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Abstract: The objective of this study was to determine the influence of selected soil properties on the relative strength of individual soil aggregates against crushing forces. Soil aggregates were crushed between a flat surface and a flat plate connected to a pocket penetrometer. Significant relationships were found between dry-aggregate stability and the clay content, sand content, CEC and ESP of the soils studied. There was also a significant positive correlation between dry-aggregate stability and wet-aggregate stability (r=0.94**). No significant relationships were found between dry-aggregate stability and silt content, organic matter content, $CaCO_3$ content or pH. Stepwise multiple regression analysis indicated that clay content with ESP was a good predictor of dry-aggregate stability and accounted for 0.90 to 0.96 % of the variability in the dry-aggregate stability of the soils studied.

Bireysel Toprak Agregatlarının Kırılmaya Karşı Dayanıklılıkları II. Bazı Toprak Özellikerinin Etkisi

Özet: Bu çalışmanın amacı, bireysel toprak agregatlarının kırılmaya karşı olan dayanıklılıkları üzerine etki eden toprak özelliklerini belirlemektedir. Agregatlar düz bir zemin üzerinde buna paralel konumda ve cep penetrometresine sabitleştirilmiş bir plaka arasına konularak yavaş yavaş arttırılan basınç altında kırılmıştır. Toprakların kuru-agregat stabiliteleri ile kum içeriği, kil içeriği, KDK ve değişebilir Na yüzdesi (ESP) arasında önemli ilişkiler bulunmuştur. Ayrıca, toprakların kuru-agregat stabiliteleri ile ıslak eleme yoluyla belirlenen stabiliteleri arasında önemli pozitif bir ilişki kaydedilmiştir (r=0.94**). Kuru-agregat stabilitesi ile toprakların silt içeriği, organik madde içeriği, $CaCO_3$ içeriği ve pH arasında önemli ilişkiler belirlenememiştir. Stepwise çoklu regresyon analizi, toprakların kuru-agregat stabilitelerindeki varyasyonun yaklaşık %90-96'sının sözkonusu toprakların kil içeriği ve ESP değerlerinin kullanılmasıyla açıklanabileceğini göstermiştir.

Introduction

Many important soil management decisions require knowledge of the resistance of soil aggregates to deformation under applied mechanical stresses. Several researchers have defined dry-aggregate stability as the energy needed to crush aggregates between two parallel plates and have used this to evaluate soil properties in tillage and erosion studies (1, 2, 3, 4, 5, 6).

The response of soil aggregates to mechanical stress depends on the relative importance of different bonding mechanisms linking primary particles together. The stability of aggregates is a function of whether the cohesive forces between particles withstand the applied disruptive forces (7). The more strongly the particles in an aggregate are held together, the greater is the work that has to be done to break the bonds (8).

The soil strength and stability of aggregates are affected by the physical and chemical properties of soils. In measuring soil strength as specific surface energy it is assumed that soil strength depends directly on the soil specific surface area or indirectly on its clay type and content and binding material or cementing agents as organic materials (9). Skidmore and Layton (10) indicated that clay content and water content at -1500 J/kg were both good predictors of mean aggregate stability, defined as the work required to crush individual aggregates between parallel plates divided by the mass of the aggregate being crushed. Some other researchers also found that dry aggregate stability increased with an increase in clay and organic matter contents (11, 12).

Perfect et. al. (12) studied the relationships between soil properties and the parameters (α and β) in the Weilbull model, which is the most widely accepted statistical approach for characterizing aggregate strength. They pointed out that sand content was more important in determinig dry aggregate strength than silt and clay contents. They also reported significant relationships between silt, clay, organic matter content, pH and Weilbull parameters but no relationship with $CaCO_3$.

The objective of this study was to determine the influence of selected soil properties on the relative strength of individual soil aggregates against crushing forces.

