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Assessing the Role of Some Soil Properties on Aggregate Stability Using Path Analysis (Case Study: Silty-Clay- Loam and Clay-Loam Soil from Gully Lands in North West of Iran)

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ABSTRACT Soil characteristics is very important in water erosion processes. The present investigation was conducted in gully lands of Ardebil Province, Iran, to assess the role of soil texture and structure on aggregate stability using wet sieve method. To achieve the study purposes, mean weighted diameter of aggregates was calculated, and its relationships with lime and clay percentages, sodium absorption ratio and soil organic matter were then determined. The research results showed, in the first and second depth, the organic matter had the highest direct and positive effect on aggregate stability. In first depth, clay and lime had a direct and positive effect on aggregate stability. In both depths, sodium absorption ratio had the highest but negative effect on aggregate stability. Organic matter and clay had the highest direct and positive effect on aggregate stability in the second depth. The highest indirect effect of the parameters on aggregate stability was in second depth due to effect of clay and organic matter on each other. In second depth, lime had the direct and positive effect on aggregate stability. Sodium absorption ratio had a direct and negative effect on aggregate stability in both study depths.

Key words: *Soil erosion, Path analysis, Ghori-Chai watershed, R software*

1 INTRODUCTION

Aggregate stability is the most important physical property that influences soil erosion (Amezketa *et al.,* 2003). This property plays major role in crop growth, runoff, erosion and in contaminant removal from agricultural lands to water bodies (Ketcheson, 1980). Kamart and Eimson (1998) have described stability index as a most important factor to describe sensitivity of soils to water erosion. There is a close correlation between soil erodibility and aggregate stability (Igwe *et al.,* 1995). Igwe *et al.* (1995) assessed various stability indices in Nigeria soils and determined its relationship with soil erodibility factor. They suggested Geometric Mean Diameter (GMD) to assess aggregates stability. The distribution of aggregate size is a logarithmic distribution, rather than a normal distribution (Gardner *et al.,* 1965), thus Geometric Mean Diameter (GMD) that is a logarithmic relationship has proven more appropriate to assess aggregate stability.

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Aggregate stability causes increase in sensitivity of soils to erosion (Six *et al.,* 2000). Aggregate dispersion results in crusting in soil surface and this causes reduced permeability and increased runoff (Anger *et al.,* 1990). Soils with robust aggregate and with a high proportion of large aggregates are stable soils. Aggregate stability correlates with soil type and with amount of organic matter, and also amount of erosion and runoff are a function of some soil properties such as soil type, aggregate stability, organic matter%, and percentage of exchangeable Sodium (Topp *et al.,* 1997). When organic matter in soil decreases, aggregates breakdown simply and small particles of soil are transferred during water erosion (silk *et al*., 2005). Tisdall and Oades (1982), Bcarden and Petersen (2000) have emphasized the positive role of organic matter in aggregate stability. But, Amesta and Karatansis (1996) have expressed in their studies that organic carbon has not major role in aggregate stability. They stated that other than organic crabon other soil factors influence aggregate stability. Alekseeva *et al.* (2009) in their studies in tropical and semitropical soils reported that existence of fine texture and dominant clay kaolinite is the major cause of aggregate formation and this covers other processes and aggregate formation processes. In wet sieve method, aggregate stability increase with increasing amount of clay in soil (Rasiah and Kay, 1994). When the amount of sodium in soil is low, clay causes increase in stability and with high amount of sodium in soil clay affect stability adversely (Kemper and Koch, 1966). Thus in some regions, negative correlation between clay and aggregate stability has been observed in many studies (Wustamidin and Douglas, 1985). Calcium Carbonate can flow between soil particles as a cement and join soil particles with each other (Shainberg *et al.,* 1981). Also, results from Boujila and Gallai (2008) showed that calcium carbonate in soil affects organic matter activity and by increasing percentage of calcium carbonate the effect of organic matter on aggregate stability abates. The state of spatial arrangement of particles relative to each other determines the type of soil structure and the shape of pores in natural environments (Kutlu *et al.,* 2008). Greenland *et al.* (1975) stated that to prevent soils from diffusion the threshold limit of organic matter should be at least 2%, however Kandiah (1976) estimated the optimal amount of organic matter about 4% to creating stable aggregate. Aggregate stability in different textures follows this pattern: clay> loam clay> loamy> loam sand (Mbagwu, 1989), when amount of Sodium in soil is low clay can improve aggregate stability, whereas in the presence of high amount of Sodium, clay adversely influence aggregate stability. In a study Wustamidin and Daglass (1985) suggested that there is a negative relationship between clay and aggregate stability and by increasing Sodium absorption ratio (SAR) the required electrolyte concentration (EC) to coagulation clays increases (Abu-Sharar *et al.,* 1987; Lebron *et al.,* 2002). Lal has classified the critical levels for aggregate stability based on levels of Mean weighted diameter as 0.5<0.1-5, 1-2, 2-2.5, 2.5<, namely very severe, severe, moderate, low, and no limitation, respectively. Gully erosion in Ghori-Chai watershed has led to degradation of desirable agricultural lands, rangelands and destruction of road facilities. The aim of this study is to assess of stability of soil structure using wet sieve method and to calculate Mean weighted diameter and its relationship with lime, clay percentage in soil, Sodium absorption ratio and organic matter in gully lands of Ardebil province.

