Chapter 6

The Humidity of the Volcanic Soils and Their Impact on the Processes of Mass Removal in Colombia

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Additional information is available at the end of the chapter

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Abstract

This chapter describes some aspects of the formation of soils derived from volcanic ash, especially soils classified according to the soil taxonomy as Andisols of the mountains of the central mountain range in Colombia, cultivated with pastures for the production of milk, meat, and potatoes. General erosion, caving, mudslides, and landslides reach and cover large urban and rural territories characterized by a high rainfall regime with decadal records of 227 days of rain per year and with total loss of arable, agricultural, and productive layers. This chapter summarizes aspects of the research carried out by the author in these soils, through the description of profiles on 52 pits, field and laboratory analysis of their physical and some chemical properties for the understanding of the moisture storage capacity, and explains the mechanisms that govern their physical properties, composition, and interaction between particles and fluids and, consequently, their intense erodability and high moisture-retention capacity as a detonating mechanism of the processes of erosion and mass removal of secular occurrence in the soils of the region with high population densities causing hundreds of deaths and incalculable economic losses.

Keywords: volcanic ash, mass removal, erodability, landslides, humidity

1. Introduction

An important part of the Colombian territory is located mainly around and in the vicinity of the volcanoes and is covered with deep mantles as deposits of volcanic ash soils modeling the landscape of mountains and especially the central mountain range.

Soils of residual origin evolve from in situ weathering, and normally, they are characterized by a finer granulometry close to the surface where the alteration has been more intense. Despite this generalization, there are residual soils that reflect greater alteration in depth; this is often the case of soils derived from volcanic ash [13].

The soils derived from volcanic ash are those formed from the weathering of deposits of materials from volcanic ejections. According to the Committee for the Recognition of Soils [24], these soils are called Andisols, a name derived from ando soil; etymologically, "an" means dark and "do" means soil in Japanese language [10, 21, 27].

The central concept of the Andisols covers two fundamental aspects: (1) parental material of volcanic origin (ash, pomace, slag, pyroclastic, etc.) and (2) soils whose colloidal fraction is dominated by non-crystalline materials.

Under this concept, the specific properties of these soils have been attributed basically to the predominance of allophane in the colloidal fraction; however, the results found by Shoji and Ono [22] in soils without the presence of this mineral showed that the properties of the Andisols are not necessarily given by the allophone and indicate that the Al-humus and Fe-humus complexes also influence the properties of these soils [10].

Based on these results, new criteria were established to define the Andisols as soils developed from volcanic ejections or volcanoclastic materials whose colloidal fraction is dominated by non-crystalline materials and/or Al-humus complexes. It was also determined that the andic properties are the result mainly of the presence of significant amounts of Al-humus, allophane, imogolite, or ferrihydrite complexes [10, 16].

The physical, mechanical, and chemical properties of these soils make them considered as being of great importance worldwide due to their high productive potential, high carbon and nitrogen accumulation, high storage capacity, and improved water quality [10, 23].

Around the volcanic zones of the entire American continent are deposits of residual soils formed from the weathering of volcanic ash. Studies on similar soils and their performance in engineering works in regions such as Indonesia, New Zealand, India, Dominica, and Japan show that this type of soil has unusual properties compared to sedimentary soils [18, 20, 28]. In: soils derived from volcanic ash in Colombia [13].

2. Localization and distribution

The soils that currently cover the regions surrounding the volcanoes of the Andes Mountains in Colombia have their origin in pyroclastic materials that emanated during the volcanic eruptions of the last 25,000 years [9]. These deposits correspond to residual soils formed from the physical and chemical alteration of volcanic ash. Worldwide, volcanic ash soils represent approximately 0.84% of soils and are located predominantly in tropical regions [10, 13, 17, 21].

The soils derived from volcanic ash in Colombia occupy about 11.6% of the national territory and are located in regions of significant demographic and economic growth. In the Colombian

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coffee zone, it is estimated that about 350,000 ha of soils grown with coffee correspond to Andisols. These soils extend from the Eje Cafetero (Departments of Antioquia, Caldas, Risaralda, and Quindío) in the center of the country, to the departments of Tolima, Cauca, and Nariño to its south west.

