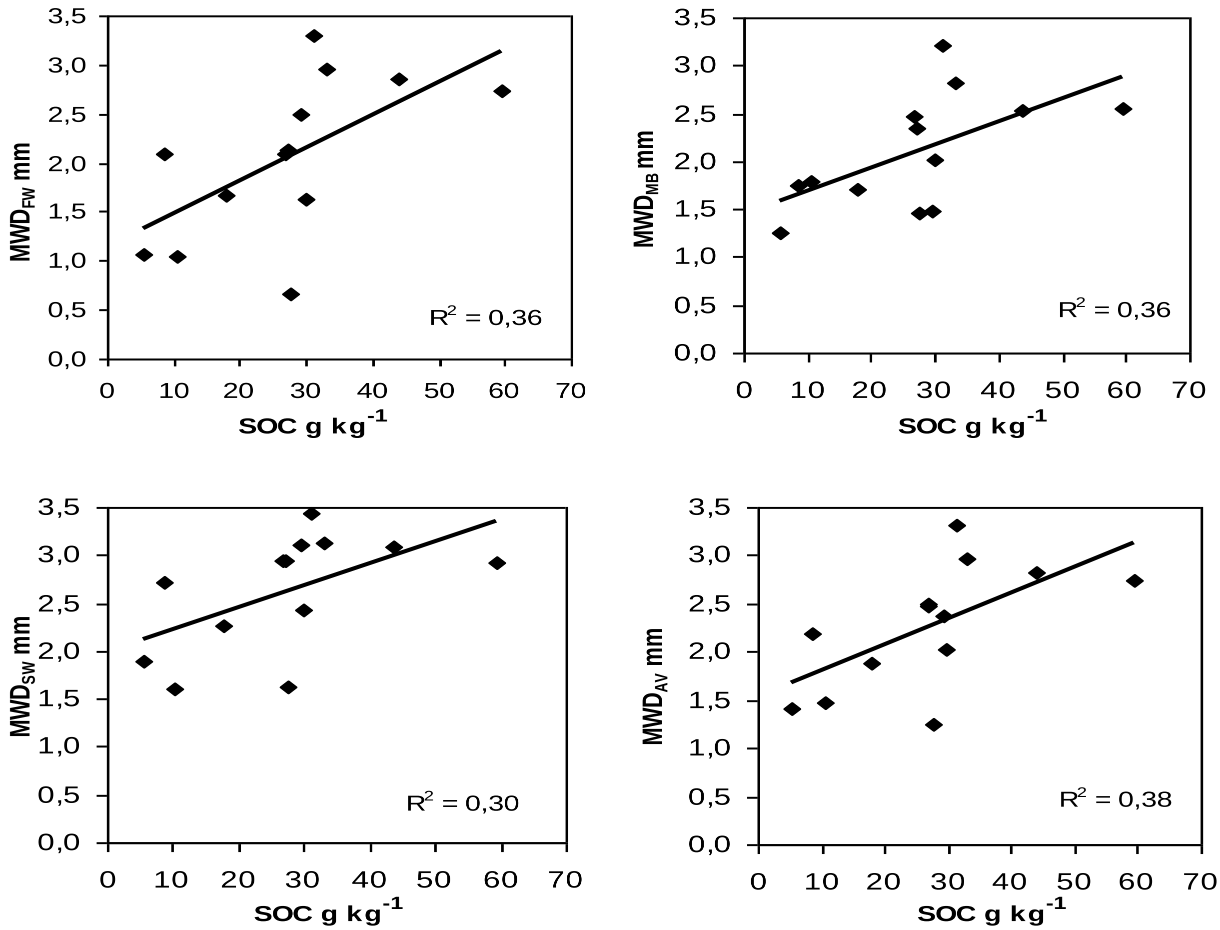

Figure 5. Relationship between mean weight diameters of different treatments: fast wetting (MWD_{FW}), mechanical breakdowns (MWD_{MB}), slow wetting (MWD_{SW}) and average (MWD_{AV}) and SOC content across all 13 samples tested.

some differences in soil characteristics were shown. Indeed, soil sequence of Ain Draham-Sedjnen showed (i) sandy texture related to the sandstone parent material nature of soils in this region (ii) low pH compared to the other soils probably the consequence of the zero level of calcium carbonate (0%) and the important precipitation in this region caused increasing occurrence of humic and fulvic acids from the humus layers (Seeber and Seeber, 2005). On the other hand, horizons sampled from Teboursouk and Siliana was characterized by neutral pH and great $CaCO_3$ content. The latest parameter derived from calcareous rock alteration, was the principal agent of decreasing soil acidity (Bortoluzzi and Tessier, 2002).

