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Short-Term Dynamic of Aggregate Fractions and their Organic Carbon Contents in a Calcareous Soil Treated with Plant Residues

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Abstract: *The interrelation of aggregation and aggregate organic carbon (AOC) dynamics was studied in a calcareous soil. The soil treated with mild alfalfa, wheat and wood chips residues (>2mm), at a rate of 20 g kg-1 and incubated for 120days under field capacity. The mean weight diameter (MWD) of aggregates, aggregation and AOC dynamic were strongly interrelated. The correlation coefficient between the percentage of macroaggregates in >2 mm fraction and the percentage of aggregates in <1 mm fraction was negative and significant. During soil incubation the organic carbon (OC) content of aggregates in >2 mm fraction was higher in the soil treated with wood chips, but the OC content of aggregates in <1mm fraction were higher in the soil treated with alfalfa. Organic carbon content of macroaggregates decreased during soil incubation in all the soil treated with 20 g kg-1. The aggregate MWD and the percentage of stable aggregates in >2 mm fraction were 0.8mm and 6.3 % respectively in the first day of the soil treated with wood chips. They increased continuously to 1.12 mm and 24.5 % in 120th day of soil incubation. But in the soil treated with alfalfa and wheat residues the highest ones were obtained in 20th day. They decreased continuously with decreasing soil active carbons and biological activities.*

Keywords: *Aggregation; Plant residue; Organic carbon; Fractionation; Dynamic.*

1. INTRODUCTION

Soil aggregation and structure stability are two important characteristics of the soil stability and productivity including root distribution (Bronick and Lal, 2005). The resistance of soil to erosion depends on aggregate stability (Barthes and Roose, 2002).Many studies focus on turnover and stability of aggregate affected by a multitude of factors such as soil flora and fauna, polyvalent cations, SOC, clay and carbonate contents in the soil(Six et al., 2002; Bronick and Lal, 2005). Golchin et al., (1994, 1995) reported meaningful findings for conceptual model of interactions between the soil primary particles, OC, flora and fauna leading to theformation and destruction of the microaggregates.

Aggregate stability in soils with low contents of oxides and hydroxides of iron and aluminum (Le Bissonnais and Le Souder, 1995) and also in non- carbonated soils (Bouajila and Gallali, 2008) depends on the soil organic matter(SOM) contents. However, the interrelations of soil structure and SOM dynamics have not been clarified and not quitewell understood, as yet. The relationship between organic matter and aggregate stability varies widely between soils and this relationship can be affected by the method used to evaluate structural stability (Chenu et al., 2000; Han et al., 2010).Bouajila and Gallali (2008) found that organic compounds are the main binding agents of aggregate and the most important factor influencing their stability in non-calcareous soil. They revealed that aggregate stability in the soils with low $CaCO_3$ content was predominately associated with the soil organic matter. On the other hand, in calcareous soils OC did not affect aggregate stability clearly. So, the role of organic matter as a binding agent for soil aggregates and the relationship between organic matter and aggregate stability may be very different in calcareous vs. non-calcareous soils.

Although many studies on soil aggregate and aggregate organic matter dynamics have been done on calcareous soils however the study of the dynamic of aggregation and fractions of OC in soil after application of plant residue may present some useful information about the role of SOC on macroaggregate formation and stability in calcareous soils. Therefore, the objective of the present study was to examine the effect of short-term changes of AOC fractions on soil macroaggregation in a calcareous soil by means of organic matter physical fractionation.

2. MATERIALS AND METHODS

2.1. Soil and Plant Residues Physical and Chemical Analyses

A composite surface-soil (0-30 cm) was obtained from the agricultural fields in Hamadan province, in North West of Iran with semi-arid climate (annual rainfall of 300 mm; annual average temperature 13 oC). Soil sample was air dried and ground to pass a 2 mm sieve prior to analyses. Selected soil properties were determined according to standard methods. Particle-size was measured using the hydrometer method. Equivalent calcium carbonate (ECC) was measured by back titration procedure. Soil pH and electrical conductivity (EC) were measured in a 1:5 soil: water extract after shaking for 30 min. Organic carbon (OC) was analyzed by dichromate oxidation and titration with ferrous ammonium sulfate. Total nitrogen in all samples was determined by the Kjeldahl method. Cation-exchange capacity (CEC) and available K were measured by the method of sodium saturation. Available phosphorus was extracted with0.5 M NaHCO3 (pH 8.5) and determined spectrophoto metrically as blue molybdate - phosphate complexes under partial reduction with ascorbic acid. These soil characteristics were determined according to methods of soil analysis published by SSSA (Klute, 1986; Page et al., 1992)

