Asian Journal of Chemistry Vol. 18, No. 2 (2006), 1500–1508

Organic and Microbial Biomass Carbon Contents of Aggregates in a Toposequence of Pasture Soils

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The objective of this study was to determine changes in microbial biomass carbon (C_{mic}) and organic carbon (C_{org}) of soil aggregates along a pasture slope. Soil samples from 0–50 mm depth were taken from three landscape positions (shoulder, backslope and footslope) of a pasture in Samsun, Turkey. For each landscape position, soil aggregates were separated into eight aggregate size classes using a dry sieving method and then C_{org} was analyzed. At all positions, macroaggregates (especially 841–1190 and 1190–1680 μm in sizes) were higher than microaggregates. The contents of C_{org} varied between 0.65 and 2.08%. The highest C_{org} contents were found in footslope position and the lowest contents in backslope. All properties are higher at footslope position than the other positions. Generally, C_{mic} was greater in microaggregates of < 250 μm, in macroaggregates of 250–420, 420–841, 841–1190 μm than in the other aggregate size at all positions, whereas $C_{org} : C_{mic}$ was higher in macroaggregates of 1190–1680, 1680–2380, 2380–4760 μm than the other macro and microaggregate size. Consequently, in macroaggregates especially this class is relatively more C_{org} than the microaggregates, even if the absolute values of C_{mic} were lower.

Key Words: Pasture soil, Soil aggregates, Microbial biomass carbon, Organic carbon, Landscape position.

INTRODUCTION

Soil aggregates are one component of soil structure and are important for maintaining soil porosity and aeration, favorable for plant and microbial growth, infiltration of water, and stability against erosion[1, 2]. Boehm and Anderson[3] have demonstrated that aggregate size and stability can indicate change in soil quality as a result of soil management. Aggregate formation and stabilization are affected by several factors, including organic materials, clay content, iron- and aluminum oxides, and microbiological activity[4, 5]. Also, it is well known that the soil organic matter is one of the most relevant factors to improve soil structure[4, 6].

The effects of topography on aggregate size distribution have been known for a long time. The relationships between aggregation and landscape position may be affected from soil organic matter in pasture soils. Earlier many researchers

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were interested in microbial biomass (C_{mic}) and organic carbon content for monitoring and evaluating microbiological properties of soil aggregates[7–10].

Generally, pasture areas have relatively a single management history in Turkey. Grazing is generally considered to be the most economic way of utilizing rangeland vegetation. But, overgrazing or uncontrolled grazing always reduces plant cover that protects the soil and generally results in soil erosion and compaction. Soil erosion which is a serious problem in many countries removes over 500 million tons of productive soil and large amounts of plant nutrients every year in Turkey[11]. Soil properties and vegetation can also be altered over time under different land management systems. Turkey's grazing lands are subject to quite heavy, uncontrolled grazing pressure and the forage production capacities of these lands are gradually decreasing, reflecting typical examples of land degradation all over Turkey[11, 12]. In the same way, pasture areas faced degradation problems in the research area.

In this study, some soil characteristics such as microbial biomass and organic carbon in different sizes of aggregates gathered from pasture soils has been measured in order to investigate the relationships between soil properties and aggregation depending on landscape positions. The objectives of the present study were (i) to characterize aggregates of pasture by aggregate size distribution and organic carbon content, (ii) to observe some properties of aggregates at shoulder, backslope and footslope positions in pasture soils.

EXPERIMENTAL

The study area is located in the Black Sea Region, Northern part of Turkey (latitude, 41°21′N; longitude, 36°15′W). The sampling area has the typical Black Sea climate (sub-humid, $R_f = 47.21$). Average monthly temperature (1974–2001) varies from 6.6°C (February) to 23°C (August). The annual precipitation is 670.4 mm[13, 14]. The annual average temperature was 15.6°C and the precipitation was 648.6 mm in sampling year. The study area was defined as pasture of Kalkanca that has relatively homogeneous vegetation. Native vegetation in the pasture of Kalkanca was dominated by the grasses *Bellis perennis* L., *Circium arvense* L., *Bromus squarrosus* L., *Trifolium resupinatum*, *Medicago hispida* Gaertn., *Medicago arabica* L., *Medicago scutellata* L.

