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Soil moisture retention and mass movement of volcanic soils from the "Sabinas" sector in Caldas, Colombia

Retenciòn de la humedad del suelo y movimiento masivo de suelos volcánicos del sector "Sabinas" en Caldas, Colombia

William Chavarriaga Montoya[1*], Gabriel Cruz Cerón[1] and Johan Cuervo Correa[2]

[1]Facultad de Ciencias Agropecuarias, Departamento de Desarrollo Rural y Recursos Naturales. Universidad de Caldas. Manizales-Caldas, Colombia.[2]Universidad Nacional de Colombia Sede Medellín. Medellín-Antioquia, Colombia. Author for correspondence: william.chavarriaga@ucaldas.edu.co

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Abstract

The mass movement of soils, are soil, rocks displacements or both, caused by soil water excesses in terrains due to gravity effects and other factors. The aim of this research was to quantify the moisture retention capacity of volcanic soils as a threat indicator in the mass removal phenomena. This research was carried out on soils of the Malteria - Las Margaritas road transept to Magdalena river, right bank of the Chinchiná river in the Department of Caldas, Colombia. Through soil sample design, 3 altitudinal ranges were stratified as follows: high, medium and low. In fact, representative plant cover was taken in the study area, sampling the combination of the following variables: "plant cover" and "altitudinal range". In total, 52 points were sampled and georreferenced. High moisture retention was confirmed with saturation levels at different stresses as fundamental triggers of the phenomenon as a consequence of the soil aggregates instability to soil moisture, high porosity and high hydraulic conductivity and its relation with the mineralogy of these soils, high rainfall regimes of the region, altitudinal position, terrain slopes, which determine the relative threat by mass movement of soils. Intervariable correlations were found to facilitate the explanation of the mass removal of soil phenomena in the study area, including some of a significant order referring to the association between "humidity threat" and soil organic matter variables for the analyzed plant covers.

Key words: Hydraulic conductivity, humidity threat, soil aggregates, soil mass removal, stability.

Resumen

Los movimientos masales son desplazamientos de masas de suelo, rocas o ambos provocados por excesos de agua en los terrenos por efectos de la gravedad y otros factores. El objetivo de la presente investigaciòn fue cuantificar la capacidad de retención de humedad de suelos de origen volcánico, como indicador de amenaza en los fenómenos de remoción masal. Esta investigación se realizó en suelos del transepto vial Maltería - Las Margaritas vía al Magdalena, vertiente derecha del río Chinchiná en el Departamento de Caldas-Colombia. Mediante el diseño muestral, se estratificaron 3 rangos altitudinales: Alto, Medio y Bajo. Se tomaron coberturas representativas en la zona de estudio, muestreando la combinación de las variables "cobertura" y "Rango altitudinal". En total se muestrearon y georreferenciaron 52 puntos. Se confirmó alta retención de humedad con niveles de saturación a diferentes tensiones como detonantes fundamentales del fenómeno como consecuencia de la inestabilidad de agregados del suelo al agua, alta porosidad y alta conductividad hidráulica y su relación con la mineralogía propia de estos suelos, altos regímenes pluviométricos de la región, posición altitudinal, pendientes del terreno que condicionan la amenaza relativa por movimientos masales. Se encontraron correlaciones intervariables que facilitan explicar el fenómeno de remoción masal en la zona, entre ellas algunas de orden significativo referidas a la asociación entre la variable "Humedad-Amenaza" y la materia orgánica para las coberturas analizadas.

Palabras clave: Agregados del suelo, conductividad hidráulica, estabilidad, humedad amenaza, remoción masal del suelo.

Introduction

The volcanic soil moisture retention is a key factor in the origin of erosion processes. The Andisols had achieved high water retention capacity, reaching saturated condition up to three times their soil dry mass, which translates into a greater sliding force in the slopes direction (Landslides). The area has undergone great erosion and significant impacts, both environmental and socioeconomic, aggravated by rainfall, which leads to large soil losses, landslides, road restriction, and various risks, which compromise resources of all kinds: soil, landscape, biodiversity and even human lives.

These soils have strong slopes of 30 (67%) to 35 degrees (78%) and extensive slope lengths; its concavity, favors the accumulation of surface and sub-surface soil waters. The predominant surface soils present a low plasticity and cohesion (Rao, 1996).

Mass movement of soils occur periodically in many regions of the world. According to Alcántara (2002), its impact varies depending on the geological conditions of each location, as well as its socio-economic vulnerability, and justifies the threat assessment of these phenomena and the ability to predict these soil movements, which has become one of the interesting themes for the scientific community.

Significant advances in this matter at the global level have been applied in recent years in the determination of critical thresholds, defined from physical or statistical models, combined with rain forecasts and real-time monitoring, as an integral and fundamental part of early warning systems (Aristizábal, Martínez & Vélez, 2010).