Plant residues pH and electrical conductivity (EC) were measured in a 1:10 plant residue: water extract after shaking for 2 h. Total dissolved solid (TDS) in plant residues were measured by evaporating the 1:10 water extract of plant residues and weighting its oven dried solids (American Public Health Association., 1998). Plant residue organic carbon (POC) was analyzed by dry oxidation in electrical furnace at 570^{o}C for 2 h (Matthiessen et al., 2005). Total P was determined in acid (HCl) solution of ash of plant residues spectrophotometrically as blue molybdate-phosphate complexes under partial reduction with ascorbic acid (Peperzak et al., 1959). Total nitrogen content was determined by the Kjeldahl method.

The important physical and chemical properties of soils have been shown in Table 1. Soil sand, silt and claycontents were 48, 31 and 21 % respectively. Soil texture was moderately coarse (loam). The soil was nonsaline (EC0.12 dS m-1), calcareous (equivalent calcium carbonate 3.7 % and pH 7.9), with moderate cation exchange capacity (CEC 23.8 cmolc kg-1), organic carbon (OC 21.34 g kg-1) and total nitrogen (TN 2.11 g kg-1). Soil available P and K were relatively high (77.16 and 186µg g-1, respectively).

Table1. *Physical and chemical properties of the studied soil*

Soil property		*Soil property*	
Texture	Loam	ECC# (%)	3.70
Sand (%)	48	OC# (g kg^{-1})	21.34
Silt (%)	31	TN# (g kg^{-1})	2.11
Clay (%)	21	C/N	10.11
CEC (Cmolc kg^{-1})	23.8	Available P (µg g^{-1} soil)	77.16
pH (1:5)	7.90	Available K (µg g^{-1} soil)	186
EC (1:5) (dSm^{-1})	0.12		

 # ECC- Equivalent carbonate calcium, OC- dichromate (oxidable) organic carbon, TN- Total kjeldahl nitrogen, cfu- colony forming unit, BR- Basal respiration, SIR- Substrate induced respiration.

Plant residues had different pH, EC and TDS values (Table 2). Wheat straw had the highest pH (7.92) value. Alfalfa straw had the highest EC (9.4 dS m-1) and TDS (306.0 g kg-1) values compared to those in wheat straw and wood chips. Alfalfa straw had also the highest TN and TP contents (21.13 and 5.84 g kg-1 respectively), but the lowest OC content (507.0 21.13 g kg-1) and C/N (24.14) and C/P (86.82) ratios. The highest C/N (544) and C/P (985) ratios were obtained in wood chips.

Table2. *Chemical properties of the studied plant residues*

Property	*Alfalfa straw*	*Wheat straw*	*Wood chips*
pH (1:10)	5.80	7.92	5.40
EC (1:10) (dSm^{-1})	9.40	4.10	0.31
TDS# (g kg^{-1} residue)	306.00	52.00	24.00
SOC# (g kg^{-1} residue)	28.56	23.20	14.00
TOC# (g kg^{-1} residue)	507.00	530.50	571.32
TN# (g kg^{-1} residue)	21.13	5.60	1.05
C/N ratio	24.14	94.73	544.09
TP# (g kg^{-1} residue)	5.84	4.20	0.58
C/P ratio	86.82	126.31	985.00

[#] *TDS- Total dissolved solid, SOC- soluble dichromate (oxidable) organic carbon, TOC- total dichromate (oxidable) organic carbon, TN- Total kjeldahl nitrogen, TP- total phosphorus.*

2.2. Soil Treatment and SOM Fractionation Technique

The experiment was considered a completely randomized design as factorial in three replicates. The factors were plant residue application (mild (d<2 mm) alfalfa, wheat and wood chips residues), and incubation time (1, 20, 60 and120 days). The soil (1 kg) was treated with mild plant residues (<2 mm) at a rate of 20 g kg-1 (dry weight basis) separately. Plant residues mixed with the soil and increase soil organic matter near 2% which may be seen in farmlands in natural condition. The treated soils were uniformly wetted with a spray to a water content corresponding to the water retained at a matric potential of -300 h Pa. This potential was known to reflect field capacity (FC) for the soils considered (Oyedele and Aina, 1989). The volume required to bring each of the soils to field capacity was determined from the difference in water content of an air-dry sample and a sample drained (following saturation) to -300 h Pa matric potential. The treated and moistened soils were incubated in lab condition (20- 25 ^{o}C) in glass containers for 120 days.