Material and Methods

Soil samples collected at a depth of 0-20 cm from fields at ten different locations were transported to the laboratory and air-dried. The air-dried clod samplas were sorted by sieving into four aggregate size groups: A-1: 25.4-19.05 mm; A-2: 19.05-9.53 mm; A-3: 9.53-4.76 mm; and A-4: 4.76-3.18 mm. The aggregates in each group were divided into two sub-groups. The first group of aggregates was crushed after their sizes and masses were recorded. The second group of aggregates was oven-dried at 105°C for 24 h before crushing. After removel from the oven, the aggregates were allowed to cool in a desiccator containing dry P_2O_5. During the crushing test, the aggregates were removed individually from the desiccator, their sizes were measured using a compass and they were crushed according to the procedure described by Öztaş et al. (13). A total of 1722 aggregates were crushed. The applied stress value necesarry to crush an individual aggregate divided by the mass of the aggregate being crushed and the quantity was referred to as the dry-aggregate stability measured in units of kg/cm^2-g.

Particle size analysis was performed according to the Day hydrometer method (14), organic matter was determined using the Walkey-Black method (15), and pH was measured in a 1:1 soil-water solution using a glass-electrode pH meter (16). $CaCO_3$ was determined using the calcimeter method, and exchangeable Na and cation exchange capacity (CEC) were determined according to the NH_4OAc method (17). The wet aggregate stability (WAS) was determined using the sieving method (7).

Correlation analysis, simple linear regression analysis and stepwise multiple regression analysis were performed to determine the degree of relations between dry-aggregate stability and soil properties and to define the factors causing variability in the strength of dry-aggregates against crushing forces (18, 19).

Results and Discussion

Selected physical and chemical properties of the soils studied are given in Table 1. The soils contain 18 to 64% clay, 32 to 43% silt and 4 to 50% sand. Texturally, four soils out of 10 were clay, another four were loam and the other two were clay loam. The organic matter content ranged from 1.61 to 3.39%, $CaCO_3$ from 0.5 to 23.8%, soil pH from 6.96 to 7.95, CEC from 26.2 to 64.8 cmol/kg, and exchangeable sodium percentage (ESP) from 0.32 to 0.76%.

The influence of physical and chemical soil properties on dry-aggregate stability was determined. The results of the correlation analysis are presented in Table 2. Dry-aggregate stability was positively correlated with clay content and CEC, and negatively correlated with the sand content and ESP of the soils. In other words, an increase in clay content and CEC or decrease in sand content and ESP resulted in an increase in the dry-aggregate stability of the soils studied. In general, dry-aggregate stability had the highest correlation with clay content, but the r values of the sand content and ESP were as high as clay.

Table 1. Selected physical and chemical properties of the soils studied.

Soils	Clay %	Silt %	Sand %	Textural Class	pH (1:1)	OM %	CaCO3 %	CEC cmol/kg	ESP %
Köprüköy Series	44	33	23	C	7.95	1.61	9.7	41.2	0.76
Uzunahmet Series	53	38	9	C	7.57	1.94	1.3	61.1	0.34
İspiryolu Series	64	32	4	C	7.65	1.74	1.2	61.3	0.33
Alaca Series	52	38	10	C	7.91	1.61	1.7	64.8	0.32
University-1	18	40	42	L	7.75	2.25	0.6	27.0	0.65
University-2	19	39	42	L	7.52	1.71	0.5	26.2	0.51
University-3	37	43	20	CL	7.89	3.39	10.7	47.9	0.67
University-4	21	38	41	L	6.96	1.71	0.6	28.1	0.42
University-5	15	35	50	L	7.75	2.84	23.8	29.4	0.76
University-6	29	41	30	CL	7.79	2.75	21.1	29.4	0.68

Table 2. Correlation coefficients for the relationships between the dry-aggregate stability and selected physical and chemical properties of the soils studied.

Aggregate size group	Clay	Silt	Sand	pH	OM	CaCO3	CEC	ESP
				Air dried aggregates				
A-1	0.60	-0.15	-0.61	-0.15	-0.44	-0.40	0.58	-0.90**
A-2	0.43	-0.49	-0.36	-0.27	-0.31	0.15	0.41	-0.42
A-3	0.76*	-0.63	-0.68*	-0.21	-0.43	-0.31	0.63	-0.71*
A-4	0.91**	-0.22	-0.92**	0.02	-0.27	-0.47	0.96**	-0.82**
				Oven dried aggregates				
A-1	0.70*	-0.35	-0.67*	-0.41	-0.42	-0.60	0.62	-0.79**
A-2	0.73*	-0.34	-0.71*	-0.35	-0.45	-0.22	0.71*	-0.65*
A-3	0.62	-0.35	-0.58	-0.29	-0.33	-0.44	0.66*	-0.73*
A-4	0.85**	-0.40	-0.83**	-0.35	-0.29	-0.41	0.81**	-0.69*

*, **: Significant at p≤0.05 and 0.01, respectively.

