The aggregates stability indicator <ASItest> to evaluate soil spatiotemporal change in a tropical dry ecosystem

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Abstract

In this work, aggregate stability was evaluated as a quality indicator in soils of tropical dry deciduous forests (TDF) with relation to land use, the sampling position in the hillslope and the sampling season. The study was done on a representative morpho-edaphological unit of the tropical dry ecosystems (hillslope on granite with eutric regosol) on the coast of the state of Jalisco, Mexico. The evaluated soil aggregation indexes were: Aggregate stability index (ASI)test, maximum stability, minimum stability, relative index of variability, and the index of quality of aggregation change. These indexes showed differences in soil aggregation resulting from changes in land use (conserved TDF, grazed TDF, and cultivated pasture). The indexes showed that there is greater stability of the aggregates during the rainy season than in the dry season; as well as in the higher part of the slope than in the lower one. The relationship of the edaphic properties with the ASItest indicator was mainly with radical volume, and less so with exchangeable bases (calcium and magnesium), clay, and organic carbon. The proposed soil aggregation indexes allowed monitoring spatiotemporal changes in soil structure.

Keywords: aggregate stability, soil quality, land degradation, soil geomorphology.

1. Introduction

The tropical dry ecosystems (TDE) have experienced continued anthropogenic disturbances that cause the deterioration of the natural resources and modifications to the ecosystem. One of the problems faced by TDE in Mexico is the loss of approximately 36,258 km^2 between 1976 and 2000, of which 23% had a change in land use to cropland and pasture (Trejo and Dirzo, 2000; Burgos and Maass, 2004). Land use changes may rapidly diminish soil quality (Aghasi *et al*., 2011).

Soil aggregation is considered a soil quality indicator that provides information on the soil's ability to function as a basic component of the ecosystem. Soil aggregation influences the transportation of liquids, gases, and heat, as well as physical processes such as infiltration and aeration (Nimmo, 2004). Soil aggregation integrates edaphic properties (physical, chemical, and biological), it is easy to measure, and it is sensitive to variations due to weather and land use (Seybold and Herrick, 2001). In addition, it is a good indicator of soil erosion and degradation (Ruiz-Sinoga and Martinez-Murillo, 2009). Consequently, it is considered an excellent tool to evaluate soil quality.

Studies about the spatial variability of soil aggregation must be done within integral units that include weather, soil, vegetation, and homogeneous geomorphology patterns (Boix-Fayos *et al*., 2001). The use of landforms (lithology and morphology) as discrete units permits an understanding of differences in soil formation, evolution and properties; thus soil aggregation depends on site-specific characteristics of the morpho-edaphological unit (Cotler and Ortega-Larrocea, 2006).

Variations in temperature and humidity can cause temporal changes in soil aggregation, which can affect soil microbial activity, arrangement of the soil particles, an increase in the isolation of organic carbon within the aggregates, changes in expansion and contraction cycles, and stability of aggregates (Franzluebbers *et al*., 2001).

Soil aggregation and aggregates stability have been evaluated using various indexes such as the geometric mean diameter, mean weight diameter, water-stable aggregation, and normalized stability index (Nichols and Toro, 2011). However, there is no universal prescription as to which of these methods should be preferred or used for specific cases. Niewczas and Witkowska (2003a) propose the aggregate stability index <ASItest> as an indicator to compare changes in soil aggregation resulting from different processes of degradation. This indicator has been tested in different soil units with various aggregate stability methods; however, it still needs to be tested across in a range of environmental conditions.

According to Niewczas and Witkowska (2003a; 2005), the ASItest indicator shows the following characteristics:

- It numerically expresses the degradation of soil aggregates as a result of the activity of different factors or processes, for example, the effect of land use and water.
- It is the first aggregate stability indicator that is evaluated from the distribution of aggregates (before the impact) and the stability of aggregates (after the impact).
- It can be used with different aggregate stability determination methods, and can evaluate aggregate degradation.
- The higher aggregates stability should correspond with a higher value of the index; the scale of ASI values is a range from 1 to 32.
- From the data available during the ASItest, the extreme stability values can be obtained, maximum (ASImax) and minimum (ASImin). There is no

other method or similar research in specialized literature that studies changes (maximum or minimum) in the stability of soil aggregates.

