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The Influence of Clay Content, Organic Carbon and Land Use Types on Soil Aggregate Stability and Tensile Strength

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Abstract: Soil tensile strength (TS) and aggregate stability (AS) values can be used as indicators of soil structural quality. The objective of this study was to determine the influences of land use types, soil carbon and clay contents on soil structure. Soil samples were collected from 51 different locations from the Kumkale Basin in Çanakkale in April and July 2003. A global positioning system (GPS) was used to determine the coordinates of sampling points. TS, AS, soil organic carbon (SOC), and clay contents were determined. Results of soil analysis and coordinates of sampling points were transferred to the Arc View geographical information systems (GIS) program. Multiple regression analysis showed that TS was positively related (r^2 = 0.89 and 0.92 in April and July, respectively) to clay content when SOC was high. The water stable aggregates in pasture soils were approximately 10 times more water stable than those in other agricultural soils in the region. In general, wet AS was more sensitive to cropping and management systems than TS. Soil AS rose with increasing soil SOC content while TS of soil aggregates was mostly influenced by clay content. However, the effect of clay content on aggregate TS rose with increasing SOC content.

Key Words: Tensile strength, GIS, soil aggregate stability, organic carbon, clay content

Kil İçeriği, Toprak Organik Karbonu ve Arazi Kullanımının Tiplerinin Toprak Agregat Stabilitesi ve Gerilim Direnci Üzerine Etkileri

Özet: Toprakların gerilim direnci ve agregat stabilitesi değerleri, toprakların strüktürel kalitesinin belirlenmesinde indikatör olarak kullanılabilirler. Bu çalışmada araştırma topraklarının gerilim direnci ve agregat stabiliteleri üzerine toprakların kil içeriğinin, organik karbon miktarlarının ve arazi kullanım tiplerinin etkilerinin belirlenmesi amaçlanmıştır. Toprak örnekleri, Çanakkale-Kumkale Ovası'nın 51 farklı lokasyonundan, Nisan ve Temmuz 2003 tarihlerinde alınmıştır. Örnekleme noktalarının koordinatları küresel konumlandırma sistemi (GPS) kullanarak belirlenmiştir ve örneklerin gerilim direnci, agregat stabilitesi, organik karbon ve kil içerikleri belirlenmiştir. Toprak analiz sonuçları ve örnekleme noktalarının koordinatları Arc View Coğrafi Bilgi Sistemi (CBS) programına aktarılmıştır. Regresyon analizleri sonucunda toprakların gerilim direnci ile kil içerikleri arasında pozitif lineer ilişki (Nisan örneklemesinde r^2 = 0.89 ve Temmuz örneklemesinde r^2 = 0.92) bulunmuş ve bu ilişkinin kuvveti toprakların organik karbon içeriği ile doğrusal olarak artmıştır. Mera olarak kullanılan alanların toprak agregat stabiliteleri, diğer tarım arazilerine kıyasla yaklaşık 10 kat daha fazla bulunmuştur. Toprakların agregat stabiliteleri, toprak organik karbonu ile beraber artarken, toprak agregatlarının gerilme dirençleri daha çok kil içeriği tarafından etkilenmiştir. Bununla beraber kil içeriğinin agregatların gerilim direnci üzerine olan etkisi, toprak organik maddesine bağlı olarak artış göstermiştir.

Anahtar Sözcükler: Gerilim direnci, CBS, toprak agregat stabilitesi, organik karbon, kil içeriği

Introduction

Soil quality shows the sustainability of lands in agroecosystems. Soil physical properties are important for both crop growth and for maintaining soil quality. Factors such as crop type (Scott et al., 1994), tillage (Pagliai et al., 1995), and application of organic residues (Rasse et al., 2000) can affect soil physical properties. Effects of cropping systems on soil physical properties are often related to increases in soil organic matter (SOM) (Dormaar, 1983; Haynes, 2000). Soil organic carbon (SOC) contents of aggregates influence aeration, water movement, and nutrition, while the SOC content of bulk soil affects water-holding capacity. Therefore, maintaining adequate soil organic matter content and proper soil structure are required for sustainability of land-use systems.