2 MATERIALS AND METHODS

Ghori-chai watershed with area 11842.7 ha is located at northern part of Ardabil province and has a distance 20 km from Iran - Azerbaijan boundary. This watershed has coordinates 29 21 42 to 39 12 37 North, and 47 35 00 to 47 45 11 East. The highest and lowest altitudes of this watershed are 1007 m and 265.5 m, respectively.

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Mean annual precipitation and annual mean temperature account for 13.9 °C and 318.8 mm, respectively. Based on De Marton modified classification and Ambroje classification, the climate of this watershed is classified as cold semi-arid climate.

3 STUDY METHODOLOGY

In order to determining the aggregate stability and to determine factors affecting it, 17 gullies were selected randomly and in two depths, 0-30 and 30-60 cm, from top of the gullies that is active part of them, the samples were taken. After transferring samples to laboratory, the samples were handled carefully to determine some physical and chemical properties of soil samples and also to determine stability of aggregate to entering water. So, to prepare samples for measuring mean weighted diameter, aggregates were allowed to wet slowly due to capillarity, because quick wetting of aggregates cause them to collapse and disperse (Movahedi Naini and Rezai, 2008). Va Biol (1949) has expressed mean weighted diameter (MWD) of aggregates as a statistical index of aggregation. Using graphs of area under cumulative curves of weighted percentage of aggregates' different sizes the mean weighted diameter is comparable. This value presents an estimate of mean size of aggregates and also represents aggregate analysis on a figure. Mean weighted diameter is a sensitive index of soil condition and treatment. Nevertheless most of available methods are classified based on: 1. How much aggregate is available; and, 2. How degree of silt and clay has became aggregate. The soil was slowly wetted during 30 minutes because of capillary properties to determine mean weighted diameter with wet sieving. In order to determining mean weighted diameter the air-dried soil was sieved using 8 mm sieve and after gradual wetting with atomizer by 30 minutes, two series of sieves, namely 4.76, 2, 1, 21.5 and 0.0 mm with 4, 10, 18, 35, 60 mesh, respectively, were placed in rotary sieve instrument. The sieves with distances 3.18 or 1.30 and with 30-35 ×g rpm were immersed in water and then quickly taken away from water; this process lasted for 30 minutes. It was observed that for most of soils after 60 excessive immersing the weight of soil in each sieve changed to a fixed amount due to each immersing because of mechanical friction of sieving and this value was used at the end of experiment as correction factor. Mechanical ingredients were passed into the same series of sieves after dispersion process and then actual weight of aggregates was measured in each sieve. Afterward, dispersion ratio, the state aggregation, degree of aggregation and mean weighted diameter (van Boil, 1949) were measured for content of each screen.

$$\mathrm{MWD} = \sum_{\mathrm{I}=1}^{\mathrm{n}} \bar{\mathrm{x}}_{\mathrm{i}}\, \mathrm{w}_{\mathrm{i}} \qquad (1)$$

where, W_i is the ratio of aggregates' weights in each screen to total weight;

X_i is the aggregate mean diameter in each screen (mean diameter of top and down sieves).