After 1, 20, 60 and 120 days of incubation a portion of each soil was taken for analysis. Different sizes of aggregates were separated by soil sieving in water. Dry weight of each aggregate size was measured and organic carbon contents in each aggregate size was determined by dichromate oxidation and titration with ferrous ammonium sulfate (Walkley and Black, 1934).

The method for aggregate separation was adopted from Six et al., (2002). In this study 50 g of soil (in FC condition) was placed directly on the uppermost of a set of graduated sieves (2, 1, 0.25 and 0.053mm) and immersed in water to simulate flooding. The sieves were then oscillated (30 pulse per minutes) vertically (h=1.3 cm). At the end of the specified period of sieving (5 min) the nest of sieves was removed from the water and the oven-dry weight of material left on each sieve was determined. The results were corrected for the coarse primary particles retained on each sieve to avoid designating them falsely as aggregates. This was done by dispersing the material collected from each sieve, using a mechanical stirrer and a sodic dispersing agent, and then washing the material back through the same sieve. The weight of sand retained after the second sieving (Wsi) was then subtracted from the total weight of undispersed material retained after the first sieving (Wi), and the percentage of stable aggregates (SA %)was calculated according to the following equation: SA % =(Wi-Wsi)/Σ(Wi-Wsi) *100).

One of the indexes for assessing aggregate stability is the mean weight diameter (MWD). It was determined based on weighting the masses of aggregates of the various size classes according to their respective sizes (Cambardella and Elliott, 1994). The change of MWD of soil aggregate was also calculated according to following equation: MWD=ΣXiWi, where Xi is the mean of aggregate diameter and Wi is the mass fraction of dry soil in each diameter range.

2.3. Statistical Analyses

Statistical analysis of the data was carried out by analysis of variance computed with the ANOVA procedure from the Statistical Analysis System. The experiment was considered a completely randomized design as factorial in three replicates. The factors were plant residues (milled alfalfa, wheat and wood chips) application and incubation time (1, 20, 60 and 120 days). Data were statistically analyzed for standard deviation, means were calculated, and Duncan’s new multiple range tests were performed to assess the effect of plant residues application and incubation on the organic carbon contents in stable aggregates (AG-OC), percentage of stable aggregates (SA %) and the mean weight diameter of stable aggregates (MWD).

3. Results and Discussion

The effects of the plant residue, incubation time and their interaction on the percentage of water-stable aggregates infractions bigger than 2 mm, betweens 1-2 mm, 0.25-1 mm and 0.053-0.25 mm were significant at 0.01 levels (Table 3). However, the effect of incubation time on the percentage of stable aggregates of 1-2 mm fraction was statistically significant at 0.05 levels. Analysis of variance of the effects of type of plant residue and incubation time on the organic carbon (OC) contents of soil aggregates in each fraction showed that, OC in macroaggregates (>2 mm) was more susceptible than that in micro aggregates.

Table3. *Analysis of variance of the effects of incubation time (IT), type of plant residue (PR) and their interaction on the percentage of stable aggregates (SA %) in different size fractions and their organic carbon (OC %) contents in a calcareous soil.*

Source	*DF*	*>2mm*	*1-2 mm*	*0.25-1 mm*	*0.053-0.25 mm*
Mean squares in SA analysis					
IT	3	995.234**	11.946*	155.602**	473.499**
PR	3	1447.626**	46.750**	1204.397**	276.860**
IT*PR	9	124.204**	110.085**	89.616**	37.138**
Error	32	2.560	3.107	4.780	3.502
Mean squares in OC analysis					
IT	3	19.654**	0.243**	0.021ns	0.024*
PR	3	7.397**	0.605**	0.061**	0.178**
IT*PR	9	0.547**	0.081**	0.009ns	0.021**
Error	32	0.005	0.011	0.011	0.007

** Mean square (MS) of the treatment is significant at the 0.05 level. ** Mean square of the treatment is significant at the 0.01 level. ns Mean square of the treatment is not significant*

The effects of type of plant residue, incubation time and their interaction on the OC contents of aggregates bigger than 2 mm and 1-2 mm size fraction were significant at 0.01 levels. The effect of incubation time on OC content of0.25-1 fraction was not statistically significant. This effect on OC content of 0.053-0.25 mm fraction was significant at 0.05levels. The effect of type of plant residue on the OC content of soil aggregates in all fractions was statistically significant ($p<0.01$).