3. Formation of volcanic soils

Volcanic ash is generated from the fragmentation of magma and materials in the cone of the volcano from previous eruptions [2, 13, 29]. Three mechanisms have been identified as the main generators of volcanic ash: the rupture of the magma due to vesiculation, the fragmentation due to high thermal stresses, and the pulverization of the lava in the walls of the volcano's chimney during eruption.

The mechanism of ash formation defines the block or vesicular morphology. The block ashes have flat surfaces resulting from the vitreous fracture of the magma. Vesicular ashes may have water drop textures or surfaces formed by the rupture of the material through areas that had air bubbles [13, 29].

The amount of water consumed in the transfer of thermal energy into mechanical energy also affects the production of volcanic ash. Dry eruptions (completely consumed water) lead to the formation of thickly laminated lapilli layers and thick ash layers (scale: dm–m). Wet eruptions (partially consumed water) lead to thin ash layers (scale: cm) [2].

Volcanic ash is composed predominantly of light primary minerals and mainly volcanic glass [14]. This primary mineral plays an important role in the formation of the minerals currently found. In a more advanced stage of alteration of the volcanic glass, halloysite is formed, a quasi-argillaceous primary mineral that is less evolved as a gel with a 1:1 Si/Al ratio. Most of the ashes that have led to soil formation in Colombia are dacitic, rich in plagioclase feldspar, volcanic glass, amphiboles, and pyroxenes, and poor in quartz [1, 13].

Residual soils derived from volcanic ash are developed through processes of physical and chemical alteration of volcanic ash deposits (dissolution, leaching, and precipitation of compounds). These processes of alteration transform the minerals, the shape and size of the particles, and the porosity. Its influence is controlled by climatic conditions and weather. Climatic conditions (such as precipitation, temperature, humidity, and wind) determine the presence of available fluids for chemical reactions, the rate at which these reactions occur, the migration of compounds, and the erosion, among other processes [4, 26]. Time, on the other hand, governs the sequence for the synthesis of secondary minerals and the distribution of particle sizes.

As a soil-forming factor, the effect of the parent material is more important in the initial stages of soil formation than in advanced stages. The weathering of the parent material depends on the presence of acidic or basic minerals. In general, acid minerals (e.g., quartz, feldspar, hornblende, mica, etc.) are more resistant to weathering than basic minerals (e.g., olivine, pyroxene, and calcium plagioclase [13, 26]).

During weathering, an elemental composition rich in Si, Al, and base cations (e.g., Na and Ca) is generally obtained. The Si and the basic cations are dissolved and removed from the surface layers and the Al tends to remain. As the climate becomes more humid, greater dissolution occurs and more aluminum (Al) is removed [13, 14, 30]. The mechanisms of dissolution and leaching are very important for the formation of soils derived from volcanic ash since they lead to highly porous surface areas and the availability of the necessary solutions for the synthesis of secondary minerals.

4. Soil-water relationship

In a general way, it can be said that the structure, the state of efforts, and the flow of water in any type of soil change when it is exposed to the intense cycles of drying and wetting, typical of the climatic conditions of the tropics. These changes affect the physical properties and mechanical behavior of the soil, which can lead to geotechnical problems (e.g., erosion, slope instability, etc.).

Soils derived from volcanic ash in Colombia are located in regions where a bimodal rainfall regime occurs during April to May and October to November and very dry periods occur between these stages. During periods of low precipitation and high temperature, high water evaporation occurs between the pores of the soil, causing its drying.

The evaporation produces contraction and increase of the suction forces in fine soils (silts and clays), for the states of complete saturation or partial saturation, respectively. The desiccation evolves occasionally toward the formation of cracks. These cracks can be understood as a consequence of the stresses produced by desiccation. Cracks in the surface of the soil make up areas susceptible to problems of erosion and instability, often observed on slopes with little plant cover, continuously exposed to drying processes. On the other hand, during humid periods, characterized by permanent and intense rains, the infiltrated water reduces the capillary effects and causes volumetric changes that can lead to swelling or collapse of the soil structure [13].