Soil sampling

Soil sampling was done in May 2001, soil samples, *ca.* 500 g weight, were taken from 50 mm soil in depth by means of a sterile soil corer. The corer was sterilized with 95% ethanol before each use. Soil samples were taken from different landscape positions throughout the slope: shoulder, backslope and footslope, in Kalkanca pasture soils (Fig. 1). Thirty soil samples were randomly collected from each landscape position in order to make three composite samples (each sample composed from ten replicates). The samples were transported to the laboratory on the same day. The soil samples were crumbled gently by hand and sieved (< 8 mm openings) without root material. The soil aggregates were separated from these samples. These samples were used to determine physical (separation of aggregates) and chemical (organic C) properties of soils. Also each sample was stored in polyethylene bags at 4°C in the refrigerator for no longer than 72 h prior to analysis. These samples were used to determine C_{mic} of soils at the field moisture condition.

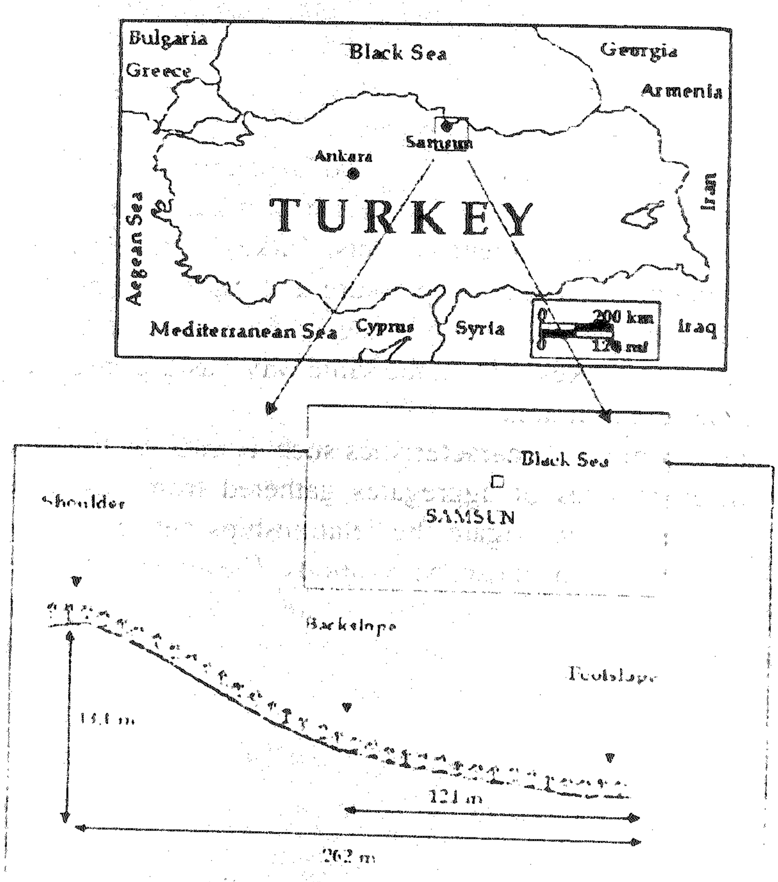

Fig. 1. Location map of the Kalkanca, Samsun and study area

Soil properties

Soil's physical and chemical properties were determined by means of appropriate methods: texture by hydrometer method[15], pH and electrical conductivity (EC) in 1 : 2.5 (w/v) in soil : water suspension by pH-meter and EC-meter[16]. The soil organic carbon content was measured by a modified Walkley-Black method[17].

Separation of aggregates

The initial aggregate size distribution was determined by sieving 5 kg soil for 2 min on a stack of sieves with openings 4.76, 2.38, 1.68, 1.19, 0.841, 0.42 and 0.25 mm, from the top to the bottom of stack, using an automatic sieve shaker (speed and time of shaker were same) manufactured ELE international. Each size fraction was weighed. Eight size classes were obtained: (I) > 4760 μm, (II) 4760–2380 μm, (III) 2380–1680 μm, (IV) 1680–1190 μm, (V) 1190–841 μm, (VI) 841–420 μm, (VII) 420–250 μm and (VIII) < 250 μm, indicated by Nearing[18] (1995). Weighed size fractions were regrouped into 2 main size classes: macroaggregates (> 250 μm) and microaggregates (< 250 μm) according to the indicated by Tisdall and Oades[6].