• Data from ASItest, (maximum (ASImax), and minimum (ASImin) stability) can be used to obtain auxiliary indexes, such as the relative index of variability (δASI) and the index of quality of aggregation change (qASI).

Most of the studies that use soil aggregation as an indicator of potential soil erosion have been undertaken in tropical humid ecosystems (Chappell *et al*., 1999; Hoyos, 2005), or in Mediterranean ecosystems (Boix-Fayos *et al*., 2001; Moreno-de las Heras, 2009). It is still necessary to do further research on the relationships and edaphological dynamics, in time and space, in tropical dry ecosystems (Garcia-Oliva and Maass, 1998; Cotler and Ortega-Larrocea, 2006). There are few studies on soil aggregation in TDE in Mexico, and therefore it is considered that establishing the benchmark of soil aggregation under a range of land use, weather, and topography typical of the TDE would be an important contribution to the characterisation of these ecosystems.

The objective of the present work was to evaluate the stability of soil aggregates as an indicator of the differences that can result from changes in land use, different topographic position, and the sampling season, in a representative morpho-edaphological unit of TDE, located on the coast of Jalisco, Mexico.

2. Material and methods

2.1 Characteristics of study area

This study was done in the Cuixmala river watershed, territorial extension 1089 km^2, located in the southwest of the state of Jalisco, Mexico. The geographical location of the watershed is 19° 29' to 19° 34' north latitude, and 104° 58' to 105° 04' west longitude. Morpho-edaphological cartography was used to select the study sites, since each morpho-edaphological unit presents homogeneous morphogenetic processes (Cotler *et al*., 2002). The most representative morpho-edaphological unit in the study zone was hillslope on granite, with eutric Regosol (Figure 1) as representative soil, given that it takes up a surface of 852.14 km^2, equivalent to 78.23% of the total area (Martinez-Trinidad *et al*., 2008). To spatially and temporally evaluate the stability of aggregates in the tropical dry ecosystem, three land uses were selected: preserved tropical dry deciduous forest (TDF), grazed TDF, and cultivated pasture. The general characteristics of the sampled sites are presented in Table 1.

2.2 Soil Sampling

Three randomly selected sites on both the higher and lower parts of the hillslope in each of the three morpho-edaphological units were sampled during the rainy season (October 2004) and the dry season (May 2005) (total of 36 samples). The samples were processed in duplicate and each replicate was considered an additional datum in the data base (total of 72 data). Sampling depth was from 0 to 8 cm, which corresponded to the topsoil. Undisturbed samples were collected as blocks, approximately 0.5 kg, and placed in 500-cm^3 containers for measurement of distribution and stability of the aggregates. Disturbed samples were collected in 1 kg bags for measurement of edaphic properties.
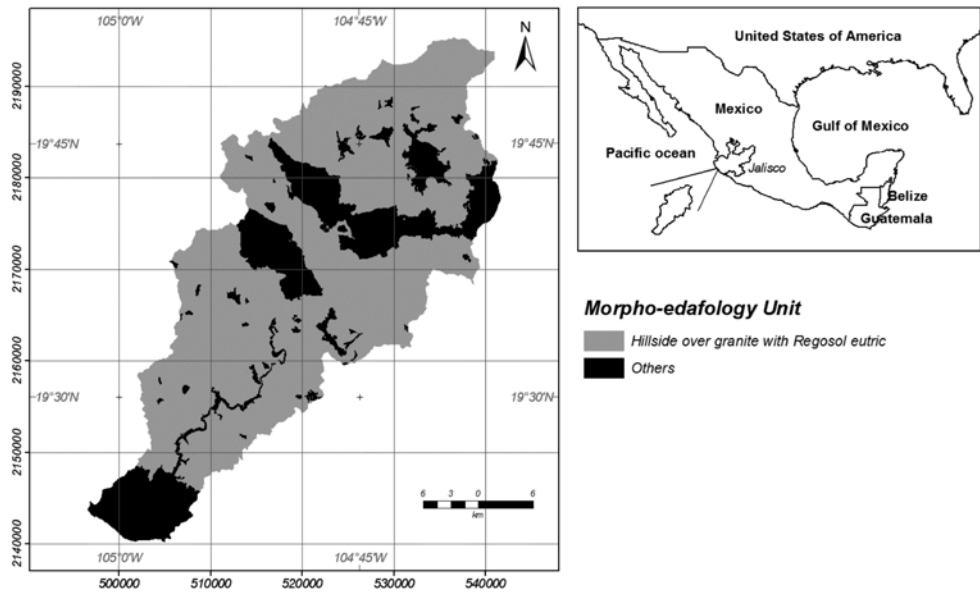
Figure 1. Study area and most representative morpho-edaphological unit.