From statistical point of view, the relationship between MWD and the percentage of masses (aggregates) larger than 1 and 2 mm amounts 91% and 95%, respectively (Movahedi Naini and Rezai, 1999). Results from MWD measurement and also physical and chemical properties obtained from experiments in two different depths, 0-30 and 30-60 cm in each gully were analyzed using statistical software R. To determine factors affecting aggregate stability the path analysis method was used. The correlation among soil properties in the first depth is shown in table 1.

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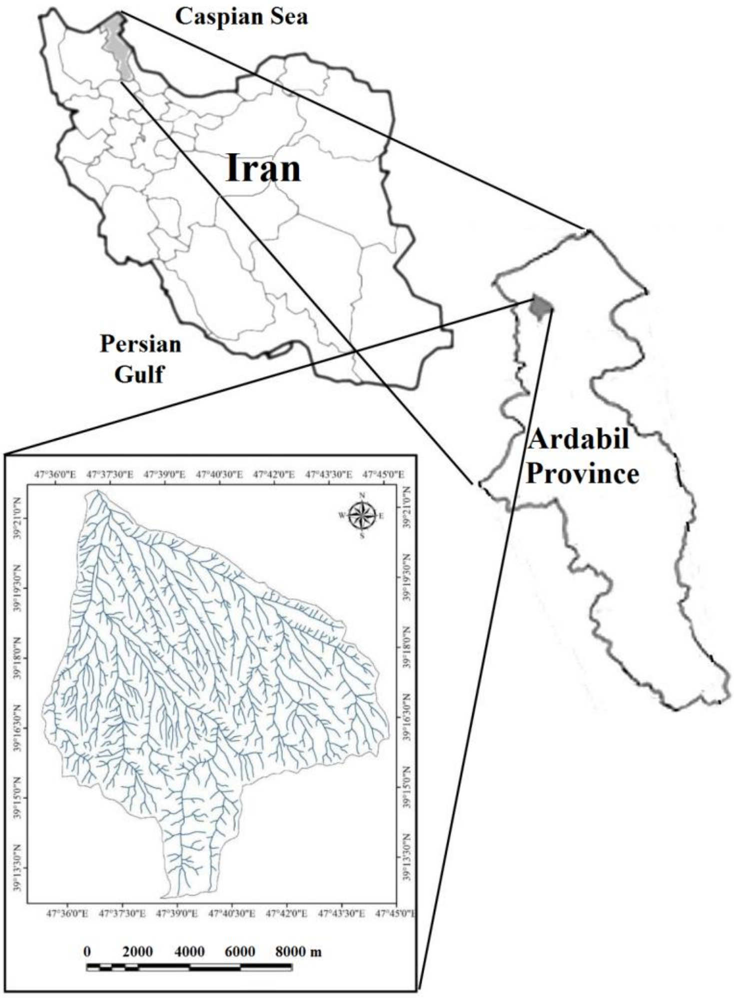

Figure 1 Location of Ghori-Chai Watershed and soil sampling point

Table 1 Correlation among soil properties in the first depth (0-30 cm)

Soil stability	Clay	Organic matter	Sodium Absorption Ratio	Lime	Parameter
-0.21	-	-	-	1	Lime
-0.62**	-	-	1	0.27	Sodium Absorption Ratio
0.74**	-	1	-0.19	-0.01	Organic matter
0.66**	1	0.59*	-0.38	0.5*	Clay

* Significant in 95 percent confidence intervals ** Significant in 99 percent confidence intervals

4 RESULTS

The results from path analysis method for detecting direct and indirect effects of properties on aggregate stability in first depth show that the organic matter has the highest direct and positive effect (56%) on aggregate stability. In other word,