Microbial biomass carbon (C_{mic})

Microbial biomass carbon was determined according to the substrate-induced respiration method[19]. A field moist soil sample equivalent to 50 g oven-dry soil (stored at 22°C for 1 week) was amended with a powder mixture containing 150 mg glucose and 500 mg talcum. The CO_2 evolution rate was measured hourly using the method described by Anderson[20]. Microbial biomass carbon (C_{mic}) was calculated from the maximum initial respiratory response in terms of mg C g^{-1} soil as 40.04 mg CO_2 g^{-1} + 3.75. Data are expressed as μg microbial C g^{-1} dry soil.

Statistical analysis

The variance analysis (ANOVA) was mainly carried out using two factors to randomized complete block design (slope × aggregate size distribution). Least significant difference (LSD) test and correlation analysis were performed in order to determine the differences and association among variables using the Statistical Package for Social Science (SPSS 10.0) program. The asterisks, ** and *** indicate significance at $P < 0.01$ and $P < 0.001$, respectively.

RESULTS AND DISCUSSION

Soil properties

Some soil properties are presented in Table-1.

TABLE-1
SELECTED PHYSICAL AND CHEMICAL PROPERTIES OF THE SOIL AT LANDSCAPE POSITIONS

Soil property	Landscape position		
	Shoulder	Backslope	Footslope
Sand, (%)	74.57 ± 1.64	77.54 ± 1.31	61.02 ± 1.72
Silt, (%)	11.42 ± 0.81	8.79 ± 0.97	15.06 ± 0.86
Clay, (%)	14.01 ± 0.59	13.67 ± 1.94	23.92 ± 1.47
Texture class	Sandy loam	Sandy loam	Sandy clay loam
pH (dH_2O)	6.83 ± 0.09	6.75 ± 0.06	6.90 ± 0.11
Organic carbon, (%)	1.16 ± 0.04	1.25 ± 0.04	1.72 ± 0.07
Electrical conductivity, (dS m^{-1})	0.143 ± 0.004	0.138 ± 0.003	0.145 ± 0.006

The pasture soils were moderately low in total organic carbon content (C_{org}), low in electrical conductivity (< 0.98 dS m^{-1}), non-saline and neutral in soil reaction (pH 6.7–7.3). Soils can be classified as sandy loam and sandy clay loam according to its texture. The soils had the lowest clay content at the backslope position. In footslope position, the soils had generally the higher clay and silt contents than the other positions. Similarly, organic carbon content was the highest at footslope position. This means, clay particles and organic matter might be lost by erosion which occurred at more severe rates on the shoulder and backslope landscape positions (Table-1).

Aggregate size distribution

Based on all positions, aggregate size was confined to two major classes 841–1190 and 1190–1680 μm which represent 41% in all size classes of the soil aggregates (Fig. 2). The proportion of macroaggregates was the highest at the f[illegible]ope position (1190 to 1680, 1680 to 2380 and > 4760 μm size classes) ([illegible].01). But the smallest aggregate sizes (< 250 and 250–420 μm) were found the highest in the backslope position.