Table 1. General characteristics of preserved tropical dry forests (TDF), grazed TDF, and cultivated pasture in the Cuixmala river watershed, Jalisco.

Characteristics	Preserved TDF	Grazed TDF	Cultivated pasture
UTM coordinates	19°29'28'' NL 104°56'14'' WL	19°38'55'' NL 104°49'35'' WL	19°36'2.4'' NL 104°52'29.2'' WL
Exposition	168° S-SW	220° S-SW	236° W-SW
Geoform	Hillslope	Hillslope	Hillslope
Parent Material	Granite	Granite	Granite
Mean slope	12°	12°	13°
Natural Vegetation	Low deciduous forest	Low deciduous forest	Induced pasture (Andropon sp.)
Antecedents	With no anthropogenic disturbance	Cattle grazing for 10 years	Cultivated for 10 years. Cattle grazing

2.3 ASItest stability indicator and auxiliary indexes: ASImax, ASImin, δASI, and qASI

The ASItest indicator was determined using the Niew-czas and Witkowska 2003a method, which consists on

the registry of the aggregates distribution and stability in a transition table. The aggregate distribution was determined using the dry sieving method (Chepil, 1952), and aggregate stability was determined using the Yoder method (modified by Kemper and Rosenau,

1986). Both determinations were done in duplicate. Six size ranges of aggregates were measured in this study: >4.76 mm; 4.76-3.36 mm; 3.36-1.00 mm; 1.00-0.50 mm; 0.50-0.25 mm; <0.25 mm.

The ASItest indicator scale has a range from 1 to 32. The highest value of the ASItest is 32, and represents complete stability of the aggregates after the degradation factor, this is to say, the aggregate frequencies before and after the impact is the same. The lowest value of the ASItest is 1, corresponding to the lowest aggregate stabilities. This happens when after the degradation factor the aggregates are broken down into aggregates of a smaller diameter. The ASItest indicator is a sum of the products of diagonal distribution frequencies by weights: $ASItest = d_0w_0 + d_1w_1 + \ldots + d_5w_5$. The most general way to express this indicator is the following:

$$ASItest = \sum_{i, j} p_{ij} w_{ij} \qquad (1)$$

Where p_{ij} are the frequencies of the transition table, w_{ij} are the weights assigned separately to each element of p_{ij}. Weight assignation (w_{ij}) makes the ASItest indicator be represented as a value of a linear function of the frequencies from the transition table.

From the data available during the ASItest, the extreme stability values, maximum (ASImax) and minimum (ASImin), were obtained as additional information about the changes in soil aggregation. The maximum (ASImax) and minimum (ASImin) stability indexes determine the interval of the ASItest stability indicator; it is a range of the possible variations that can be found within a soil sample. To obtain ASImin and ASImax, it is necessary to build the transition tables, considering the input and output frequencies of the ASItest transition table, and the weights assigned diagonally. After that, a lineal programming algorithm is used to find the extreme values corresponding

to ASImin and ASImax, this procedure is described in Niewczaz and Witkowska, 2003b.