Table4. *Duncan's new multiple range tests of means of the percentage of water-stable aggregates (SA %) in different size fractions and their organic carbon (OC %) contents in a calcareous soil as affected by incubation time.*

Incubation time (days)	*>2mm*		*1-2 mm*		*0.25-1 mm*		*0.053-0.25 mm*	
	Mean	SD	mean	SD	mean	SD	Mean	SD
	SA							
1	8.11 d	4.13	25.14 ab	6.45	41.01 a	13.52	25.74 a	5.30
20	29.89 a	16.95	24.61 ab	6.93	33.04 c	8.36	12.46 c	5.68
60	20.82 c	8.91	26.13 a	3.75	38.29 b	5.47	14.76 b	6.00
120	23.16 b	10.97	23.75 b	2.87	40.29 a	11.54	12.80 c	4.44
	OC							
1	4.19 a	1.25	0.97 c	0.21	0.91 a	0.10	0.84 b	0.00
20	2.16 b	0.68	0.97 c	0.25	0.95 a	0.15	0.95 a	0.21
60	1.51 c	0.49	1.27 a	0.31	0.86 a	0.11	0.88 ab	0.16
120	1.47 c	0.46	1.08 b	0.25	0.87 a	0.09	0.89 ab	0.13

** Means followed by the same letter in each column are not significantly different ($P < 0.05$).*

The test of means of the percentage of water-stable aggregates (SA %) in different size fractions showed that the percentages of SA in >2mm fraction fluctuated significantly in alfalfa and wheat straws treatments during soil incubation (Table 4). The percentage of stable aggregates in >2mm fraction in the alfalfa treated soil increased from 11.9 % at first day to 45.6 % at twentieth day of soil incubation. After that it decreased to 25.6 % in 60 days of incubation and increased to 32.0 % at the end of soil incubation. These increases and decreases of the percentage of SA in >2 mm fraction were statistically significant ($p<0.05$). The change of the percentage of water-stable aggregates in wheat straw treated soil was similar to that of in the alfalfa treated soil. These changes strongly depend on soil biological activity. Six et al. (2004) suggest that during plant residue decomposition, microorganisms bind organic and mineral particles through mechanical connection by the fungus hyphae, and adhesion gluing by extracellular polysaccharides and mucilage secretions produced by the tipof the root of the plant and the soil bacteria (Six et al., 2004). The relationship of the fast formation and the disappearance of macroaggregates (> 2 mm) and soil organic residue has been shown in laboratory incubation (Bossuyt et al., 2001). Macroaggregates have their own life cycles (Denef et al, 2001; Han et al., 2010), repeating formation-breakdown, depending on biological activity and fresh plant residue inputs (Bidisha, 2010). In the present study the highest percentage of water-stable macroaggregates was obtained in the alfalfa and wheat straws treated soils. It was near 45 %. The time for the formation of macroaggregates in alfalfa and wheat straws treated soils was near 20 days. The mean residence time of macroaggregates has been estimated to average 27 days with estimates as low as 5 days (Planteet al., 2002). The changes of different chemical and biological fractions of OC during the soil incubation and their correlations were studied (Safari Sinegani and Afzalpour, 2014). This study revealed that the soil microbial biomass carbon (MBC) had high dependence and coherence with fulvic acid carbon, cold water (CW) and hot water (HW) extractable OC in the soil treated with plant residues. The highest fulvic acid carbon, MBC, CW and HW extractable OC was measured in 20th day of soil incubation, the highest percentage of water-stable macroaggregates was obtained, as in the present study.