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The stability of soil aggregates often decreases for soil under annual crops (Angers et al., 1999). Gantzer et al. (1987) reported that residue quantity had a greater effect on splash detachment, shear strength, and aggregate stability than did residue type. Soil aggregate stability (AS) is a dynamic property of soil that changes over time (Coote et al., 1988). Continuous tillage and production may cause a reduction of soil AS. Soils with stable surface aggregates resist to water and wind erosion better than soils with unstable aggregates (Lehrsch, 1998). Cropping practices may result in poorer soil quality for crop growth. On the other hand, TS is defined as the stress, or force per unit area, required to cause soil to fail in tension (Dexter and Watts, 2000). TS is considered to be one of the most useful indicators of the soil structural condition (Dexter and Kroesbergen, 1985). TS is affected by several factors such as water content, dispersible clay wetting and drying cycles (Kay and Dexter, 1992), clay content and mineralogy (Ley et al., 1993), SOC (Rahimi et al., 2000), and cementing materials (Kay and Angers, 1999). The influence of these factors on soil TS and soil AS depends on climatic conditions, management practices, and soil composition (Kay and Dexter, 1992). The objective of this research was to trace the influence of clay content, SOC and land use types on soil TS and AS in the Kumkale Basin, Çanakkale, Turkey.

Materials and Methods

A survey was conducted from April 2003 to July 2003 in 51 cultivated fields owned by farmers in the Kumkale Basin (Figure 1). The farms ranged from 0.2 to 7.9 ha in size. Primarily the crops were wheat, cotton and tomato followed by corn, sunflower, alfalfa, pepper, rice and forages. Tillage depth was generally 25 cm in the study area.

The study area consisted of 2 different physiographical units namely flood plain soils (young and old river terraces) and delta soils. The free screening method was used to determine soil-sampling points and care was taken to represent physiographical changes during the sampling using soil maps based on great soil groups (scaled 1:100,000) and topographical maps (scaled 1: 25,000). Collected soil samples were generally classified as subgroups of xerofluvents and haploxererts. A global positioning system (GPS) was used to determine the coordinates of sampling points. Soil samples were collected with a shovel from 0-25 cm soil depths. At the laboratory, the samples were air-dried and the large clods were carefully broken up by hand into their constituent aggregates. Extractable potassium (K^+), sodium (Na^+), calcium (Ca^{++}) and magnesium (Mg^{++}) contents of soils were determined using 1 N ammonium acetate at pH 7 (Soil Survey Laboratory Staff, 1996): minimum, maximum and average values are presented in Table 1. Aggregates between 2 and 3.3 mm were separated for TS and AS analyses. These sizes of aggregates were chosen as they may be fragmented by tillage to form an ideal seedbed that is typically composed of aggregates with diameters between 1 and 5 mm (Dexter, 1988). Soil texture was determined according to Bouyoucos (1951). SOC contents of aggregates were determined using the Smith-Weldon method (Smith and Weldon, 1941). A total of 1020 individual tests (i.e. 51 locations, each with 20 aggregates) were done to determine the TS of aggregates. Before the tests, each aggregate was