Organic matter is known to improve the physical condition of soil and its effect is commonly associated with an increase in soil aggregation. However, the relationship between dry-aggregate stability and organic matter content was not statistically significant at $p<0.05$. The range of organic matter content in the soils studied was only 1.78%, which may not be enough to detect the influence of organic matter on the strength of the aggregates against crushing forces. Although the relationship between dry-aggregate stability and organic matter content was not statistically significant, these two properties were inversely correlated to each other. As a rule of thumb, organic matter improves soil aggregation but organic matter slightly reduces the strength of aggregates against crushing forces.

In addition, no significant relationships were found between dry-aggregate stability and the silt content, pH and $CaCO_3$ content of the soils studied.

Significant relationships determined by the correlation analysis in Table 2 are illustrated in Figure 1 using the average dry-aggregate stability values for each soil. The regression line for clay explained about 81 and 85% of the variability in the oven and air-dried aggregate stabilities, respectively. One of the means by which primary particles are joined together is the mutual attraction of surfaces to each other. Thus, the total amount of clay in a soil controls the aggregation of all particles. However, dry-aggregate stability decreased by 0.068 to 0.082 unit per 1% increase in sand content in air and oven-dried aggregates. A strong relationship was found between dry-aggregate stability and the CEC of soils. It may be indirectly caused by the effect of clay content on dry-aggregate stability since the CEC of a soil is a direct function of clay content (r=0.94**). Figure 1 also shows that dry-aggregate stability was strongly dependent on ESP. As is well-known, the proportion of sodium in the adsorbed layer has an important role in the structural status of the soil.

Soil properties affecting the strength of aggregates against crushing forces also affect the wet-aggregate stability of soils. The relationships between the soil properties and wet-aggregate stability of soils aro not shown but, the relationship between wet-aggregate stability and dry-aggregate stability is shown in Figure 2.

Stepwise multiple regression analysis was conducted to determine the soil properties causing variability in dry-aggregate stability. The results indicated that a model with either sand, clay or CEC together with ESP was a good predictor of dry-aggregate stability. Since the clay content of a soil is tho most important factor in aggregation, the model containing clay and ESP was considered the best model for dry-aggregate stability. The model parameters and standard errors are summarized in Table 3.

The chosen model explained 90 to 96% of the variability in the dry-aggregate stability of air and oven-dried aggregates, respectively. Introducing organic matter into the regression model slightly increased R^2, but the regression was not significant at $p<0.05$.

Conclusions

In this study it was found that clay content, sand content, CEC and ESP were the most important soil properties affecting the dry-aggregate stability of the soils studied. Stepwise multiple regression analysis indicated that 90 to 96% of the variability in dry-aggregate stability could be explained by the clay content and ESP of the soils studied.