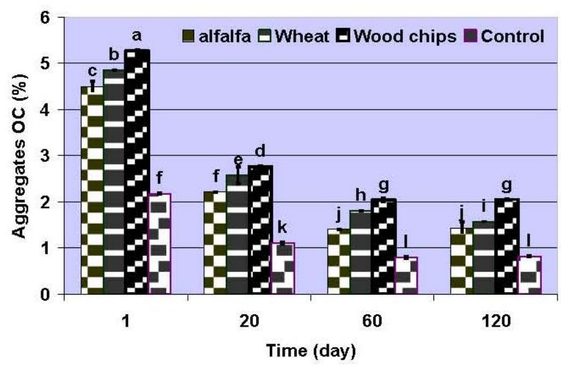
The percentage of water-stable aggregates in >2 mm fraction in the soil treated with wood chips increased continuously during soil incubation. This finding may be related to the gradual increase of microbial activity in the6soil treated with wood chips.

The percentage of stable aggregates in 1-2 mm fraction changed markedly in the soils treated with plant residues during soil incubation. The highest percentage of this aggregate size fraction (32.1 %) was obtained in control after 20days of soil incubation. It was also relatively high in the soil treated with alfalfa straw (29.8 %) at first day of soil incubation. The percentage of stable aggregates in 1-2 mm fraction decreased at twentieth day and increased at sixtieth day in the soils treated with alfalfa and wheat straws. The increase of the percentage of stable aggregates in 1-2mm fraction at sixtieth day in the soil treated with wheat straw was statistically significantly high. The percentages of stable aggregates in 0.25-1 mm fraction fluctuated significantly in the alfalfa and wheat straws treatments during soil incubation. The percentage of stable aggregates in 0.25-1 mm fraction in the alfalfa treated soil decreased from 34.5 % at first day to 21.8 % at twentieth day of soil incubation. After that it increased to 36.4 % at sixtieth day of soil incubation and decreased to 35.1 % at the end of soil incubation. The fluctuations of the percentage of water-stable aggregates in 0.25-1 mm fraction may be interrelated to the changes of the percentage of water-stable aggregates in >2 mm fraction. The change of the percentage of this size fraction of water-stable aggregates in the wheat straw treated soil was similar to that of alfalfa treated soil. In contrast, the percentage of water-stable aggregates in 0.25-1 mm fraction in the soil treated with wood chips decreased continuously during soil incubation. This finding may be related to the gradual increase of microbial activity in the soil treated with wood chips (high C/N ratio) and formation new macroaggregates. In this study the highest percentage of water-stable aggregates in 0.25-1 mm fraction was obtained in the control soil.

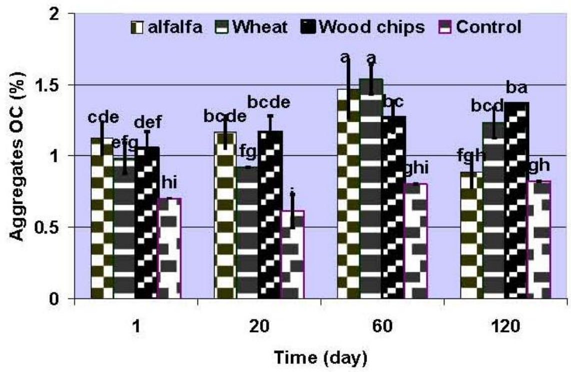
The percentage of stable aggregates in 0.053-0.25 mm fraction decreased significantly from 23.8 % at first day to6.6 % at twentieth day in the soil treated with alfalfa straw. After that it did not changed significantly. This result was also obtained in the soil treated with wheat straw. In all treatments the highest percentage of stable aggregates in0.053-0.25 mm fraction was measured at first day of soil incubation and the lowest was observed at twentieth day of soil incubation. It may be concluded that the significant increase of macroaggregates at twentieth day of soil incubation may be a result of soil microbial activity in enlargement and/or attachment of microaggregates. This finding needs to be more fully studied.

The present study showed that the effect of the type of plant residue on the percentage of stable aggregates indifferent size fractions in a calcareous soil was significantly different. The addition of alfalfa straw (with low C/N ratio and high quality for microbial activity) during 120 days of soil incubation increased the percentages of macroaggregates and decreased the percentages of microaggregates in soil compared to untreated soils. The addition of wheat straw to soil also increased the percentage of stable aggregates in >2 mm fraction significantly compared to those measured in untreated soils. However the positive effect of wood chips (with high C/N ratio and low quality for microbial activity) on the percentage of stable aggregate in >2 mm fraction was lower than that of alfalfa and wheat straw. These findings may be related to a higher microbial activity in soils treated with higher quality plant residues. The test of means of the OC contents of water-stable aggregates in different size fractions during soil incubation has been reported in Fig. 1. The OC content of aggregate size fraction bigger than 2 mm decreased significantly and continuously during the soil incubation. Soil treatment with plant residues increased OC content of soil aggregates differently. The increase of OC content of stable aggregates bigger than 2 mm was significantly high in all treatments compared to that in control. The positive effect of plant residues on this SOC fraction was statistically significantly different ($p<0.05$). It was in the order of wood chips>wheat straw>alfalfa straw may be related to their C/N and C/P ratios. Plant residues with higher C/N and C/P increased this fraction of