Niewczas and Witkowska (2005) proposed the following indexes:

a) Relative range of aggregate stability (δASI); it is the variation in stabilities that can exist in a soil sample, and is defined by the following equation:

$$\delta ASI\,(\%) = [(ASImax-ASImin) / ASItest] \times 100 \qquad (2)$$

b) Index of quality of aggregation change (qASI); it is the measurement of the position of ASItest in the stability interval [ASImin 0% and ASImax 100%], and is defined by the following equation:

$$qASI\,(\%) = [(ASItest - ASImin) / (ASImax - ASImin)] \qquad (3)$$

2.4 Edaphic properties

Residual moisture content was measured gravimetrically (water content in the sampling season). Clay content was determined using the pipette method (Gee and Bauder, 1986). Real density was determined using the pycnometer method, and apparent density using the cylinder method (Blake and Hartge, 1986). Total porosity (Pt) was calculated from the apparent density (Da) and real density (Dr) data:

$$Pt(\%) = [1- (Da / Dr)](100) \qquad (4)$$

Organic carbon was measured by the dry combustion method (Shimadzu, TOC-5050A model). Exchangeable bases were measured by the method of ammonium acetate 1N pH 7.0 (Sumner and Miller, 1996). Root biomass was quantified with the methodology used in Castellanos *et al*. (2001), which uses the principle of displaced volume.

2.5 Clay mineralogy

The diffractograms of clays isolated from the surface soil samples allowed distinguishing the type of clay mineralogy present in preserved TDF, grazed TDF, and cultivated pasture. Clay mineralogy was determined using the X-Ray method. A 20 g soil sample was sifted through a 2 mm sieve, after having been cleansed of organic matter with H_2O_2 at 30%, at 70°C. The solution was decanted in a 1 liter beaker, taken to volume, and shaken 40 times. After 16 hours, it was siphoned to a height of 15 cm. Then, it was centrifuged at 3500 rpm for 20 minutes. The collected soil solution was used to impregnate previously labeled slides for each land use. The slides were then left to dry at room temperature. Some samples were treated with glycol ethylene and others were put in a muffle at 400ºC for 2 hours. Lastly, an X-Ray diffractometer was used at a 2k resolution, these indicated from 35° to 2° (2ө). The reflections (peaks) of the difractograms were identified using the charts reported in the Mineral Powder Difraction File (JCPDS, 1980).

2.6 Statistical analysis

The obtained results were subjected to a factorial analysis of variance for the factors of land use, sampling season and the slope position, with their respective interactions: land use*position, land use*sampling season, position*sampling season, and land use*position*sampling season. The mean comparison was done with the Tukey minimum significant difference criterion ($\alpha = 0.05$) when there was an effect and/or significant interaction. Lastly, a correlation of the ASItest indicator with the edaphic properties was done. The SAS software, version 8 (Cody and Smith, 1997), was used for the statistical analysis.

3. Results and Discussion

3.1 Factorial analysis of variance

The factorial analysis of variance is showed in Table 2. The indicators were specially influenced by the primary factor of land use, while sampling season and the slope position had a lesser degree influence. The main effects were independent, due to lack of interactions. With regard to the main effect exceptions, it is worth mentioning the case of maximum stability index (ASImax), and the index of quality of aggregation changes (qASI), which were not influenced by sample position in the slope; and the relative index of variability (δASI) and the index of quality of aggregation change (qASI), which were not affected by the sampling season. Finally, the land use affected all indicators.

Table 2. Factorial analysis of variance for the indicators in the Cuixmala river watershed, Jalisco.

Factors and interactions	Indicators Pr > F				
	ASImax	ASItest	ASImin	δASI (%)	qASI (%)
Land use (Lu)	<.01	<.01	<.01	<.01	<.01
Position		<.01	<.01	<.01	
Sampling season (Ss)	<.01	<.01	<.01		
Lu*Position					
Lu* Ss					
Position* Ss					
Lu*Position* Ss					

ASImax: maximum stability index. ASItest: stability index. ASImin: minimum stability index. δASI: relative index of variability. qASI: index of quality of aggregation change.