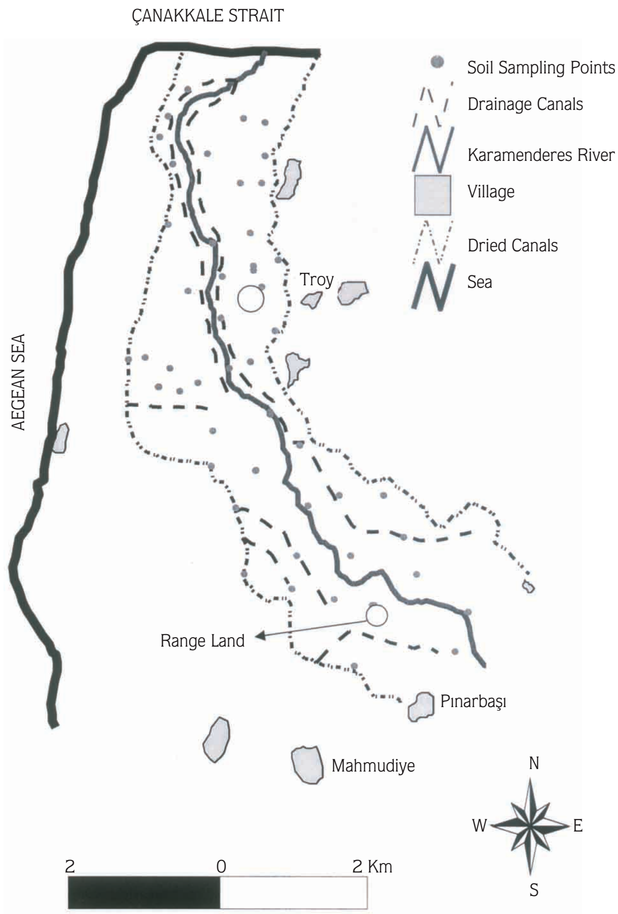

Figure 1. Study area and soil sampling points.

Table 1. Minimum, maximum and average values of exchangeable K^+, Na^+, Ca^{++} and Mg^{++} of study soils sampled in April and July 2003.

Exchangable Cations	April 2003			July 2003		
	Minimum mg kg^{-1}	Maximum mg kg^{-1}	Average mg kg^{-1}	Minimum mg kg^{-1}	Maximum mg kg^{-1}	Average mg kg^{-1}
K^+	77.54	430.07	194.30	13.42	385.47	87.18
Na^+	35.76	987.64	147.51	38.60	440.91	131.08
Ca^{++}	319.17	2068.32	1076.28	343.46	2203.08	1264.95
Mg^{++}	111.06	2299.18	602.85	83.43	2284.33	540.58

weighed and then placed on a flat surface. It was then crushed using a sensitive flat tip penetrometer between 2 parallel plates. The pressure required to crush each aggregate was determined. Since the water content of each aggregate influences the failure pressure, each crushed aggregate was oven dried at 105 °C to calculate the water content at the time of TS analysis. The average water content of aggregates sampled in April 2003 was 2.11%, and in July it was 2.05%. Water contents of aggregates ranged between 1.45% and 3.03% in April 2003, and between 1.59% and 2.91% in July 2003. TS of aggregates was calculated using equation 1 described by Dexter and Kroesbergen (1985):

$$TS = 0.576 \times (F/D^2) \quad (1)$$

where 0.576 is the proportionality constant, F is the applied force at failure (N) and D^2 is the effective diameter (m). Assuming that the aggregate density is constant, the effective diameter of each aggregate was calculated using equation 2 after Watts and Dexter (1998):

$$D = Dm \times (M/Mo)^{1/3} \quad (2)$$

where M is the mass of the individual aggregate (g), Mo is the mean mass of the 20 aggregates (g), and Dm is the mean diameter of the 20 aggregates (mm). In this case the mean diameter of the 20 aggregates is the mean of the upper and lower sieve sizes, which was 2.65 mm. To perform water stability analysis of aggregates (AS), 4 g air-dried aggregates between 2 and 3.3 mm in sizes were placed on the sieve. Aggregates were wetted using misting sprays. AS was determined according to Yoder's wet sieving method (Kemper and Rosenau, 1986).

Results of soil analysis and coordinates of sampling points were transferred to the Arc View geographical information systems (GIS) program. Soil clay content, AS, TS and SOC maps were produced using a spatial analysis extension component (ESRI, 1996). Coefficient of determination (r^2) was used to determine the relationships between measured parameters. The results were analyzed using the Statistical Analysis System (SAS Institute, 1999).

Results and Discussion

Results showed that the stability of pasture sites as well as SOC were significantly higher than those in the other agricultural fields (Figures 2a and b). Average SOC values in agricultural sites other than pastures were 1.14% in April and 1.10% in July. However, SOC values of pasture sites were 2.05% in April and 3.33% in July. Similarly, average AS values in agricultural sites were 5.36% in April and 6.89% in July while the AS values in pasture sites were 54% in April and 64% in July. Although the water stability of aggregates decreased with tillage due to breakdown of natural aggregates and pores, the pasture developed good aggregates and extensive roots, which also contributed to the stability of aggregates in these sites (Figure 2b). Pasture soils were approximately 10 times more water stable (Figure 2b) than tilled agricultural soils although the SOC difference between the 2 agro-ecosystems was only 22.5 g kg^{-1} of soil.