The mass movement of soils are soil or rock displacements caused by excess soil water and by gravity effect, is estimated that 16% of the Colombian area is affected by this phenomenon (IDEAM,1996), they are factors that predispose mass movement of soils as follows: types of susceptible rocks, hillside hydrology, unstable bedrock structure and tectonism. In fact, mass movement of soils can be detonated by earthquakes or associated with volcanic activity and are often the most catastrophic because they occur unexpectedly. The mass movement of soils by rainfall are the most frequent.

Lal, Hall & Miller (1989), indicates that soil degradation processes usually starts with soil structure deterioration and especially, soil functional attributes, which have allowed to transmit and retain soil moisture and facilitate root development. Given these concerns, the aim of this research was to relate soil physical characteristics with soil moisture storage capacity, and to assess the soil moisture retention capacity and soil cover as detonating factors for mass removal phenomena of volcanic soils in Caldas, Colombia.

Materials and methods

The study was carried out on soils of the "Maltería - Las Margaritas" transept, in the Department of Caldas-Colombia. The units of analysis, landscape or soil use, consisted of 5 types of plant cover in 3 altitudinal ranges, as described in Table 1.

Table 1. Plant cover and altitudinal ranges

Plant cover	Altitude ranges (m.a.s.l.)
Secondary plant cover	
Pasture mosaic with natural space	Low: 2400 – 2600
Forest	Medium: 2600 – 2800
Clean pasture	High: > 2800
Weeded pasture	

For soil sampling, digital cartographic information was taken as base (IGAC-CORPOCALDAS, 2013), stratified in 3 altitudinal ranges: high, medium and low duly specified, and considered representative of the study area (IDEAM,1996). Sampling sites were randomly selected using ArcGIS ® software functions. Such sampling sites was performed based on 4 replicates in combination of the "plant cover" and "altitudinal range" variables (Table 2). At each point, soil profiles were described at 1.50m depth. Each soil profile was described according to the methodology suggested by IGAC- CORPOCALDAS (2013).

Therefore, soil physical analysis for the evaluated variables were processed in the laboratory of soil physics at the Universidad Nacional de Colombia campus Palmira, Palmira-Valle del Cauca, Colombia. (Table 3).

Table 2. Plant cover and altitudinal range system relationship in evaluation

id	Plant cover system	Altitudinal range (m.a.s.l.)	Convention (m.a.s.l.)
1	Weeded pasture	High: > 2800	PE>2.800
2	Secondary plant cover	High: > 2800	VS>2.800
3	Secondary plant cover	Medium: 2600 a 2800	VS(2.600-2.800)
4	Secondary plant cover	Low: 2400 a 2600	VS(2.400-2.600)
5	Pasture mosaic with natural space	High: > 2800	MP>2.800
6	Pasture mosaic with natural space	Medium: 2600 a 2800	MP(2.600-2.800)
7	Pasture mosaic with natural space	Low: 2400 a 2600	MP(2.400-2.600)
8	Dense high forest of dry land	High: >2800	BDA>2.800
9	Dense high forest of dry land	Medium: 2600 a 2800	BDA(2.600-2.800)
10	Dense high forest of dry land	Low: 2400 a 2600	BDA(2.400-2.600)
11	Clean pasture	High: > 2800	PL>2.800
12	Clean pasture	Medium: 2600 a 2800	PL(2.600-2.800)
13	Clean pasture	Low: 2400 a 2600	PL(2.400-2.600)

Table 3. Variables, units and determination methods relationship

Variables	Method	Unities and/or calculation
Plant cover	Descriptive	
Altitude range	Measurement	m.a.s.l.
Description guide of soil profiles	Descriptive	
Soil apparent density	Core method	
Real soil density	Picnometer	
Total porosity	Calculation	$N = \left[1 - \frac{D_A}{D_R}\right] * 100$
Coefficient of dispersion	Pipette method	
Saturation		
Soil moisture retention	Tension pots and plates	Bars: 0.1, 0.3, 1.0, 3.0, 5.0, 10, 15
Stability of soil aggregates	Yoder method	Tamices: 10, 20, 35, 60, >60
Soil stability index	Método de Yoder	IE= $(X_2+X_3+X_4)/(X_1+X_5)$
APD	Average particle diameter	mm
Soil aggregation status	Percentage	%
Saturated hydraulic conductivity	Constant head permeameter	mm. hour^{-1}
Humidity of threat	Calculated	m^3

Allofanes were identified with the NaF test (+) (Fieldes & Perrot, 1966). The concept of humidity threat was calculated taking into account the soil surface weight and saturation point (80, 35, 41 and 38%, respectively). This have allowed to quantify the soil water, which can be retained in each soil horizon. The variables were statistically processed using the SAS® 9.2 software, calculating mean, standard deviation, minimum and maximum parameters. Simple correlations among physical variables included in the database, were estimated. To identify significant difference among treatments and statistical significance for all comparisons was made at p ≥0.05 with the Spearman test.