3.2 Distribution and aggregate stability

The distribution and aggregate stability of different fractions of aggregate size for each land use, is showed in Figure 2. For the aggregate distribution, the preserved TDF had the highest ratio of macro-aggregates ranged from 1.00 to 3.36 mm size, while in grazing TDF prevailed, especially, macro-aggregates sized > 4.76 mm, and the cultivated pasture had a larger ratio of micro-aggregates sized < 0.25 mm. The aggregate stability was not the same in all the fractions of aggregate size, the relative ratio of aggregate < 0.25 mm was high in all of the three land uses, but mainly, in preserved TDF. The stability of aggregate sizing from 1.00 – 3.36 mm, were highest in preserved TDF, but aggregates sizing > 4.76 mm were higher in grazing TDF and cultivated pasture.

The distribution of aggregates sized < 0.5 mm and 1.0 – 2.0 mm resulted significantly higher in rainy season than in dry season. The stability of aggregates ranged from 0.25 – 0.50 mm were more significantly stable in rainy seasons than in dry seasons. The distribution of aggregates ranging from 3.36 – 4.76 mg resulted significantly higher in the low position than in upper position of the hillslope. There were not significantly differences between the upper and low positions of the hillslope for aggregate stability. The minor significant differentiation in aggregate distribution and stability in sampling season and in hillslope sampling position was because of the high standard deviation showed by different fractions of aggregate size.
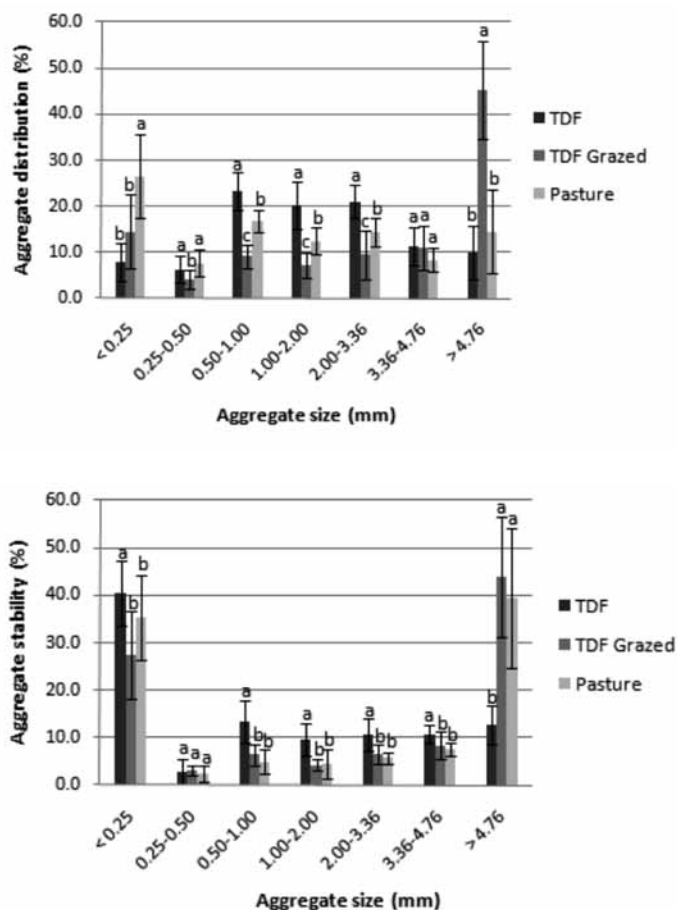
Figure 2. Aggregate distribution and stability means, done on soil samples from preserved and grazed tropical dry forest and cultivated pasture in the Cuixmala river watershed, Jalisco, Mexico. Error bars represent the standard error of the means. Different letters in the same aggregate size class mean significant differences (Tukey, $p \leq 0.05$).