Sodium concentrations of research soils varied from 35.76 to 987.64 (Table 1) with an average of 147.51 mg kg^{-1}. Only one sampling point had 500 mg kg^{-1} Na^+ content and one of the pasture soils had a higher level than that. This field was saline and concave. In contrast to the dispersion effect of sodium, this particular soil sample

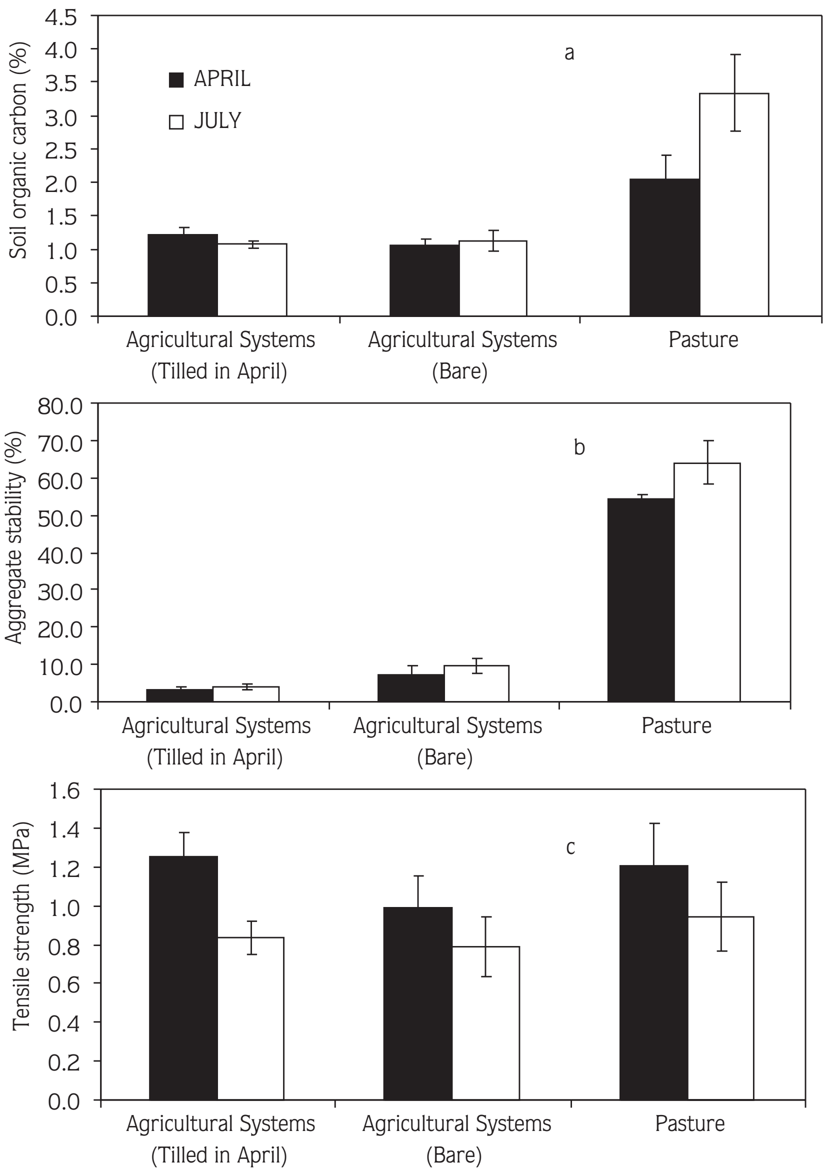

Figure 2. Soil organic carbon (a), aggregate stability (b) and tensile strength (c) values of soil aggregates between 2 and 3.3 mm. Bars represent standard errors.

had a very high soil organic matter content as well as AS. The apparently negative effect of the high sodium content of this soil was masked by high SOC content. The calcium content of this soil sample was 1354 mg kg^{-1}. The main source of the calcium in this area was applied fertilizer and porent material. There were no significant correlations observed between sodium vs. soil AS and TS. Similarly, the effects of K, Ca, and Mg on soil AS and TS were not significant.