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the high amount of organic matter among considered variables has the highest effect directly on increased aggregate stability, so by increasing every unit of organic matter the aggregate stability increase 0.56 (Table 3); indeed, the relationship between this property and aggregate stability is significant in confidence level 99%. The effect of parameters on aggregate stability in first depth account for effect of clay and organic matter on each other (Table 3); this is due to close correlation between these factors in first depth (although, comparing indirect effects of this parameters on aggregate stability show the higher importance of organic matter than clay on aggregate stability). In first depth, clay has a direct and positive effect on aggregate stability (0.15) so that increased every unit of clay by 0.15 enhances aggregate stability. In the first depth, lime has the lowest and also negative effect on aggregate stability (0.006) (Table 2). Apart from organic matter in first depth, Sodium absorption ratio has the highest but negative effect on aggregate stability (0.45). So that, increased every unit in Sodium absorption ratio the aggregate stability decreases by 0.45 (Figure 2).

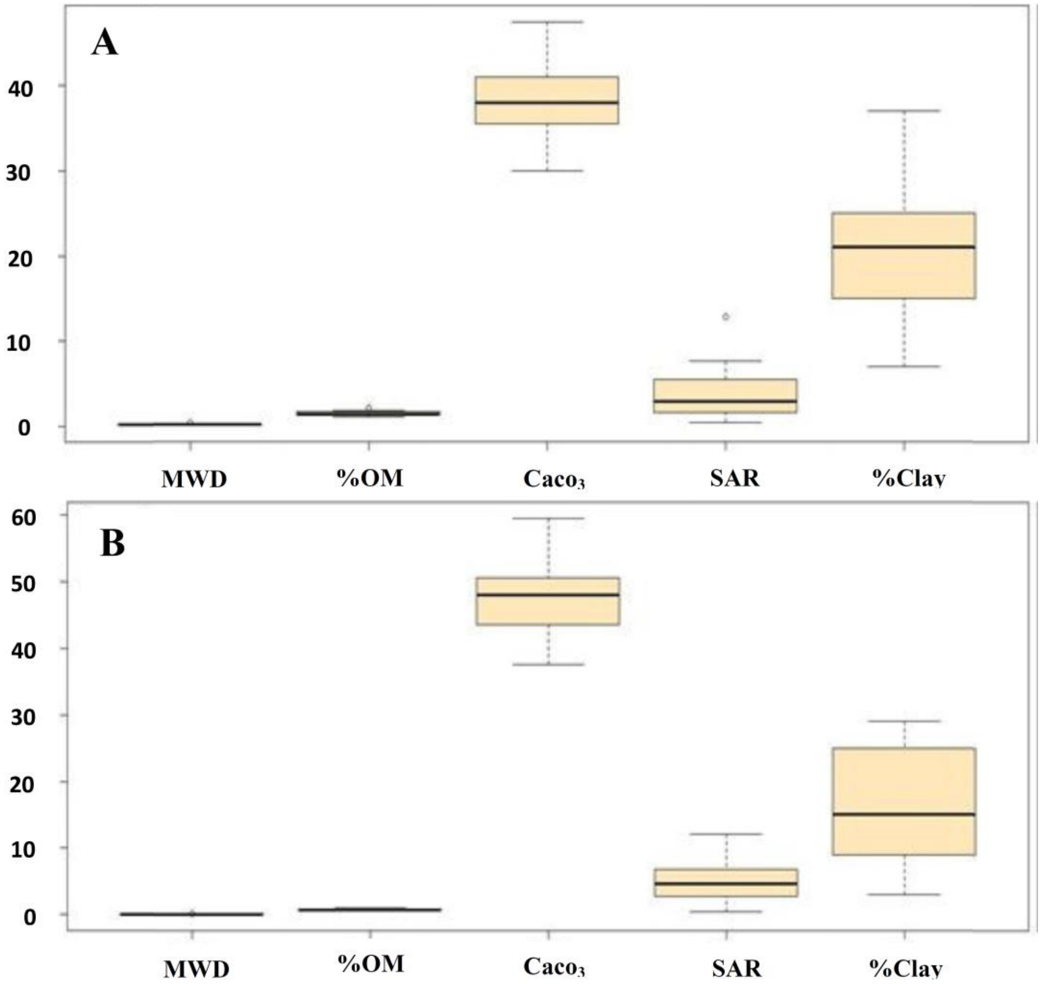

Figure 2 Boxplots of soil clay (A: First depth: (0-30cm), B: Scond depth: (30-60 cm))