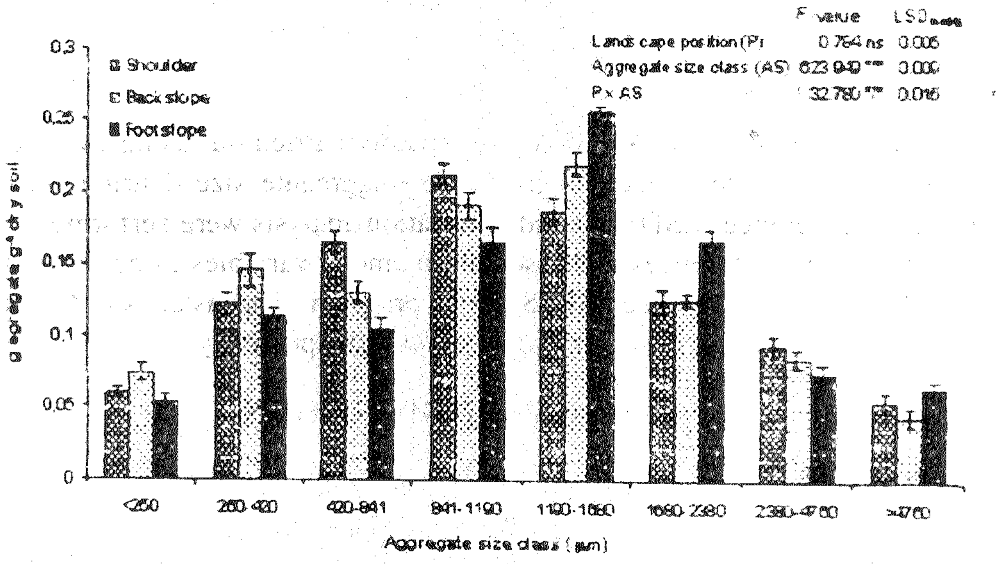

Fig. 2. Distribution of soil aggregates by landscape position (Vertical bars indicate standard error of mean of three replicates at 95% confidence level)

Organic carbon (C_{org}) distribution

Organic carbon (C_{org}) content changed depending on aggregate sizes and landscape positions along the slope (Fig. 3).

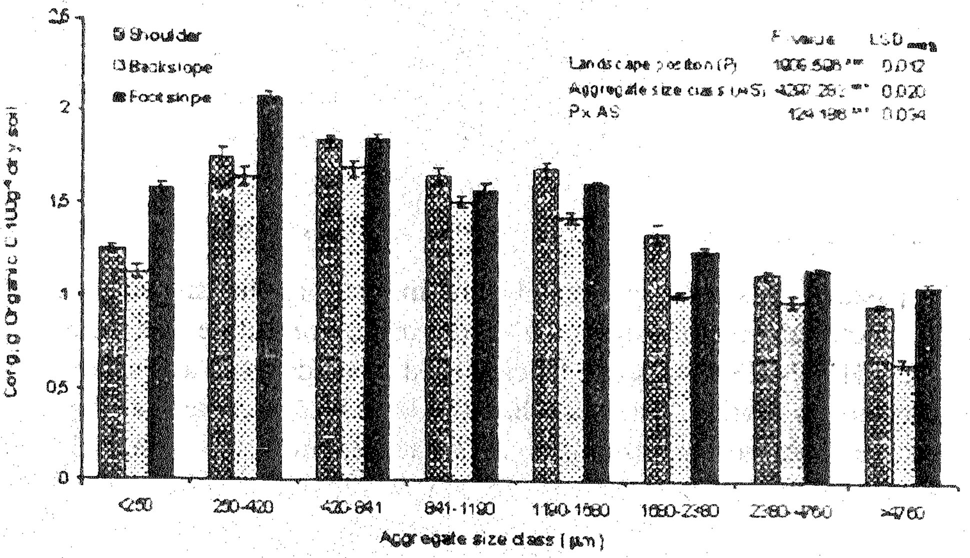

Fig. 3. Organic carbon (C_{org}) distribution in soil aggregates by landscape position (Vertical bars indicate standard error of mean of three replicates at 95% confidence level)

In the backslope position, the organic carbon contents of aggregate position were less than the other positions ($p < 0.01$). In addition, the C_{org} contents decreased with slope (except those lower than 250 μm size class).

Microbial biomass carbon (C_{mic})

In the shoulder position, C_{mic} ranged from 322.7–763.7 μg C g^{-1} dry soil in all sizes of aggregates (mean 543.6) (Fig. 4).