The nature of changes induced by cultivation also depends upon particular soil management (Christensen, 1992). As the amount of crop residue returned to the soil is increased, SOC sequestration is also expected to increase if the residue C is not lost to the atmosphere as CO_2 because of tillage induced decomposition (Larney et al., 1997). Therefore a decrease in soil AS in tilled systems can be attributed to loss of C from the soil.

There was an increasing trend in SOC in July when soil was not tilled during the spring and summer (Figures 2a and 3). However, SOC levels decreased from April to July, especially in cotton planted soils (Figure 2a).

Wet AS declined in the order pasture > wheat > cotton. Kay et al. (1994) reported that continuous cotton production reduced soil wet AS compared to that of pasture. AS increment was correlated with the increment in SOC content in July ($r^2 = 0.66$, $p<0.05$). However, no significant correlation was found between these 2 parameters in April. Six et al. (2000) reported that cultivation reduces soil C content and changes the distribution and stability of soil aggregates. Breakdown of macro aggregates results in the release of labile SOM accompanied by increased availability for microbial decomposition. The increased microbial activity depletes SOM, which reduces microbial derived binding agents and causes aggregate losses (Jastrow, 1996; Six et al., 1998). Therefore, depending on the land use, tillage reduced soil AS much faster than did the loss of SOC in April. Soil AS values increased slightly in July compared to those in April in non-tilled bare soils (Figures 2b and 4), suggesting that decomposed residues in spring can affect soil structure during the next growing season.

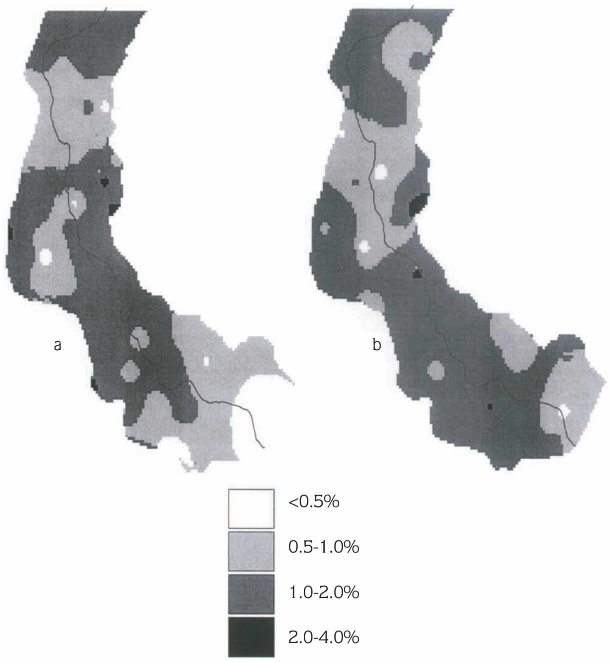

Figure 3. Organic carbon contents (%) of soils sampled in April (a) and July (b), 2003.