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Table 2 Direct (diagonal) and indirect effects of path coefficients on the soil stability in the first depth (0-30 cm)

Clay	Organic matter	Sodium Absorption Ratio	Lime	Parameter
-0.07	-0.005	-0.12	-0.006	Lime
-0.05	-0.1	-0.45	-0.001	Sodium Absorption Ratio
0.08	0.56	0.08	0.00001	Organic matter
0.15	0.33	0.17	0.003	Clay

The highest and positive effect of parameters on aggregate stability in second depth (similar to first depth) is caused by organic matter (0.53). By increasing every unit of organic matter aggregate stability increases 0.53 (Table 4). After organic matter in the second depth, clay had the highest direct and positive effect on aggregate stability (0.35). Hence increased every unit in clay cause increased aggregate stability by 0.35 (Figure 3). In the second depth, the highest indirect effect of the parameters on aggregate stability is due to effect of clay and organic matter on each other; that, this is due to close relationship between these factors in the first depth (Table 4). Also in second depth, comparing indirect effect of these parameters on aggregate stability shows the higher importance of organic matter than clay on aggregate stability. In second depth, lime has the direct and positive effect on aggregate stability (0.16) so increased every unit in lime causes increased aggregate stability by 0.16. Sodium absorption ratio has the direct and negative effect on aggregate stability (0.18) so increased every unit in Sodium absorption ratio causes decreased aggregate stability by 0.18.

Table 3 Correlation among soil properties in the second depth (30-60 cm)

Soil stability	Clay	Organic matter	Sodium Absorption Ratio	Lime	Parameter
-0.15	-	-	-	1	Lime
-0.4**	-	-	1	0.02	Sodium Absorption Ratio
0.69	-	1	-0.15*	-0.42	Organic matter
0.68**	1	0.55	-0.38*	-0.25	Clay

* Significant in 95 percent confidence intervals ** Significant in 99 percent confidence intervals

Table 4 Direct (diagonal) and indirect effects of path coefficients in the second depth (30-60 cm)

Clay	Organic matter	Sodium Absorption Ratio	Lime	Parameter
-0.08	-0.22	-0.0037	0.16	Lime
-0.13	-0.08	-0.18	0.0033	Sodium Absorption Ratio
0.19	0.53	0.028	-0.07	Organic matter
0.35	0.29	0.071	-0.04	Clay

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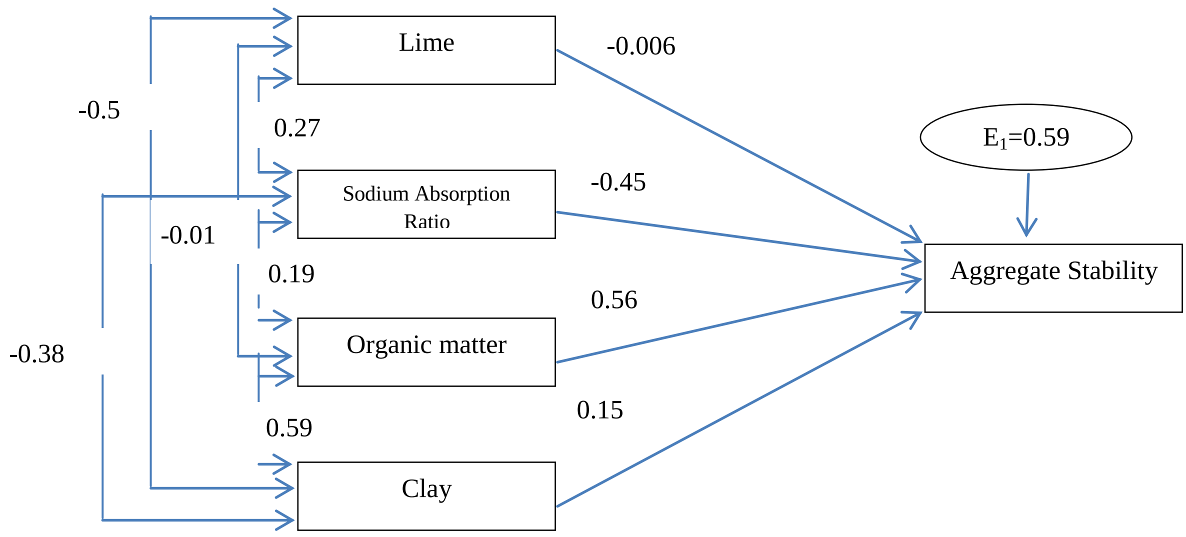