Samples collected from forest soils showed high SOC and POC content. Under forest soils, the presence of litter recycles continuously organic carbon storage in top-soil horizons (Garcia-Pausas et al., 2004). However, in the pasture lands and specially cultivated soils, perennial herbaceous or crop residues were the only carbon resources. Moreover, Cultivation decreases the amount of carbon by the following processes: (i) accelerated mineralization, (ii) leaching and translocation as dissolved or particulate organic C and (iii) accelerated erosion (Bongiovanni et al., 2006; Li et al., 2007). Change in soil occupation from forest to pasture or agriculture lands harmfully affected SOC and POC content (Bongiovanni et al., 2006) essentially in sandy soils (Ain Draham-Sedjnen region). This is because a higher amount of clay in these soils does not reduce organic compounds sequestration (Feller and Bear, 1997).

Relationship between soil aggregate stability and organic matter: Effect of soil use

The most stable samples were derived from a carbonated horizon (soil ZP_2). In carbonated soils, in addition to organic matter and clay, $CaCO_3$ was considered an important agent of aggregation. In contrast where soils were characterized by sandy texture and low amount of $CaCO_3$, organic matter was the principal agent of aggre-gate stability. The three tests used to evaluate aggregate

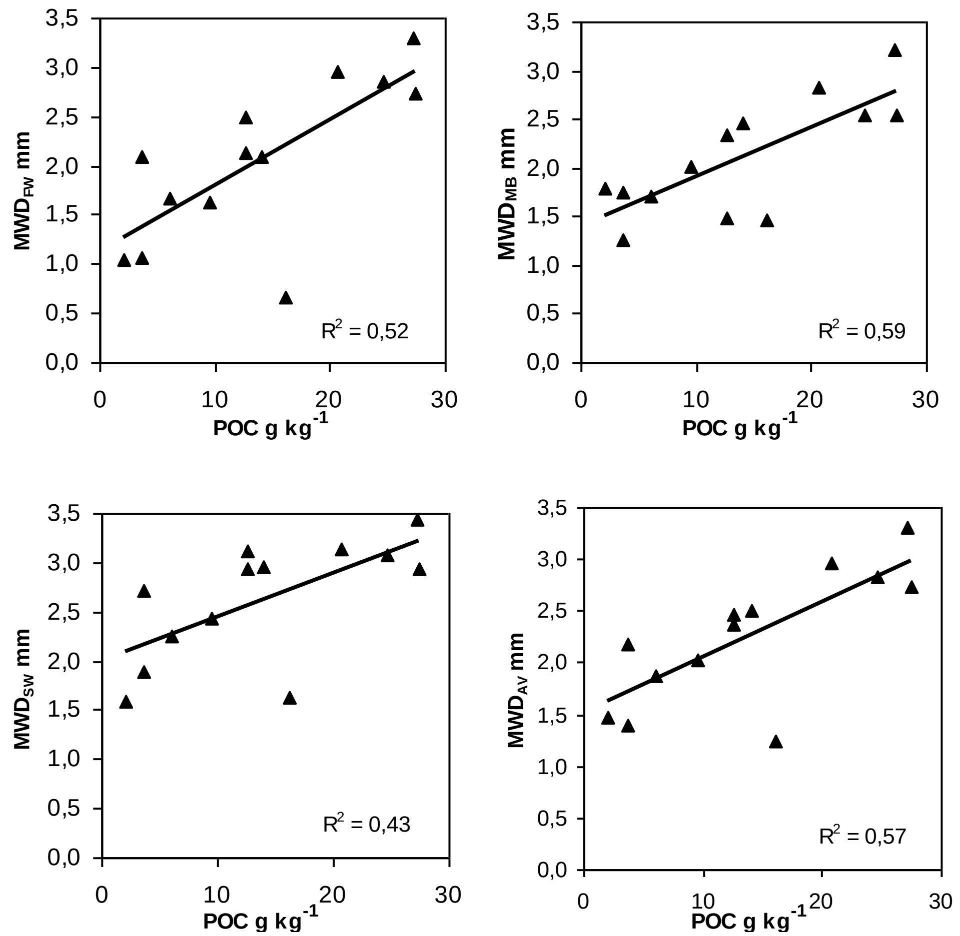

Figure 6. Relationship between mean weight diameters of different treatments: fast wetting (MWD_{FW}), mechanical breakdowns (MWD_{MB}), slow wetting (MWD_{SW}) and average (MWD_{AV}) and POC content across all 13 samples tested.