Results

Soil stability index for different plant covers in the 3 altitudinal ranges

Figures 1,3 describes the soil aggregate stability variable for 3 established altitude ranges. In fact, soil stability index estimates the degree of soil susceptibility to erosion. Figure 1, shows the soil profile and horizons. It was observed with particular interest on the soil stability index, the following results are highlighted as high: For the B horizon in "WP" plant cover and altitude range> 2800 m.a.s.l.; in the average altitudinal range and in the "PMNS" plant cover, the soil stability index is 0.470 for A horizon (Figure 2), and in the low altitude range for "CP" plant cover, a soil stability index of 0.345 in the Bb horizon (Figure 3).

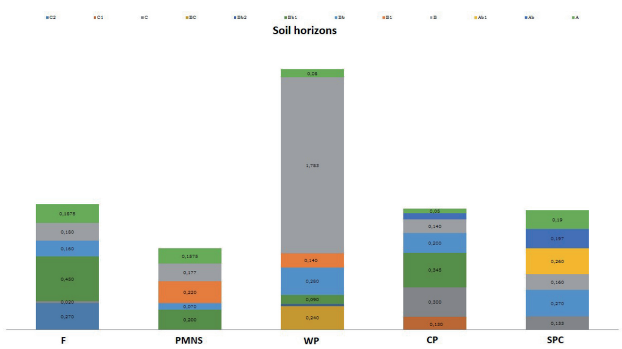

Figure 1. Soil stability index of soil aggregates for horizons in the evaluated plant covers in the high altitudinal range (>2800 m.a.s.l.). F: forest; PMNS: Pasture mosaic with natural space; WP: weeded pastures; CP: clean pastures; SPC: secondary plant cover

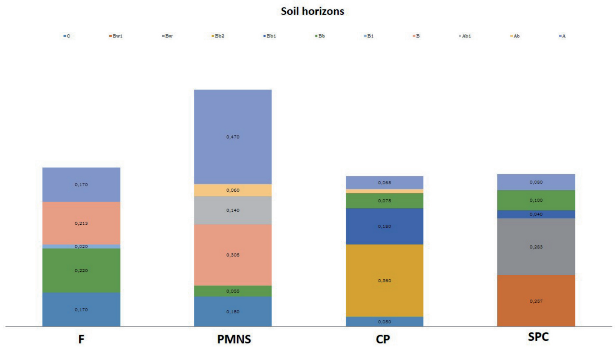

Figure 2. Soil stability index of soil aggregates for horizons in the evaluated plant covers in the medium altitudinal range (2600-2800 m.a.s.l.). F: forest; PMNS: Pasture mosaic with natural space; CP: clean pastures; SPC: secondary plant cover.

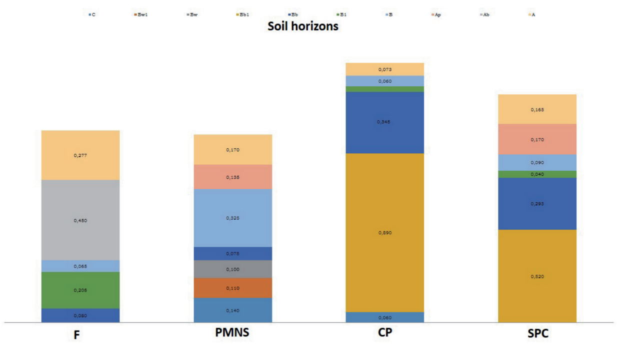

Figure 3. Soil stability index of soil aggregates for horizons in the evaluated plant covers in the low altitudinal range (2400-2600 m.a.s.l.).F: forest; PMNS: Pasture mosaic with natural space; CP: clean pastures; SPC: secondary plant cover.

Humidity – Threat index for different plant covers in the 3 altitudinal ranges

Figures 4-6, represent Humidity-Threat variable of soil aggregates in the 3 established altitudinal ranges. For example, for SPC variable, in the medium altitudinal range, the soil moisture retained in each soil horizon, corresponded to values of 3041010 and 626831 m^3, respectively, which added up to 3667841 m^3 of soil water. ha^{-1}, referred to herein as humidity-threat (Table 4).

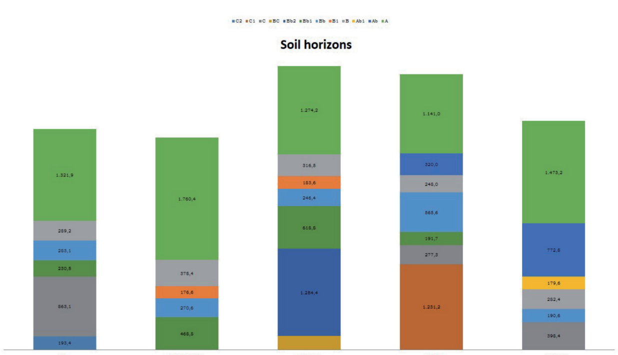

Figure 4. Humidity-threat index for soil horizons of plant covers in the high altitudinal range (>2800 m.a.s.l.). F: forest; PMNS: Pasture mosaic with natural space; WP: weeded pastures; CP: clean pastures; SPC: secondary plant cover.