Figure 3 Path analysis diagram for the first depth (0-30 cm)

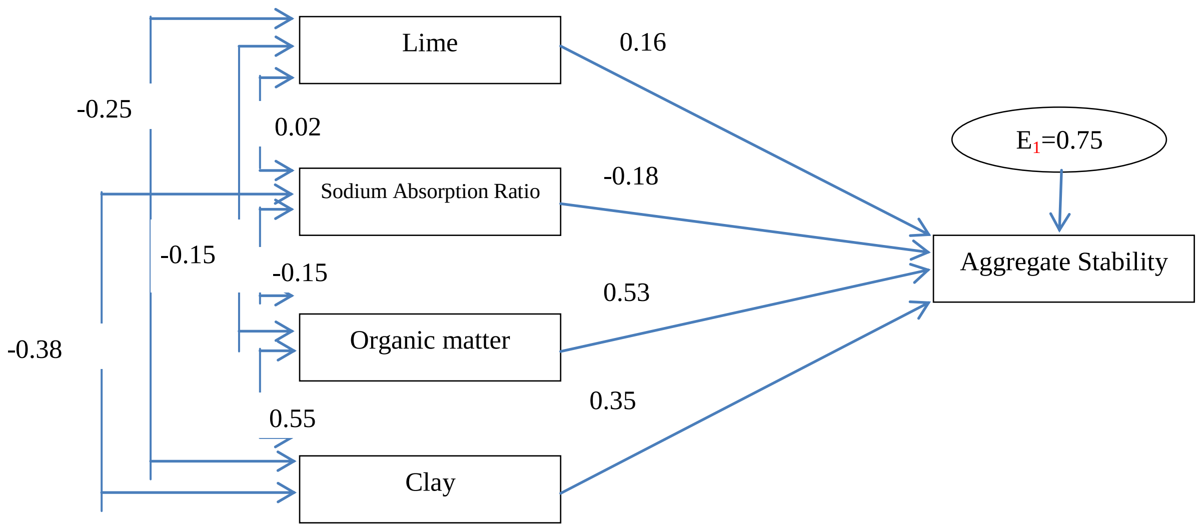

Figure 4 Path analysis diagram for the second depth (30-60 cm)

5 DISCUSSION AND CONCLUSION

Results showed that in gully lands of Ghori-Chai watershed organic matter is the most important factor affecting increased aggregate stability and thereby decreased soil erosion. Increased organic matter causes increasing stability of aggregates to break down and soil degradation and erosion. Effect of organic matter on aggregates relates humus and humic substances. Humic compounds have some positive charges in the end of itself, where there are more carboxylic groups, and for this reason they act as organic colloids of polar compounds. Clayey colloids have negative