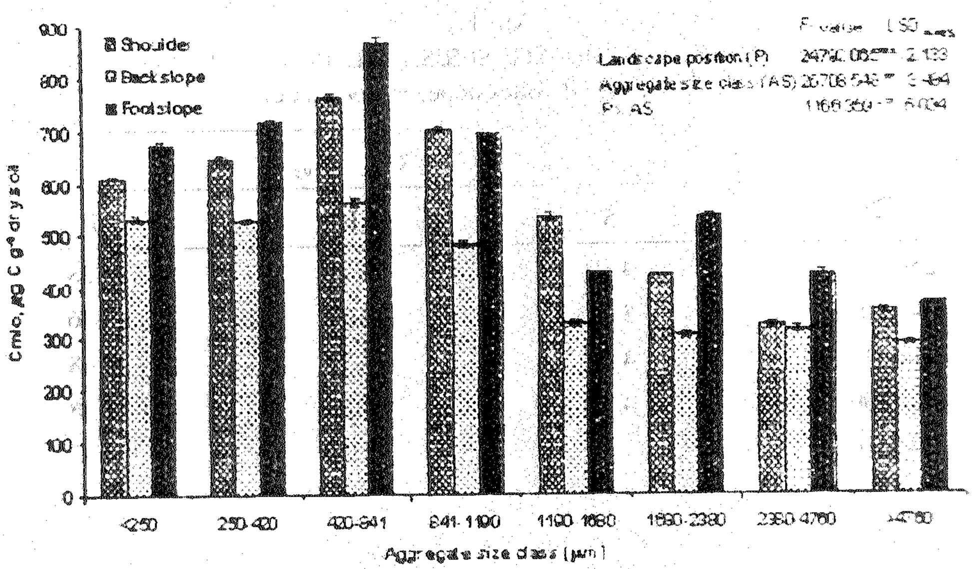

Fig. 4. Microbial biomass carbon (C_{mic}) in soil aggregates by landscape position (Vertical bars indicate standard error of mean of three replicates at 95% confidence level)

In the backslope position, values ranged from 285.0–562.0 μg C g^{-1} dry soil in all sizes of aggregates (mean 416.8). In the footslope position, values ranged from 362.0–868.7 μg C g^{-1} dry soil in all sizes of aggregates (mean value 586.8) (Fig. 4). On the average, it was the lowest in backslope whereas the highest in footslope position ($P < 0.01$).

Microbial biomass C: Organic C ($C_{mic} : C_{org}$)

$C_{mic} : C_{org}$ ratios of soil aggregate values in soil aggregate sizes by landscape position are given Table-2.

Consequently, in macroaggregates (especially the three major classes of 1190–1680, 1680–2380 and 2380–4760 μm) have relatively more C_{org} content than the microaggregates, even if the absolute values of C_{mic} resemble with microaggregates. The $C_{mic} : C_{org}$ ratio reflects the physiological level of a soil ecosystem and appears to be a much more sensitive indicator for soil quality than either C_{org} or C_{mic} alone[21]. According to Anderson and Domsch[22] the microbial communities are more efficient with an increasing $C_{mic} : C_{org}$ ratio.

At all positions, macroaggregates (> 250 μm), especially two major classes 841–1190 and 1190–1680 μm, were higher than microaggregates (< 250 μm) in pasture soils (Fig. 2). Macroaggregates form readily under pasture or forage grasses (dense, fibrous root mass). Macroaggregates are more sensitive to changes in management than microaggregates and, thus, are considered a better indicator for changes in soil quality. Macroaggregate stability depends on management because of the transient nature of the binding agents[23]. Tisdall and Oades[6] formulated an aggregate hierarchy theory. It explains a gradual breakdown of macroaggregates into microaggregates, preceding complete dissociation into primary particles. Another consequence of this principle is the fact of the younger and the more labile organic matter is contained in macroaggregates than in microaggregates.

TABLE-2

C_{MIC} : C_{ORG} IN SOIL AGGREGATE SIZES BY LANDSCAPE POSITION

(S, Shoulder; B, Backslope; F, Footslope)

Aggregates (µm)	C_{mic} : C_{org}		
	S	B	F
< 250	4.89	4.71	4.28
250–420	3.71	3.22	3.46
420–841	4.17	3.33	4.68
841–1190	4.25	3.19	4.38
1190–1680	3.16	2.28	2.65
1680–2380	3.12	2.98	4.25
2380–4760	2.87	3.21	3.66
> 4760	3.62	4.37	3.39