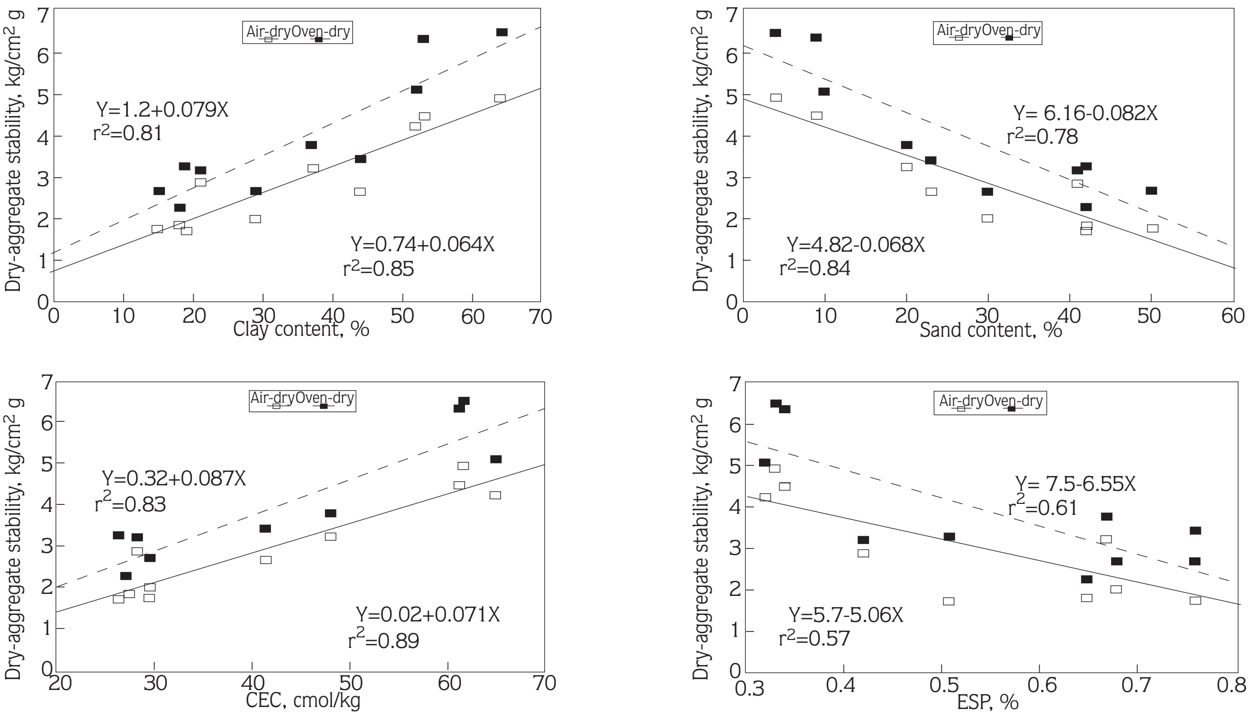

Figure 1. Relationships between dry-aggregate stability and the soil properties studied

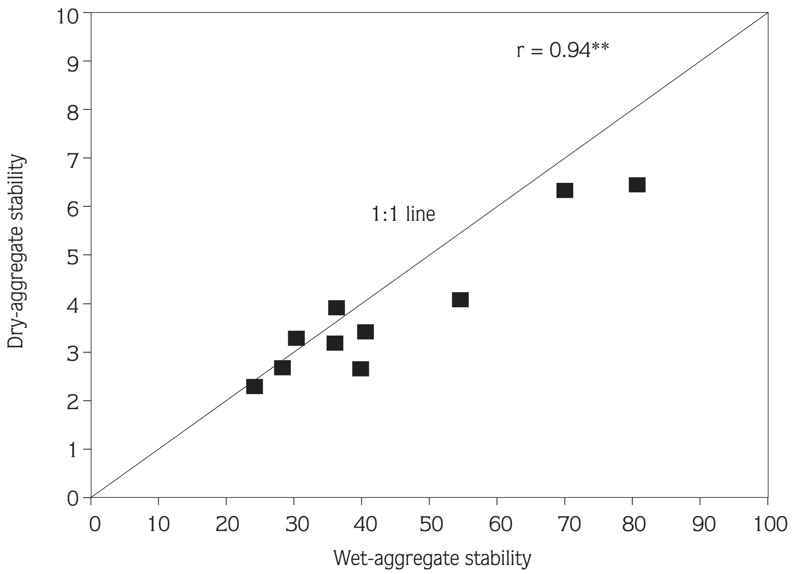

Figure 2. Relationship between the wet-aggregate stability and dry-aggregate stability of the soils studied.

Variables	Coefficients	Standard error	p-level	R^2
		Air dried aggregates		
Intercept	2.982	0.584	0.0014	
Clay	0.645	0.104	0.0004	0.96**
ESP	-0.428	0.104	0.044	
		Oven dried aggregates		
Intercept	3.690	1.131	0.0136	
Clay	0.654	0.159	0.0045	0.90**
ESP	-0.382	0.159	0.0470	

Table 3. The optimum model and model parameters chosen to describe variability in dry-aggregate stability as a function of soil properties determined using stepwise multiple regression analysis.

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