Table 4. Soil physical properties of soil horizons: secondary plant cover and medium altitudinal range (2400-2600 m.a.s.l.)

Plant cover/Altitudinal range	Soil horizons	
2400-2600 (m.a.s.l.)	**A**	**Bb**
Altitude (m)	2.444	2.444
Ad (g cm^{-3})	1.05	1.01
Dr (g cm^{-3})	2.41	2.55
Total porosity (%)	56.43	60.39
Macro (%)	24.25	43.84
Meso (%)	13.25	6.81
Micro (%)	18.93	9.74
Coefficient of dispersion	11.42	13.33
CC	32.18	16.55
Saturation point	80.45	41.38
Sieve # 10 (2mm) (%)	87.8	92.8
Sieve # 20 (0,84 mm) (%)	3.48	1.52
Sieve # 35 (0,5 mm) (%)	2.88	3.36
Sieve # 60 (0,25 mm) (%)	1.48	1.24
Sieve # >60 (<0,25 mm) (%)	4.36	1.08
Soil stability index	0.08	0.06
DPM (mm)	5.1	5.33
Soil aggregation status	94.16	97.68
Hydraulic conductivity (K) (mm h^{-1})	145.51	138.9
Humidity-threat (m^3)	3.041.01	626.831
SOM (%)	16.46	14.36

Average coefficients of dispersion recorded for the previous soil horizons of 12.38%, allow to qualify the soil as stable. In fact, AWD (average weighted diameter) with an average of 5.22 as well as the soil aggregation status (95.92%), which have allowed to evaluate the soil as very stable; compared to the standard parameter (> 90%).

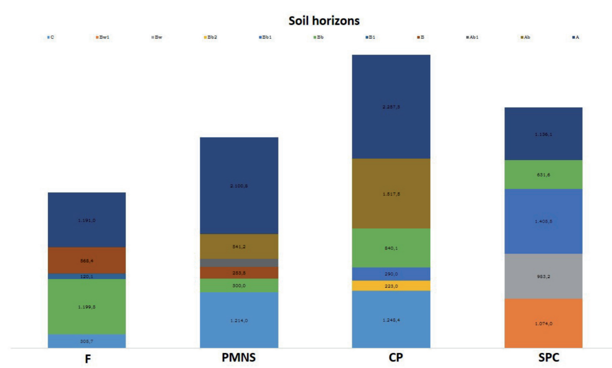

Figure 5. Humidity-threat index for soil horizons of plant covers in the medium altitudinal range (2600-2800 m.a.s.l.). F: forest; PMNS: Pasture mosaic with natural space; CP: clean pastures; SPC: secondary plant cover.

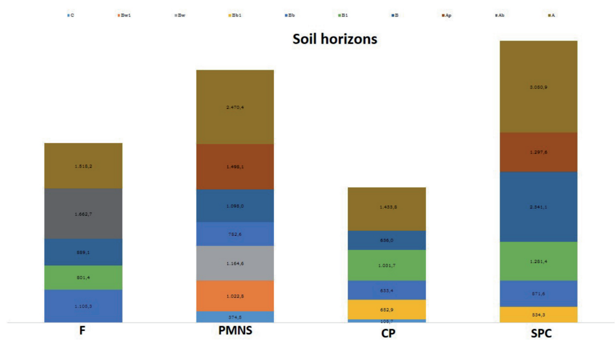

Figure 6. Humidity-threat index for soil horizons of plant covers in the low altitudinal range (2400-2600 m.a.s.l.). F: forest; PMNS: Pasture mosaic with natural space; CP: clean pastures; SPC: secondary plant cover.

The saturated hydraulic conductivity (Ks), with values of 145.51 and 138.9 mm.h^{-1}, for soil horizons A and Bb; identifies the speed with which soil water permeates the soil horizon. According to the results presented in Tables 5 and 6, the analyzed variables; they emphasize soil physical behaviors according to those reports previously described.

In the present research was found that in secondary plant cover (SPC) at medium altitudinal range, the hydraulic conductivities for soil horizons A, Bw and Bw1, are very high (Tables 5,6).

Table 5. Soil physical properties of the soil horizons: secondary plant cover and low altitudinal range