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charges in their surface and they create orientation of polar compounds in vicinity of their surface. In moist condition superficial absorption of organic colloids by clay is partly reversible, and if drought occurs this process become quite irreversible. Thus in this process minerals interlock with each other. Finally drying the superficially absorbed humus leads to stable association between organic and inorganic materials. Since rewetting occurs slowly this process causes a strong cement effect on aggregate formation. Humus materials either in the state of flocculated or dispersed create a closed system on aggregate surface or on first ingredients of soil and make the strong cement between them. Positive effect of organic matter on aggregate stability has reported by many scientists (Tisdall and Oades 1982; Bcarden and Petersen 2000; silk 2005). After organic matter clay had the highest effect on increased aggregate stability. Clay hydration that became cemented is very difficult and long. Generally water hardly penetrates into under clay plates and the amount of this penetration is depended on the temperature in which colloid drying takes place (water between clay plates in contact with each other and in contact with sand) and also depended on amount of colloids orientation. Some of clays such as sequestered clays on surface of soil particles and in pores are not reversible. Thus durability of soil structure stability is highly depended on reversibility of hydrated clays and rate of reversibility. The cumulative effect of organic matter and clay on aggregate formation is higher than effect of organic matter or clay solely. However, effect of organic matter and clay on amount of aggregate formation is higher than effect of clays on accumulation of fine materials such as silt and clay. Rasiah and Kay (1994) found that aggregate stability with wet sieve method increase by increasing amount of clay in soil. The amount of lime in first depth had a very little and negative effect on aggregate stability but in second depth this factor had a noticeable effect on aggregate stability. In most soils liming enhance physical condition and structure of soils. In calcareous soils lime cause substitution of Sodium (with high hydrated radius) by Ca (with low hydrated radius) and consequently lead to flocculation and improve physical condition and soil structure and enhance permeability. Calcium Carbonate can sediment between soil particles as a mortar and connect them to each other. Also, effect of Ca on formation and increasing aggregate stability could be indirect and could affect production and break down of organic matter. Shainberg *et al.* (1981) concluded that by increasing the amount of Calcium Carbonate the soil structure increases. Many studies have showed that by increasing Sodium absorption ratio, electrical conductivity (EC) required for coagulation of clays increase (Abu-Sharar *et al.,* 1987; Lebron *et al.,* 2002). When wetting occurs the electrolyte concentration decreases to lower than critical limit. As a result, clay accumulation and formation of domin fails and clays become dispersed and thereby aggregates collapse. Based on these results, the most important factors affecting increased and decreased the stability of aggregates are organic matter and Sodium absorption ratio, respectively. It could be concluded that the process of aggregate stability is a very complex process and factors affecting it are correlated with each other and besides direct effect on stability they affect indirectly and also affect each other. Thus, study and controlling via increasing in stability is a very difficult task. It appears that further studies about identifying related chemical process, role of ingredient and organic matter compounds and determining contribution of aggregate stability in soil erodibility are useful to complete results obtain from this study.

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ارزیابی اثر برخی از خصوصیات خاک بر پایداری خاکدانه با استفاده از تحلیل مسیر (مطالعه موردی: خاک‌های سیلتی کلی لوم و کلی لوم در اراضی خندقی شمال غرب ایران)

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چکیده تعیین خصوصیات خاک در در اراضی که تحت تاثیر فرسایش آبی قرار دارند، بسیار مهم است. این تحقیق برای تعیین اثر بافت و ساختمان خاک بر پایداری خاکدانه‌ها با استفاده از روش الک تر در اراضی خندقی استان اردبیل اجرا شد. برای دستیابی به اهداف تحقیق، میانگین وزنی قطر خاکدانه‌ها محاسبه و ارتباط آن با میزان آهک، درصد رس، درصد جذب سدیم و مواد آلی تعیین گردید. نتایج نشان داد که مواد آلی موجود در عمق اول و دوم بیشترین اثر مستقیم مثبت را بر پایداری خاکدانه‌ها داشتند. در عمق اول، رس و آهک بیشترین اثر مثبت مستقیم را بر پایداری خاکدانه‌ها ایجاد نمودند. درصد جذب سدیم در هر دو عمق بیشترین اثر منفی را بر پایداری خاکدانه‌ها داشت. در عمق دوم مواد آلی و رس بیشترین اثر مثبت را بر پایداری خاکدانه‌ها موجب شدند. بیشترین اثر غیر مستقیم و مثبت در پایداری خاکدانه‌ها در عمق دوم از پارامترهای مواد آلی و رس ایجاد گردید. در عمق دوم، آهک پارامتر اثر مستقیم و مثبتی بر پایداری خاکدانه‌ها داشت. درصد جذب سدیم در هر دو عمق مورد بررسی اثر مستقیم و منفی بر پایداری خاکدانه‌ها ایجاد کرد.

کلمات کلیدی: فرسایش خاک، تحلیل مسیر، حوزه آبخیز قوری چای، نرم افزار R

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