stability allow for distinction between two elementary mechanisms of aggregate breakdown: (i) slaking caused by the compression of air entrapped inside aggregates during wetting and depending on the rate of wetting, and (ii) mechanical breakdown depending on the applied shaking energy (Le Bissonnais, 1996). Physicochemical dispersion can also contribute to aggregate breakdown, but can be neglected since it is typically associated with soils of large clay content and exchangeable Na. In the fast and slow wetting tests, the dominant breakdown mechanism is slaking, with intensi-ties that differ according to the wetting rate of aggregates. In the fast wetting test, corresponding to a rain of strong intensity (>30 mm h−1; Legout et al., 2005), more intense slaking is observed because of the larger compression of entrapped air inside the aggregates when suddenly immersed in water.

No slaking occurs during the mechanical breakdown test, since aggregate porosity is saturated with ethanol that decreases surface tension and contact angle and thus favours water penetration (Annabi et al., 2007). Themechanical breakdown test simulates raindrop impacts on wet aggregates, which can detach soil particles. Two major properties contribute to aggregate resistance against breakdown: (i) aggregate hydrophobicity, which slows down the rate of water penetration in aggregate porosity and decreases the slaking, and (ii) internal aggregate cohesion, limiting both slaking and mechanical breakdown.

The considerable effect of organic matter on aggregate stability of the soils was discussed in literature. However, several studies showed that the relationship between organic matter and aggregate stability varies widely bet-ween soils. In addition, this relationship can be affected by the method used to evaluate structural stability (Chenu et al., 2000; Le Bissonais and Arrouays, 1997). Both SOC and POC increased aggregate resistance toward the strong disaggregating energy developed in the fast wetting test. POC had a more positive effect on aggre-gate stability in the tree tests and a lower association with slow wetting test, which involves a weaker disruptive energy than the fast wetting test, since the aggregate