Plant cover/Altitudinal range	Soil horizons		
Secondary plant cover (SPC) 2.600-2.800 m.a.s.l.	**A**	**Bw**	**Bw1**
Altitude (m.a.s.l.)	2630	2630	2630
Ad (g cm^{-3})	0.75	0.77	0.87
Rd (g cm^{-3})	2.41	2.55	2.57
Total porosity (%)	68.88	69.8	66.15
Macro (%)	35.36	45.95	44.18
Meso (%)	13.8	9.82	9.05
Micro (%)	19.72	14.03	12.92
Coefficient of dispersion	11.42	13.33	40
CC	33.52	23.85	21.97
Saturation point	83.8	59.63	54.93
Sieve # 10 (2mm) (%)	87.24	86.16	80.52
Sieve # 20 (0.84 mm) (%)	2.88	3.64	4.96
Sieve # 35 (0.5 mm) (%)	1.32	1.32	3.56
Sieve # 60 (0.25 mm) (%)	1.08	1.08	1.88
Sieve # >60 (<0.25 mm) (%)	7.48	7.8	9.08
Soil stability index	0.05	0.06	0.11
DPM (mm)	5.05	5.01	4.73
Soil aggregation status	91.44	91.12	89.04
Hydraulic conductivity (K) (mm h^{-1})	147.86	130.96	127.32
Humidity-Threat (m^{3})	1131.30		
SOM (%)	18.85	12.38	11.95

Similar results are observed in secondary plant cover (SPC) at high altitudinal range (Table 6), where soil physical properties such as total porosity, was high and hydraulic conductivity are highlighted with equally high values.

Table 6. Soil physical properties of the soil horizons: secondary plant cover and high altitudinal range: SPC ≥2800 m.a.s.l.

Plant cover/Altitudinal range	Soil horizons		
SPC ≥ 2800 m.a.s.l.	**A**	**B**	**Bb**
Altitude (m.a.s.l.)	3654	3654	3654
Ad (g cm^{-3})	0.82	1.11	0.89
Rd (g cm^{-3})	2.41	2.57	2.55
Total porosity (%)	65.98	56.81	65.1
Macro (%)	39.77	48.33	55.58
Meso (%)	10.79	3.49	3.92
Micro (%)	15.42	4.99	5.6
Coefficient of dispersion	18.01	11.62	9
CC	26.21	8.48	9.52
Saturation point	65.53	21.2	23.8
Sieve # 10 (2mm) (%)	75.72	78.56	70.44
Sieve # 20 (0.84 mm) (%)	8.24	4.16	10.04
Sieve # 35 (0.5 mm) (%)	5.08	6.96	8.2
Sieve # 60 (0.25 mm) (%)	2.96	2.88	3.52
Sieve #>60 (<0.25 mm) (%)	8	7.44	7.8
Soil stability index	0.19	0.16	0.27
DPM (mm)	4.57	4.62	4.32
Soil aggregation status	89.04	89.68	88.68
Hydraulic conductivity (K) (mm h^{-1})	132.86	143.24	138.9
Humidity-threat (m^{3})	805.958	282.384	190.638
SOM (%)	20.54	15.8	16.23

Soil organic matter levels for different plant covers in 3 altitudinal ranges

Figures 7-9 describe the soil organic matter variable in 3 established altitudinal ranges. The soil organic matter levels found in the clean pastures (CP), secondary plant cover (SPC) and forest (F) (23.2; 20.3 and 23.7%, respectively) plant covers, evidences an organic soil colloidal richness with low mineralization value due to their altitudinal position and influence of the cold climate.

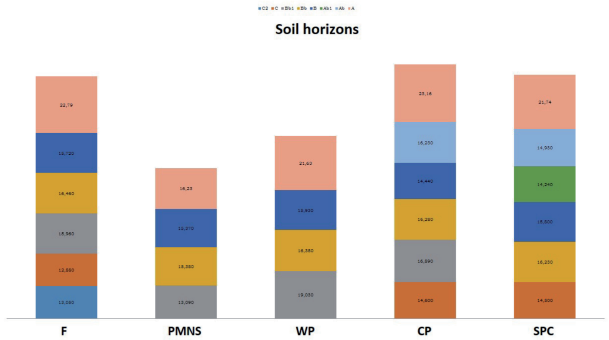

Figure 7. Soil organic matter levels for soil horizons of plant covers in high altitudinal range (≥2800 m.a.s.l.). F: forest; PMNS: Pasture mosaic with natural space; WP: weeded pastures; CP: clean pastures; SPC: secondary plant cover.

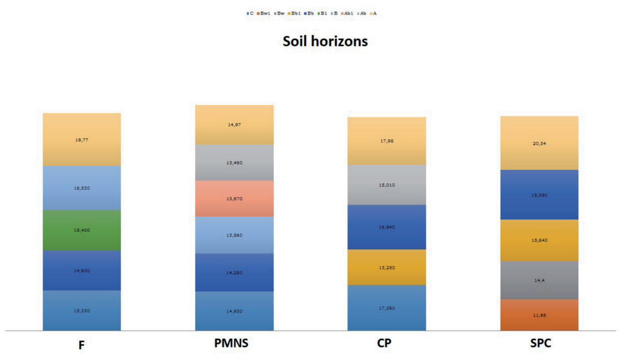

Figure 8. Soil organic matter levels for soil horizons of plant covers in medium altitudinal range (2600-2800 m.a.s.l.). F: forest; PMNS: Pasture mosaic with natural space; CP: clean pastures; SPC: secondary plant cover.