	F-value	LSD$_{\alpha = 1\%}$
Landscape position (P)	776.952***	0.030
Aggregate size class (AS)	1998.672***	0.050
P × AS	489.747***	0.086

In general, the C_{org} level increased with increasing aggregate size ($P < 0.01$), reaching a maximun in the > 250 µm at all positions (Fig. 3). Similar observations have been reported by Tisdall and Oades[6], suggesting the presence of partially decomposed roots and hyphae within macroaggregates increasing the C concentrations and contributing to aggregate formation. The high C_{org} content of the > 250 µm soil fraction can be explained by the no-till in this area. The relatively high C_{org} concentration in the > 250 µm fraction as compared with the microaggregates suggests a large amount of fresh and partially decomposed organic matter[24]. In aggrement with this, Elliott[25] found in a temperate grassland soil that organic matter associated with macroaggregates was more labile than organic matter in microaggregates. Similar results have been reported by Puget *et al.*[26] and Oades *et al.*[27] Organic carbon content of aggregates in the backslope position was less than the other positions ($p < 0.01$) by the lower clay content. In addition, C_{org} contents of aggregates (except at lower than 250 µm) decreased depending on the slope. Walker *et al.*[28] reported that backslope soils were the most affected by erosion and footslope soils showed a higher clay and organic matter content. Because of low in soluble salt contents (EC) and the absence of free carbonates, it was assumed that free $CaCO_3$ content and EC might affect the C_{org} content of aggregates.

Generally, C_{mic} concentrations were greater in microaggregates. In addition, it is possible to state that soil properties are the greater in all aggregates at footslope position than the other positions (Figs. 2–4).

The total C_{org} per cent presented as C_{mic} in a soil over long-term treatment was through to represent C equilibrium in the soil[22]. Insam *et al.*[29] proposed the relations between C_{mic} and C_{org} in a soil that might serve as quantitative indicators for carbon dynamics. At all positions, the C_{mic} percentage of total C_{org} in the macroaggregate was relatively consistent, suggesting near C equilibrium status and aggregation. However, a consistent trend was not found among macroaggregates suggesting that aggregation still may be affected by microbial biomass. Except for large macroaggregate (> 4760 μm), the percentage of total C_{org} presented as C_{mic} increased with increasing aggregate size at the shoulder position. On the contrary, the higher $C_{mic} : C_{org}$ ratios were in the 1190–1680 μm size class than the other macroaggregates at the backslope and footslope positions. This situation may be welded water erosion and differences of organic carbon deposition in the footslope position. Although no universal equilibrium constant was found after surveying 129 permanent monoculture plots, Anderson and Domsch[22] showed that the average percentage of C_{mic} in C_{org} was about 2.3% in 34 soils under long-term continuous monoculture with inorganic fertilizer treatment and 2.57% in 15 soils with straw or farmyard manure treatments. The percentages obtained from the present study were generally higher than reported by Anderson and Domsch[22]. These differences should welded soil management, vegetation cover or sampling time.

Conclusion

The results indicate that the aggregate size distribution and microbiological properties of aggregates along a hillslope had great differences in the pasture depending homogeneous vegetation. The footslope position has greater clay and C_{org} contents compared to the other positions, because the higher levels in the fine particles and C_{org} content clearly show erosional deposits at the footslope and denudation of shoulder. The highest coarse particles in backslope position denote increasing the intense selective fine particles compared to the other positions.

The soil aggregates, macroaggregates (especially two major classes 841–1190 μm and 1190–1680 μm size class) were higher than microaggregates at all landscape positions. Generally the moderate macroaggregates have greater C_{mic} properties and C_{org} content. Especially three major classes: 1190–1680, 1680–2380 and 2380–4760 μm, consumed relatively the lower C_{org} than the microaggregates.

This study demonstrated that changes of aggregate size distribution can alter the soil microbiological properties and C_{org} within the aggregates. In conclusion, the results clearly indicated that the pastures have a greater risk of overgrazing around Samsun province like in all Turkey. Soil properties changed depending on landscape positions and aggregate sizes. Therefore, the pastures must be used according to site specific management principles.

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(*Received*: 21 November 2005; *Accepted*: 31 December 2005) AJC-4599