Tensile strength

TS maps are presented in Figure 5. Minimum TS was 0.03 MPa and the maximum TS was 3.51 MPa in April 2003, while minimum TS was 0.04 MPa and the maximum TS was 2.66 MPa in July 2003 (Figure 5). TS rose with increasing clay content. Minimum clay content of the study soils was 8% and the maximum was 54% (Figure 6). Wet AS was more sensitive to cropping and management systems than was TS. There was a significantly high correlation between the TS and clay content of soils in both April and July. However, no relationships were observed between TS and SOC, as were reported by Dexter et al. (1984) and Ley et al. (1993). Aggregate samples were divided into 3 groups according to their SOC contents to determine the effects of land use on the TS of soils. Results showed that the r^2 value between TS and clay content was 0.92 for $p< 0.001$ where SOC is greater than 1.5% (Figure 7). This finding was applicable to both sampling dates (Figures 7 and 8). This result also suggests that the effect of clay content on soil aggregate strength will vary with SOC content. Increasing SOC content, on the other hand, will increase TS. Kay (1997) reported that increasing carbon content can strengthen the bonds between mineral materials, especially for clay soils, thus increasing the TS of soils. When the seasonal variation of TS was examined, the TS of aggregates sampled from tilled lands in April was significantly greater than that in July (Figures 2c and 5). In general, factors such as intensive tillage and traffic on wet soil have been found to result in increased TS of dry aggregates (Kay and Dexter, 1992). The higher TS values in April were probably due to tillage practices and intensive traffic on the wet soil in this season in agricultural soils. Increasing TS values of pasture soils in July and those in April were not statistically different. Since there was a direct correlation between clay content and TS values cementation of clay dispersed during the wet period (Kay and Dexter, 1992) may explain the higher TS measured in April than that in July. However, soil AS which rose with increasing SOC content in this research, was higher in July than in April. Soil aggregates sampled from the tilled lands in April had significantly lower water stability (AS) and higher TS compared to those of non-tilled lands (Figure 2c). Similar results were also observed by Chan and Hulugalle (1999).

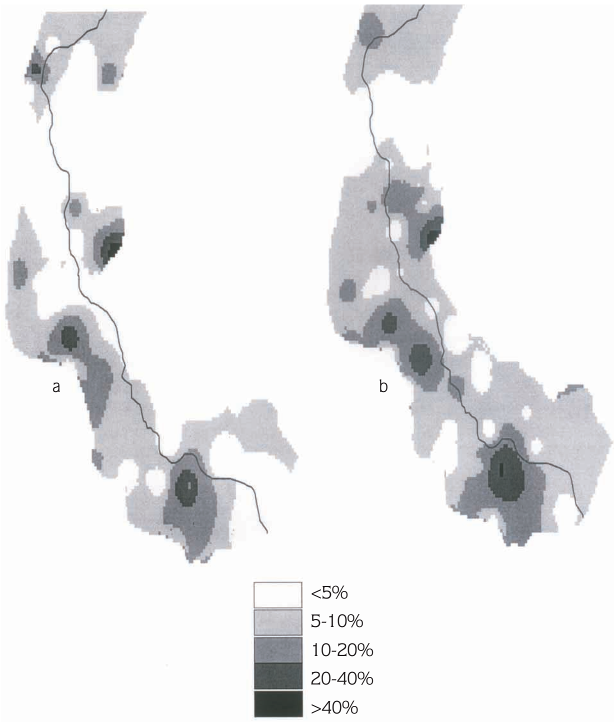

Figure 4. Aggregate stability (%) of aggregates sampled in April (a) and July (b), 2003.

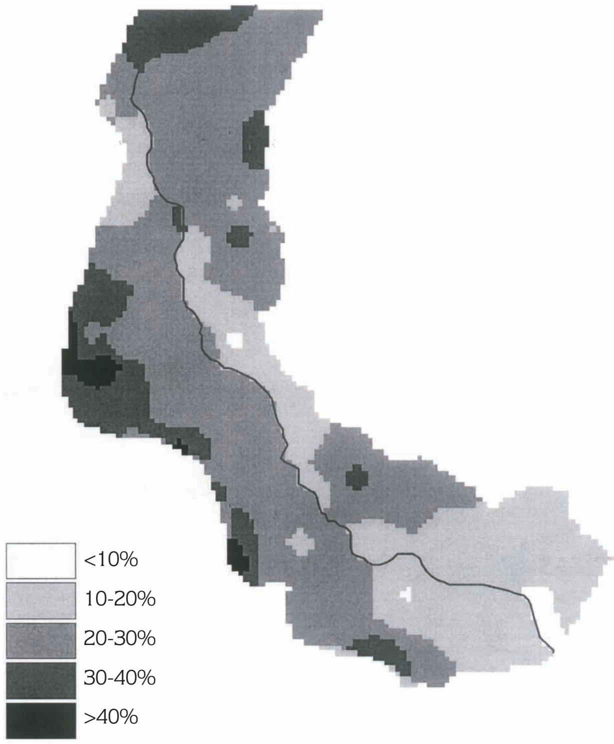

Figure 6. Clay contents (%) of soils.