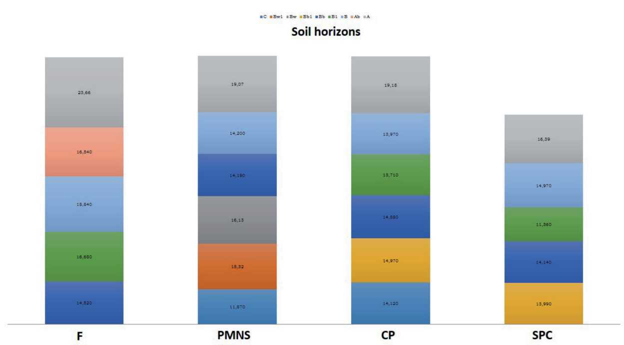

Figure 9. Soil organic matter levels for soil horizons of plant covers in low altitudinal range (2400-2600 m.a.s.l.). F: forest; PMNS: Pasture mosaic with natural space; CP: clean pastures; SPC: secondary plant cover.

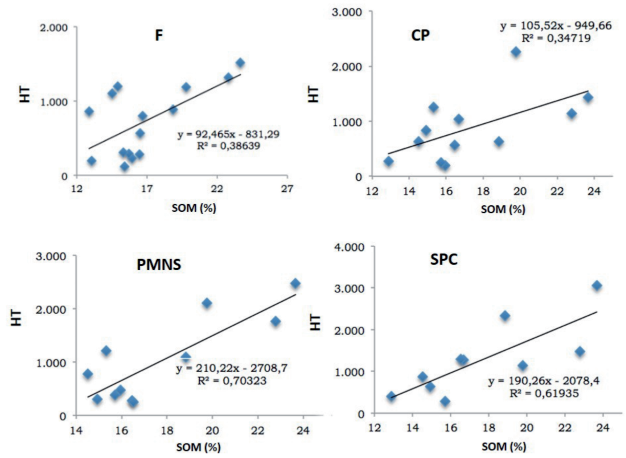

Figure 10. Relationship between Humidity-Threat and SOM levels for evaluated plant covers.

HT: Humidity-Threat index (m^3); SOM: soil organic matter; F: forest; PMNS: pastures mosaic with natural space; CP: clean pastures; SPC: secondary plant cover.

Soil moisture retention

Figures 11-13 illustrate average soil moisture content (%) and soil moisture tension (Bars), and in addition, indicates that as soil tension increases, the soil moisture content decreases and suggests that when the tension is zero (0) the soil is at saturation point. Such behavior is evident for soil horizons: A and Bb (Figure 11).

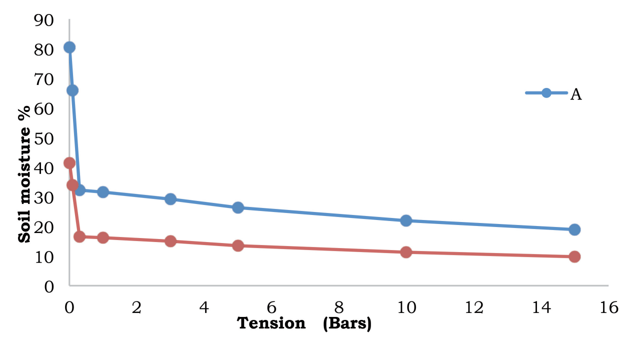

Figure 11. Tension-soil moisture relationship for soil horizons in secondary plant cover at low altitudinal range (2400-2600 m.a.s.l.)

Secondary plant cover at low altitudinal range, registers very high values of hydraulic conductivity for soil horizons A, Bw and Bw1(Figure12, Table 5).

Analysis of significant correlations among variables

The statistical analysis have allowed to find significant correlations between "Humidity-Threat" and soil organic matter variables for all the analyzed plant covers (Figures 10-13).

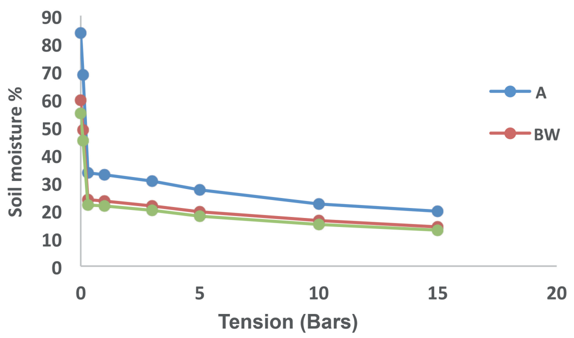

Figure 12. Tension-soil moisture relationship for soil horizons in secondary plant cover at medium altitudinal range (2600-2800 m.a.s.l.)

The soil moisture- tension relationship (Figures 12,13), suggests behaviors commonly found in other volcanic origin soils research.