SOC significantly. However, this effect was milder on OC contents of smaller aggregate fractions. The OC content of stable aggregates in 1-2 mm fraction increased during 60 days of soil incubation (Fig 1). The highest OC content was measured in the soils treated with alfalfa and wheat straws at sixtieth day of incubation. This increase may be related to splitting and breakdown of larger aggregates with higher OC content. After that it decreased especially in the soil treated with alfalfa. The OC content of stable aggregates in 1-2 mm fraction increased in the soil treated with wood chips during 120 days of soil incubation continuously.



(A)



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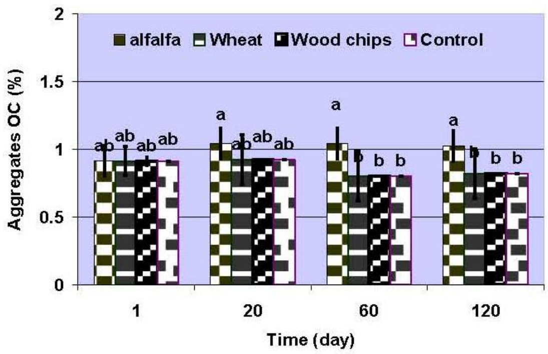

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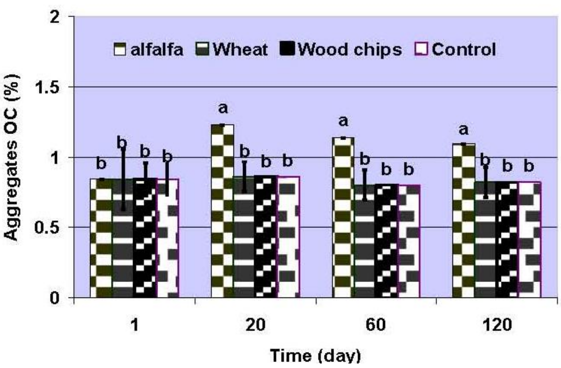

(D)

Fig1. *Changes of organic carbon contents of stable aggregates in different fractions (A > 2mm, B between 1-2 mm, C between 0.25-1 mm and D between 0.053-0.25 mm) of a calcareous soil treated with different plant residues and incubated in field capacity condition for 120 days.*

The OC content of the water-stable aggregates in 0.25-1 mm fraction did not change significantly during the 120 days of soil incubation. The OC content of stable aggregates in 0.25-1 mm fraction increased in the soil treated with alfalfa straw at twentieth day of soil incubation. The OC content of stable aggregates in 0.25-1 mm fraction in the soil treated with alfalfa straw was significantly higher than those in soils treated with wheat straw and wood chips at sixtieth day and at the end of soil incubation. The addition of wheat straw and wood chips had no significant effect on the OC content of stable aggregates in053-0.25 mm fraction during 120 days of soil incubation. Likewise the means of OC content of stable aggregates in0.053-0.25 mm fraction did not increased in the soil treated with alfalfa straw at first day of soil incubation. The OC content of stable aggregates in 053-0.25 mm fraction increased significantly in the alfalfa treated soil after 20 days of soil incubation. It may be related to newly formed organic carbon by soil microorganisms.

This section of study supported the previous findings. The addition of plant residues with higher C/N ratio to soil only had significant effect on OC content of macroaggregates. The water-stable macroaggregates especially the fraction bigger than 2 mm were richer in carbon than the microaggregates. This enrichment in carbon can be attributed exclusively to the young carbon fraction of plant residues, whereas the old carbon fraction remained constant among smaller aggregates. The addition of alfalfa straw to the soil could increase the OC contents of microaggregates during 120 days of soil incubation. The quality alfalfa for microbial degradation is high due to its low C/N and C/P ratios. It might be degraded to humic substances to react with clays to make new microaggregates in the soil with higher OC contents. The splant-derived POM plays an important role in the formation of microaggregates (Gale et al., 2000; Puget and Drinkwater, 2001) and that microaggregate formation is crucial for the storage and stabilization of soil C in the long term (Gale et al., 2000).