3.3. Effect of land use

The effect of land use caused significant differences on ASItest indicator, and on ASImax and ASImin indexes (Table 3). Grazed TDF and cultivated pasture showed higher aggregate stability (ASImax and ASItest). For the case of grazed TDF, this could be due to livestock trampling, which causes soil aggregate compaction. Stavi *et al.* (2010) found a higher

number of macro-aggregates on surfaces affected by grazing. For the case of cultivated pasture, it could be due to dense roots and large root systems, supporting the soil aggregation. The exudates and other organic components provided by roots, promote the production of binding agents in soil aggregation (Paudel *et al.,* 2011).

By establishing a relationship between the ASItest indicator and water erosion, grazed TDF and cultivat-

ed pasture showed higher resistance to water erosion effect, showing a larger amount of aggregates sized > 4.76 mm (Figure 2 – aggregate stability). Compressed soil by cattle trampling reduces infiltration and increases laminar erosion; it is characterized by the removal of fine soil particles (Descroix *et al.,* 2008). It has been found a lower rate of water erosion in pasture than in forest (Zokaib and Naser, 2011).

Preserved TDF and cultivated pasture showed smectite clay, montmorillonite type, and a few particles of mica, while grazed TDF presented kaolinitic clay, some swollen clay and mica. The clay mineralogy could be an influence for major stabilities of grazing BTC (ASItest, ASImax and ASImin). Lado and Ben-Hur (2004) established that kaolinitic soils, which do not contain smectite, were stable soils, in contrast, smectitic soils were unstable. Preserved TDF showed lower stability indicator values (ASItest, ASImax and ASImin), displaying a greater number of aggregates sized < 0.5 mm (Figure 2 – aggregate stability). The susceptibility of preserved TDF to water erosion process could be caused by the major diversity in the aggregate sizes, mainly, in aggregates sizing from 0.5 to 3.36 mm (Figure 2). This causes greater susceptibility of the aggregates to suffer disruption due to water. This aggregate distribution is seen with the relative range of aggregate stability (δASI), thus, showing preserved TDF the highest percentage of variability, which is re-

lated with a better structural state of soil, which benefits liquid, gas and heat transport, providing favorable conditions for the growing of dry tropic vegetation.

The physical and chemical properties of preserved TDF, grazed TDF and cultivated pasture soil, are described in Martínez-Trinidad *et al.* (2008). This work shows that an increase in the intensity of soil management caused an increase in the apparent density value, a decrease in the internal porosity of the macro-aggregates, decrease in the pH value and organic carbon.

The preserved TDF and cultivated pasture showed a higher value in quality index of aggregation change (qASI), being lesser in grazing TDF. This index takes into account the location of ASItest within the stability interval (ASImax 100%; ASImin 0%). The ASItest index of preserved TDF and cultivated pasture are closer to the ASImax; while the ASItest of grazing TDF is nearest to ASImin (Table 3). The most favorable location of ASItest (from the point of view of aggregation stability of a given soil) is overlapping the location of ASImax; such a location of ASItest means that the real changes of aggregation of a soil sample corresponded, in that case, with the most favorable changes that could be obtained in the frame of the variation range, being determined by a pair of distributions from the input and output aggregate frequencies (Niewczas and Witkowska, 2005).

Table 3. Statistical data of the indicators from land use, sampling season and sampling position of the hillslope in the Cuixmala river watershed, Jalisco, México.

Indicator	MSD	M	SD	M	SD	M	SD
		Preserved TDF		Grazed TDF		Cultivated pasture	
ASImax	2.4	23.3 b	2.3	28.4 a	2.6	26.1 a	2.3
ASItest	2.4	20.8 b	2.2	24.4 a	2.8	23.9 a	2.1
ASImin	2.7	17.3 b	2.6	22.1 a	3.2	21.1 a	2.0
δASI (%)	7.6	34.1 a	6.6	26.3 b	7.5	16.6 c	2.9
qASI (%)	6.1	50.9 a	6.6	36.0 b	6.0	56.5 a	5.6

Continued...