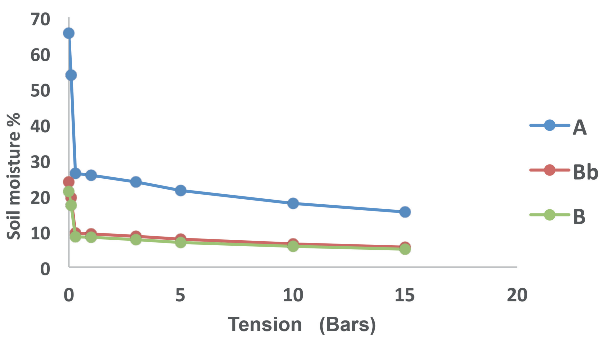

Figure 13. Tension-soil moisture relationship for soil horizons in secondary plant cover at high altitudinal range ≥ 2800 m.a.s.l.

Discussion

Soil stability indexes for different plant covers in the three altitudinal ranges

Soil stability indexes for plant covers and altitudinal range are different due to high spatial variability of hillside soils, which indicates high soil aggregates stability to water with indixes higher than 1.0.

For soil stability index variable, the results confirm the influence of the soil organic matter (SOM) and according to Golchin *et al.*, (1994), citados por Zagal & Córdova (2005), in most soils, SOM is the major linking agent, stimulating soil formation and soil aggregates stabilization, which are differentiated according to size in soil macro aggregates (> 250μm) and soil micro aggregates (<250μm), which is why SOM incorporation plays a key role in soil stability.

All evaluated plant covers at medium and low altitudes, represent ≤ 1.0 indixes with predominance of soil aggregates greater than 5 mm, which could indicates soil aggregates instability and susceptibility to soil mass movements. Conversely, Pla (2011), was found in Andisols with very stable soil micro aggregates, soil layers, which suffers cohesion between soil micro aggregates and tend to acquire fluid consistency close to saturation point. In fact, Andisols erodability is due to soil aggregate instability, susceptibility to soil moisture retention, soil surface porous layers followed by sub-surface layers rich in clays, organic matter of low dry bulk density and high fluidity when is saturated on a massive and compact soil layer with higher dry density and low permeability. This is common in deforested Andisols on natural pastures, specifically in overgrazing.

Jaramillo (2014a,b), suggests desirable soil aggregate sizes with 3 mm diameter. Granulometry and mineralogical composition of volcanic ash originate different soils as follows: Fresh ashes to Entisols and evolved soils to Ultisols, for that reason do not generalize on the typical soil profiles, which can affect the volcanic soils erodability. In this sense, spatial variability is added to the soil description and morphology, irregular and in successive soil layers, which had achieved recent volcanic processes and soil horizons with or without volcanic ash evolution, some of them, with loose soil, without consistency.

Humidity- Threat index for different palnt covers in the three altitudinal ranges

The Humidity-Threat variable, is considered of great value in reference to soil mass movements, which have allowed us to understand the soil ability to retain moisture, in fact, a volumetric and gravimetrically increasing in the natural soil condition, can be observed. Therefore, Humidity-Threat index records the potential of soil moisture retention at the soil sampling time. Conversely, this is a constituted value of significant argument to estimate the extraordinary erosive soil ability of soil moisture retention factor and soil water storage, as well as an increasing in soil susceptibility to soil mass movements, such as slope, mountainous relief, gravity, geomorphology, natural soil deprotection or forest cover and poor management of pastures.

Another meaning is to say that 3667.8 tons of water migrate from A horizon to C, which is constituted by pyro clasts, where infiltration speed is increasing in contact with the soil moisture of the Bb horizon, the soil water is hung (drain hung) and due to the slope inclination, the impervious rocky surfaces or last contact of the percolating water and the soil horizon become in sliding planes.

In contrast, the soil stability index of less than 1.0, shows the presence of large soil aggregates, greater than 5 mm, which indicates soil instability and as confirmed by DPM (5.22 mm) with susceptibility to soil mass movements. In addition, soil stability indexes greater than 1.0 would be ideal and could indicates predominance of intermediate and well distributed soil aggregates, which favors soil mechanical properties and resistance to soil mass movements. The registered usable soil moisture (12.8%), is an average value of available soil water.

The results indicate a fast hydraulic conductivity and/or soil permeability. These values can be harmful to crop establishment and favors soil mass movements. Pla (1992), indicates high hydraulic conductivity in saturated or unsaturated soils, high soil moisture retention, high total porosity and low bulk density, which are soil hydrophysical properties that determine an unique hydrological patterns for these soils.

Soil organic matter levels for different plant covers in three altitudinal ranges

Soil organic matter data, which have allow us to assess the "forest" plant cover with greater contribution to organic wealth. An indicator of good soil structure is the stability of soil aggregates to water, and is influenced mainly by SOM quality and quantity. In fact, the soil moisture plasticity and availability improves by increasing the SOM and thus decreases the cohesion that finally influence the soil moisture regime (Obando & Tobasura, 2012). The results prove all ofane-SOM complexes highly stable in complex and varied soil horizons, which can be limit the excess of soil water infiltrated (restricted internal drainage).