The water-stable macroaggregates especially the fraction bigger than 2 mm were richer in organic carbon than the microaggregates. The more important was the diameter of water-stable aggregates. Aggregates with diameter higher than 1 mm which had considerably higher carbon contents. This enrichment in carbon can be attributed exclusively to the young carbon fraction of plant residues, whereas the old carbon fraction remained constant among smaller aggregates. The results of this work showed that SOM with different location in the soil structure had different dynamics. In the calcareous soils studied water stable macroaggregation can be attributed to the young SOM. In the hierarchical concept of soil structure, developed by Tisdall&Oades (1982) and Odes & Waters (1991), the additional SOM defined as transient pool and responsible of aggregation of microaggregates into macroaggregate is constituted by 60 to 80 % of young or C4-derived carbon and by 60 to 70 % of POM carbon. Golchin et al., (1994) proposed that when fresh plant residues enter the soil, they induce the formation of Aggregates, because they stimulate the production of microbial-derived binding agents by increasing microbial activity. During decomposition, plant material fragments or particulate organic matter (POM) gradually become encrusted with clay particles and microbial products to form the core of stable microaggregates. Microbial mucilages and metabolites further impregnate the mineral crust surrounding the still decomposing organic cores to form very stable microaggregates. Eventually, the organic cores are depleted of available SOM resulting in a cessation of microbialactivity and production of mucilages. The halting of production of binding agents and the use of them as substrate leads to a loss of stability of the microaggregates. Upon breakdown of the microaggregates, the mineral crusts impregnated with microbial byproducts are released to form stable silt-sized organo-mineral complexes.

The calculated mean weight diameter (MWD) of soil aggregates increased during 120 days of soil incubation at FC (Fig. 2). Aggregates MWD of the soils treated with alfalfa and wheat straws increased at twentieth day of soil incubation. It decreased after 20 days of soil incubation and reached its nearly constant values at sixtieth day of soil incubation. Aggregates MWD of the soils treated with wood chips increased during 120 days of soil incubation regularly. Aggregates MWD of the soil untreated with plant residue also increased at twentieth day of soil incubation. After that aggregates MWD of the soil untreated with plant residue decreased gradually. These fluctuations may be due to changes in soil OC and microbial activity. The particulate organic matter (POM) of plant residues (i.e. mainly fresh and coarse POM) is first located outside of aggregates and is rapidly colonised by microorganisms when incorporated into the soil matrix. POM and microbial by-products would correspond to the additional SOM or transient pool responsible for aggregate stability. Stable macroaggregates would be small volumes of the soil where enough young POM has been incorporated with soil matrix, as occurred in wood chips application. In the case of application of alfalfa and wheat straws, the proportion of POM in aggregation is more important, and leads to a greater percentage of water-stable aggregates and MWD in the soil.

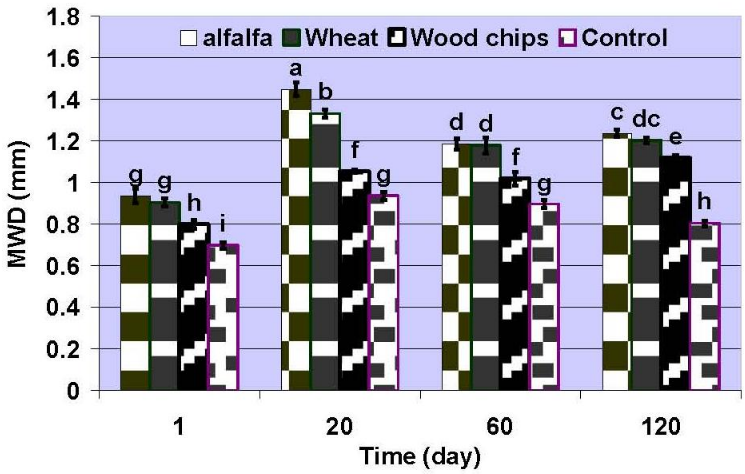

Fig2. *Changes in the mean weight diameter of aggregates in a calcareous soil treated with different plant residues and incubated in field capacity condition for 120 days.*