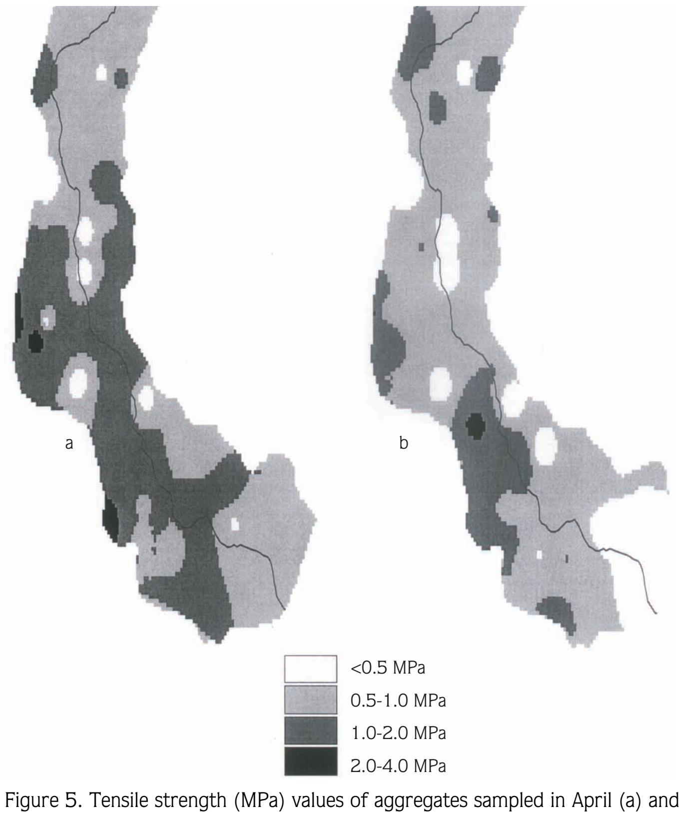

Figure 5. Tensile strength (MPa) values of aggregates sampled in April (a) and July (b), 2003.

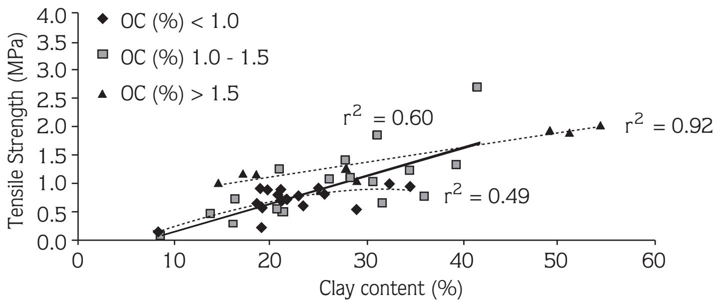

Figure 7. Relationships between aggregate tensile strength and clay contents of soils with different soil organic carbon contents in April, 2003.

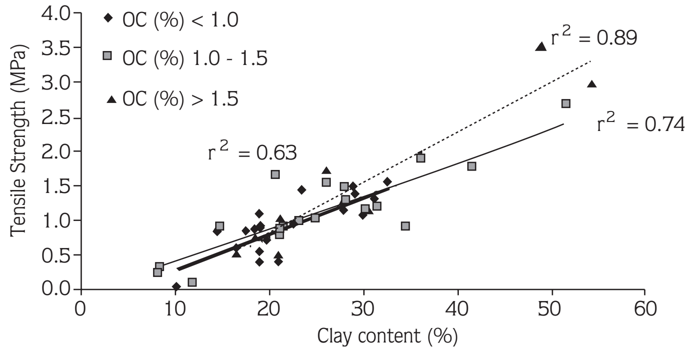

Figure 8. Relationships between aggregate tensile strength and clay contents of soils with different soil organic carbon contents in July, 2003.

Conclusion

In this research wet AS was more sensitive to cropping and management systems than TS. Pasture soils had the highest percentage of water stable aggregates among all the cropping systems. Soil AS rose with increasing SOC content while TS of soil aggregates was mostly influenced by clay content. In addition, the effect of clay content on soil aggregate strength varied with SOC.

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