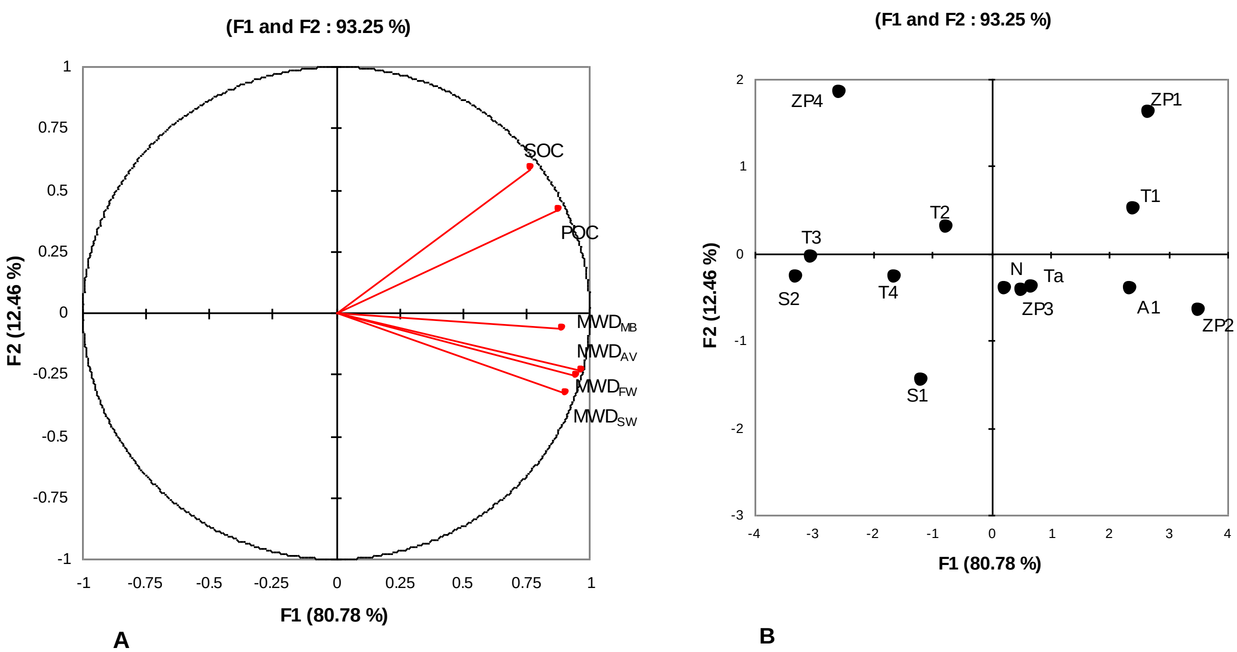

Figure 7. Principal component analysis between soil organic carbon (SOC), particulate organic carbon (POC) and different mean weight diameter: fast wetting (MWD_{FW}), mechanical breakdowns (MWD_{MB}), slow wetting (MWD_{SW}) and average (MWD_{AV}). (A) Correlation circle variable axis (F1 – F2) factorial plane; (B) The F1 – F2 factorial map of sites.

wetting is done progressively by capillarity. Larger positive effects of SOC and POC were observed in the mechanical breakdown tests. The organic carbon content was involved, as evidenced by increases in aggregate cohesion through enmeshment of aggregates by organic compounds and in aggregate hydrophobicity (Annabi et al., 2007). When comparing soils for their aggregate stability, usually the two wetting tests and the mechanical breakdown test similarly classify the soils (Le Bissonnais, 1996). In this study, the mechanical breakdown test gave results that differed from the two wetting tests. In this latest, aggregate stability is only related to interparticular cohesion. Across all sites we found greater MWD under Forest than pasture and agriculture soil. Average (all sites) MWD was 2.79 mm under Forest, 2.10 under pasture and 1.70 under agriculture soils. The relationship of aggregate stability to SOM and POM was possibly related to the binding agents (hyphae and roots) and fungal exudates such as polysaccharides and glomalin (Wright and Upadhyaya, 1996; Wright et al., 1999) which improve the stability of larger aggregates. These organic compounds may impart some degree of water repellency, thereby improving soil stability (Eynard et al., 2004; Degens, 1997).

When SOC and POC decrease from forest soils to agriculture or pasture lands, aggregate stability decreases as well. The reason for this is the destruction of macroaggregates by tillage causing exposure of the inner core of POC facilitating rapid decomposition by micro organisms of this important organic carbon reserve in soil (Six et al., 1999, 2004). Consequently, tillage and pasture activity through aggregate damage reduce both soil stability and organic matter content. However, this phenomenon was more important in sandy texture soil (Ain draham-Sedjenen soil sequence; zero $CaCO_3$ percentage) compared to fine texture soils (height amount of $CaCO_3$; Sequence soils of Teboursouk and Siliana). This result, which may be expected, can be attributed to a greater sensibility of aggregate in sandy soil to the destruction (Six et al., 2004) and the effect of $CaCO_3$ as an aggregation agent (Munneer and Oades, 1989). In summary, SOC content in the no carbonated top sub soil horizons improves aggregate stability. Also, the data indicated that this influence was ensured essentially by particular fraction. Similar results were found by Ashagrie et al. (2007) and Piccolo and Mbagwu (1999). Principal Component Analysis (PCA) representation from 13 soils samples that aggregate stability was mostly associated to the SOC and POC contents. However, we suggest through PCA analysis that particular organic carbon (POC) had the greater effect on structural stability compared to the other organic carbon fractions that can exist in soils.

Conclusion

In northern subhumid and semiarid regions of Tunisia, wind and water erosion are persistent problems. However, change in land occupation from forest to agriculture