Analysis of significant correlations among variables

The degree of correlation among cited variables, suggests greater responsibility of the soil organic matter in soil moisture retention on the plant cover variable. The general analysis shows a higher association degree between soil organic matter and pastures mosaic with a coefficient of determination of 70%.

In this respect, Pla (1992), indicates that Andisols with high soil organic matter (10-20%), udic water regimes and formation of stable allophan- soil organic matter complexes, which are responsible for high soil moisture retention (saturation, field capacity and tension of 1.5 MPa). On the other hand, Rivera(1998), warns that: the soil erodability increases when soil organic matter content, cation exchange capacity and soil aggregate size, decrease.

Soil moisture retention

The soil moisture retention is high at different tensions, although higher in the A horizon, as a result of the presence of allophane and high levels of soil organic matter. In fact, rainfall and soil moisture retention are detonating factors in the occurrence of soil mass movements with deep weathering and high precipitation profiles. Therefore, soil moisture retention variable is similar and independent of altitudinal ranges.

According to Jaramillo (2014a), due to soil water adheres into the solid particles thereof, there is a close relationship between the amount of soil water that these particles are able to retain and their composition. The climate conditions, the soil moisture and relation with soil physical properties of Andisols and its special dynamics with changes of soil moisture, due to its mineralogical composition, with allophane contents greater than 50% plus haloysite, soils with a very dark A horizon, relatively thick textures to the touch, friable, low bulk density and high soil organic matter.

Humidity-Threat index

The soil once encountered moisture contents close to the saturation point, behaves like a viscous fluid and in particular in Andean soils, factors such as slope and gravity act as predisposing to soil mass movements.

The slip surface can be both flat and irregular in shape, and the underlying soil layer composed of lightly weathered detrital volcanic materials. Dramatic differences in permeability of these strata, as stated; can leads to the formation of suspended soil moisture levels by decreasing "effective efforts" and increasing in soil instability.

The allophane soils in the domain of vegetation of high Andean forest and paramo, which are rich in soil organic matter, with high capacity of soil moisture retention turns them into a water source (IDEAM-UNAL, 1996). For allophanic soils, had achieved under the same suction conditions, higher hydraulic conductivity than soils containing high levels of crystalline clays (Fieldes & Perrot, 1966; Rao, 1996).

Volcanic ash forms clay minerals (e.g., haloysite, allophane and imogolite) whose presence is almost exclusively of these soils, their mineral structure, morphology and their properties, determine how the particles interact with each other with fluids (water and air).

The inner soil moisture in the allophonic structure considered as "rigid water" forms part of the soil solid phase and is not part of the free water in the soil pores. Their tendency to form aggregates leads to soil having high moisture retention and high porosity as increasing in allophane contents, which also increases the soil porosity and rigid soil water content (Wesley, 2001-2003; Regalado, 2006).

High humidity retention even at high tensions and poor connection between soil pores, makes Andisols with moist climates, even with good drainage, maintain poor aeration conditions at shallow depths that restrict plant root development. In fact, to achieve these high soil moisture retentions a certain degree of volcanic ash weathering is required, with formation of halloysite and accumulation of soil organic matter, since with very recent ash, usually with sandy to heavy textures, the volumetric capacity of soil moisture retention is usually very low (Pla, 1992).

According to Pla (1992), infiltrated water moistens the soil and induces stresses and deformations producing a response in volumetric and mechanical behavior. The wetting produces volumetric changes that can be positive or negative and collapse or swell the soil, which depends on mineralogy, bulk density, porosity, etc., and also on soil chemical properties of the fluid and in the amount of infiltrated fluid, the latter factor is affected by topography and plant cover.

Generally, the moistening of natural soils occurs from an initial or zero soil moisture. Even in dry periods most of these soils are partially saturated. As saturation increases and suction decreases, the infiltration potential is reduced. According to Table 5, high values of total porosity confirm what is expressed; rapid wetting will lead to an increasing soil aggregate disintegration potential by inducing a smaller size and reducing macro pores. Andisols with high moisture retention capacity close to the saturation point mean that MS values (wet soil mass) and therefore Fv (vertical force or weight) are very high. In addition to the lower resistance, due to the lack of cohesion and greater soil fluidity when wetting at values close to saturation opposite to said sliding force is the main explanation that in Andisols landslides present smaller slopes (20%) than in other soils (Pla, 2011).

Conclusions

The high soil moisture retention or high saturation levels were confirmed at different tensions as fundamental detonators of soil mass movements of the studied soils, as a consequence of the instability of soil aggregates to water, high porosity and high hydraulic conductivity and their relationship with the mineralogy of these soils of volcanic origin, the high pluviometric regimes of the region, the altitudinal position, slopes or terrain inclination, which determine a high relative threat by soil mass movements.

Given these concerns, was found inter-variable correlations, which have allowed an explanation of the soil mass movement phenomena in the study area, among them, some of significant order referring to the association between "Humidity-Threat" and soil organic matter variables for all the evaluated plant covers.

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