Aggregates are formed around POM. However as the decomposition proceeds, the size of POM decreases, the microbial activity and the production of biopolymers with aggregating activity also decreases and eventually the stability of the macroaggregates declines (Golchin, et al., 1994).The OC content of stable aggregates in 0.25-1 mm and 0.053-0.25 mm fractions decreased with time in untreated soil and treated soils with wheat straw and wood chips during 120 days of soil incubation gradually (Fig. 1). However they were increased markedly in soils treated with alfalfa straw, may be due to its higher microbial activity and humification. The humic matter, considered as a persistent cementing agent, is involved in stabilizing microaggregates (Bongiovanni and Lobartini, 2006).In our study the percentage of water-stable aggregate in >2mm fraction changed, same as aggregates MWD in the soil treated with plant residues. The study of Pearson correlation coefficients between aggregates MWD and the percentage of water-stable aggregate in each fractions showed that only the correlation coefficient between aggregates MWD and the percentage of water-stable aggregates in >2mm fraction was positive and strongly statistically significant (Table 5).

Table5. *Duncan's new multiple range tests of means of percentage of stable aggregates (SA %) in different size fractions and their organic carbon (OC %) contents in a calcareous soil as affected by type of plant residue.*

Type of plant residue	*>2mm*		*1-2 mm*		*0.25-1 mm*		*0.053-0.25 mm*	
	Mean	SD	mean	SD	mean	SD	Mean	SD
	SA							
Control	5.67 c	2.14	24.21 b	7.46	53.08 a	8.56	17.05 b	2.22
Alfalfa	28.78 a	12.71	27.22 a	2.66	31.95 c	6.25	12.04 d	7.29
Wheat	28.86 a	12.33	22.59 c	5.43	34.81 b	2.74	13.74 c	8.42
Wood chips	18.67 b	7.89	25.61 b	3.20	32.79 c	3.13	22.94 a	6.39
	OC							
Control	1.23 d	0.59	0.73 b	0.11	0.86 b	0.11	0.83 b	0.05
Alfalfa	2.39 c	1.32	1.16 a	0.24	1.01 a	0.09	1.07 a	0.19
Wheat	2.70 b	1.35	1.17 a	0.26	0.86 b	0.11	0.83 b	0.05
Wood chips	3.03 a	1.38	1.21 a	0.17	0.86 b	0.11	0.83 b	0.05

** Means followed by the same letter in each column are not significantly different ($P < 0.05$).*

The correlation coefficient between aggregates MWD and the percentage of water-stable aggregate in 1-2 mm fraction was not statistically significant. However, the correlation coefficients between aggregates MWD and the percentages of small water-stable aggregates (in 0.25-1 mm and 0.053-0.25 mm fractions) were negative and strongly significant. The correlation coefficients between the percentage of water-stable macroaggregates (2>mm) and aggregates in0.25-1 mm and 0.053-0.25 mm fractions were also negative and strongly significant. This negative correlation maybe related to the formation of new macroaggregates from microaggregates (Six et al., 2004) and/or to the formation of new microaggregates within macroaggregates (Jastrow, 1996).

4. CONCLUSION

The results showed that plant residues with different quality had different dynamics and effects on the soil aggregation.

- Water stable macroaggregation can be attributed to the young POM from plant residues and bacterial mucilage especially those with higher quality (like alfalfa and wheat straws). It depends strongly to the active soil carbons and biological activities in the calcareous soil treated with plant residue.
- Macroaggregates had considerably high active OC content in initial days of soil incubation, decreasing in the soil treated with plant residue. The content of OC in stable aggregates in >2 mm fraction decreased with time significantly and gradually in all of the treated soil.
- The aggregate MWD and the percentage of stable aggregates in >2 mm fraction increased gradually in the soil treated with wood chips during 120 days of soil incubation. Conversely in the soil treated with alfalfa and wheat residues after an initial increase (in 20 days), it decrease continuously with decrease of soil active carbons and biological activities.
- The addition of wheat straw and wood chips did not change OC content of stable aggregates in 0.25-1 and0.053-0.25 fractions. But the addition of alfalfa straw increased OC content of stable aggregates in 0.25-1 and0.053-0.25 fractions in the soil significantly.
- These findings show that aggregation and AOC dynamics are strongly interrelated in the calcareous soil studied.

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