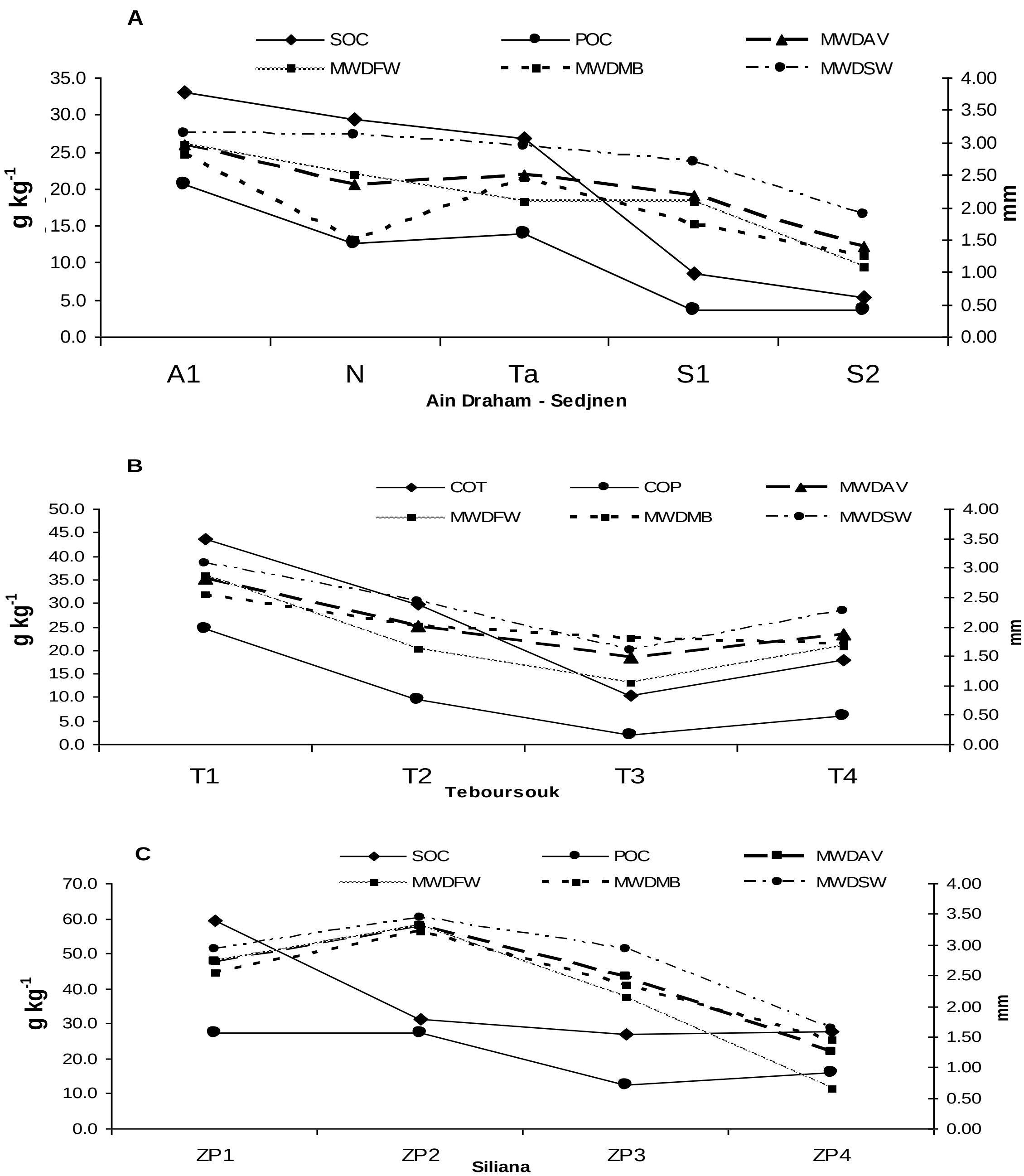

Figure 8. Evolution of soil organic carbon (SOC), particulate organic carbon (POC) and different mean weight diameter: fast wetting (MWD_{FW}), mechanical breakdowns (MWD_{MB}), slow wetting (MWD_{SW}) and average (MWD_{AV}) (A) soil sequence of Ain Draham-Sedjnen (B) soil sequence of Teboursouk (C) soil sequence of Siliana.

soils improves decrease in soil quality by organic carbon fractions loss. Our results show significant differences in SOC components as a result of different soil management. There was an important interaction between SOC and POC content and aggregate stability. Both SOC and POC decreased from forest to pasture and agriculture soils. This decrease was greater in soil with sandy texture with zero $CaCO_3$ content than in fine texture and carbonated soils. In the first class the organic matter was the main aggregate binding agent and decrease of organic carbon can produce soil instability. However, in carbonated soils the loss of SOC and POC caused smaller effect on soil stability. Importantly, we show a relationship between SOC, POC and aggregate stability that was consistent across a broad spectrum of soil and soil management. These results provide and improve the use of agricultural practices limiting soil organic matter loss and soil sensibility to degradation essentially in sandy texture soils characterizing arid African lands.

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