Indicator	MSD	M	SD	M	SD	M	SD
		Rainy season		Dry season			
ASImax	1.3	27.6 a	2.1	25.0 b	1.9		
ASItest	1.2	24.4 a	1.8	22.0 b	2.0		
ASImin	1.1	21.7 a	2.2	19.3 b	1.7		
		High position		Low position			
ASItest	1.2	24.3 a	1.8	22.1 b	1.6		
ASImin	1.1	22.0 a	2.3	19.0 b	1.9		
δASI (%)	3.7	20.7 b	8.1	30.7 a	7.2		

MSD: minimum significant difference. M: mean. SD: standard deviation. Different letters in the same line mean significant differences (Tukey, $p \leq 0.05$). TDF: tropical dry forests. ASImax: maximum stability index. ASItest: stability index. ASImin: minimum stability index. δASI: relative index of variability. qASI: index of quality of aggregation change.

3.4 Effect of sampling season

The effect of sampling season was statistically significant in maximum stability indicators (ASImax), ASItest stability and minimum stability (ASImin). These indexes were higher in rainy season than in dry season (Tabla 3). Soil samples collected in rainy season showed better aeration, having higher porosity and lower bulk density than in dry season (Table 4). The rainy season exhibited higher radical volume content due to the increase of moisture. There were not significantly differences in organic carbon content for both sampling seasons, but it showed higher content levels. The greatest aggregate stability during rainy season could be due to the increase in radical volume and the high organic matter content in soil.

García-Oliva *et al.* (2003) established that at the end of the rainy season, an accumulation of labile nutrient forms was developed, and its accumulation enhances microbial activity; therefore, this seasonality influences the nutrient redistribution between aggregate fractions. They suggest that soil organic matter associated with macro-aggregates, represents the main energy source for microbial activity at the onset of the wet season, while micro-aggregates protect the labile nutrient forms during the growing season.

There are different studies disclosing that in dry season, greater contents of total carbon are acquired, decreasing of this property from dry to wet season suggests a rapid decomposition and mineralization of litter-derived organic materials during the wet season (Montaño *et al.,* 2007; Yamashita *et al.,* 2011). These soil processes could be positively influencing the stabilization of soil aggregates.

There were not significant differences between both sampling season for relative range of aggregate stability (δASI), and for quality index of aggregation change (qASI).

3.5 Effect of slope position

The effect of the slope position, where samples were collected, showed significant differences in the stability index ASItest, minimum stability (ASImin) and relative index of variability (δASI).

The stability index ASItest and the minimum stability suggest greater aggregate stability at the upper position than at the low position of the hillslope (Table

3). The greater stability of aggregates and total porosity at the upper position of the hillslope could be due to the organic carbon content, although there were no significant differences in the organic carbon content in both hillslope positions (Table 4). Montaño *et al.* (2007) found that organic carbon concentrations were higher at the hilltop than at the hillslope soils, which is in line with a higher organic material accumulation. The lower clay percent occurred at the upper position of the hillslope, where clay is removed by erosion. The decreased of total porosity was influenced by the increase of clay at the low position of the hillslope. Ruiz-Sinoga and Martinez-Murillo (2009) stated that the soil surface components act as regulator for the hydrological dynamics of soil with varied spatial and temporal effects, due to their heterogeneous spatial distribution. The relative index of variability (δASI) was greater at the low position than at the upper position of the hillslope (Table 3). This result suggests a higher variety of aggregates with different sizes in said position. Such behavior could be due to the susceptibility of hillslope to water runoff causing the transport of soil particles toward topographically lower areas (Bryan, 2000). The quality index of aggregation change (qASI) showed no significant differences in both positions of the hillslope.

Table 4. Statistical data of the edaphic properties from sampling season and sampling position of the hillslope in the Cuixmala river watershed, Jalisco, México.

Edaphic properties	MSD	M	SD	M	SD
		Rainy season		Dry season	
Residual moisture (%)	1.0	11.6 a	5.0	0.4 b	0.3
Bulk density (Mg m^{-3})	0.04	1.0 b	0.1	1.1 a	0.1
Total porosity (%)	1.8	58.5 a	6.3	53.6 b	5.4
Organic carbon (%)	0.6	3.6 a	1.7	3.0 a	1.1
Humid roots (cc)	1.0	4.6 a	0.8	0.2 b	0.1
		High position		Low position	
Residual moisture (%)	1.0	5.0 b	6.5	6.9 a	6.8
Bulk density (Mg m^{-3})	0.04	1.0 b	0.1	1.1 a	0.1
Total porosity (%)	1.8	58.2 a	4.8	53.8 b	7.0
Clay (%)	1.7	12.4 b	6.3	17.6 a	6.6
Organic carbon (%)	0.6	3.1 a	1.5	3.6 a	1.4
Humid roots (cc)	1.0	2.4 a	2.8	2.4 a	2.9

MSD: minimum significant difference. M: mean. SD: standard deviation. Different letters in the same line mean significant differences (Tukey, $p \leq 0.05$).

3.6 ASItest correlation with edaphic properties

The stability index ASItest exhibited significant correlations with the edaphic properties (Figure 3). The figure displays that the higher correlations acquired with the ASItest indicator were the volume of wet and dry roots. Such positive relationship points out that roots have an important contribution into the aggregate stability. The roots exude organic compounds and minerals which promote the production of binding agents,

supporting soil aggregation (Czarnes *et al.,* 2000; Paudel *et al.,* 2011). The relationship of clay with the ASItest was significantly negative. Clay-sized particles are commonly associated with aggregation by re-arrangement and flocculation, although swelling clay can disrupt aggregates (Bronick and Lal, 2005). Calcium and magnesium showed a significant negative relationship with the ASItest indicator. Cations such as calcium and magnesium promote precipitation of compounds that act as bonding agents for primary particles; also cations are capable of forming bridges between clay and carbon organic particles resulting in aggregation (Zhang and Norton, 2002). The rela-tionship of organic carbon with the ASItest indicator was significantly low and negative; this latter result is contrary to what it has been disclosed in the sci-entific literature. There are studies showing the close relationship between organic carbon and aggregate stability (Tisdall and Oades, 1982; Malamoud *et al.,* 2009). The relationship of aggregate stability (macro-aggregate > 1 mm and microaggregate < 1 mm) with edaphic properties have been disclosed in Martínez-Trinidad *et al.* (2008). This work shows that macroag-gregates have a positive relationship with the volume of roots and organic carbon, while microaggregates have positive relationships with clay and calcium.
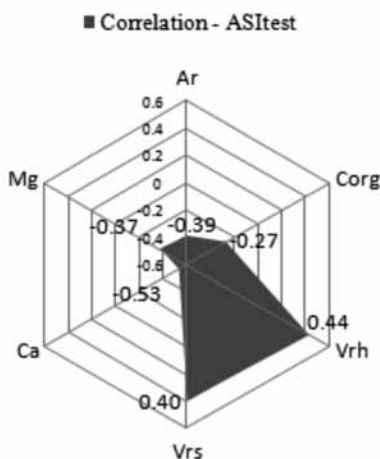

Figure 3. ASItest correlation with edaphic properties in the Cuixmala river watershed, Jalisco, Mexico. Ar: clay. Corg: organic carbon; Vrh: volume of wet roots. Vrs: volume of dry roots. Ca: calcium. Mg: magnesium. Significant correlations (Pearson, $p \leq 0.05$).

4. Conclusions

The aggregate stability index (ASItest) and their aux-iliary indexes showed differences in soil aggregation resulting from changes in land use. The aggregate stability index as a linear function, allowed to found significant differences between sampling season, and sampling position of the hillslope, this behavior was not showed in aggregate stability. The sampling sea-sonal changes, showing greater aggregate stability in rainy season than in dry season. The structural state of soil on hillslope revealed greater aggregate stability on high position than in low position on hillslope, but this lower position showed higher variability in aggre-gate stability. The aggregate stability index exhibited, mainly, a relationship with root volume, in a lesser ra-

tio with clay, organic carbon, and exchangeable bases (calcium and magnesium).

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