5. Erodability

In Colombia, the natural slopes in soils of volcanic origin reach heights between 10 and 20 m with slopes greater than 60° [8, 13, 19]. Despite this, the slopes are susceptible to instability, erosion, and cracking depending on the climatic conditions and vegetation cover. In the Colombian Coffee Region, landslides detonated by intense rainfall or locally intense earthquakes are often reported. These landslides can have a high potential for destruction in densely populated areas in mountainous reliefs of great length and high slope.

The soils of the region are characterized by steep slopes of 30° (67%) to 35° (78%), extensive slope lengths; the shape of the concave slope is favorable to the accumulation of surface and sub-surface waters. In addition to the detonating agent, the occurrence of a landslide is determined by previous conditions related to deficient plant cover, or the misuse or management of the soil, the poor disposition of agricultural production systems, the indiscriminate felling of forests for planting of pastures and livestock production and their precarious management and essentially physical causes inherent or intrinsic to these soils.

The coffee axis is located in a tropical zone that presents great climatic changes due to altitude changes and has a bimodal climatic regime given by two humid periods and two dry periods. The zone receives an annual precipitation varying between 1500 and 2250 mm. Surface landslides (depth < 1.5 m) are usually activated during periods of heavy rains, April to May and October to November, in which the accumulated rainfall during 1 or 2 days exceeds 70 mm [13, 25].

The superficial soils predominant in the area have deficiencies in the properties of resistance to the cut, since they are recently formed volcanic ash, unconsolidated, and sandy (Ruiz and Cerro Bravo volcanic complex in the Department of Caldas). These materials generally have low plasticity and cohesion due to their loose grain condition with sandy textural appreciations. The cohesion is drastically reduced (or even disappears) when the soil becomes saturated (reduction in the suction capacity), during the occurrence of intense rainfall, for example (the suction is lost and the natural cements dissolve).

The landslides have a flat and irregularly shaped surface defined by the contact between the layer of soils derived from volcanic ash and the layer that underlies it, composed of materials of vulcano-detrital origin, that are moderately or slightly weathered and/or evolved and they often come in slices. Slides of greater depth (depth: 3–10 m) are produced with detonating precipitation less than 50 mm, when the previous accumulated precipitation exceeds 200 mm [13, 25]. Dramatic differences in the permeability of these strata layers or horizons of these soils lead to the formation of a hung phreatic level that reduces effective efforts and increases instability or susceptibility to erosion.

6. Causes and effects of masal removal

Erosive processes are due to natural causes such as contact between geological units, in particular, a geometrically unfavorable contact between the upper volcanic ash (sandy and permeable and without aggregation) and the underlying igneous and metamorphic sedimentary rocks (compact, massive, and impermeable). This contact coincides with the fault surface of many of the landslides that have occurred and favors the accumulation of water that infiltrates through permeable surface of volcanic ash.

High torrentiality of permanent and intermittent drainage channels and lines exists in the region. Trees and very heavy shrubs on the crown of steep slopes generate a significant overload and negative "lever action."

The deforestation of the protection areas of the micro-basins, and the areas dedicated to pastures in the study area, becomes an accelerating factor due to the lack of protection of vegetation cover that counteracts the runoff associated with degadation phenomena gives origin to loss of soils and biodiversity and the alteration of the hydrological cycles of the basins or rivers of the region. This determines that areas of productive vocation, which are close to the micro-basins, that have lost their protective capacity of the ecosystems of strategic interest, are also affected due to the factors that undermine the stability of the soil, thus diminishing the potential to offer environmental services, of which the populated communities of the region are beneficiaries, limiting the production processes, and, therefore, their social and economic life.

Other determining factors of the drastic hydrological imbalances of the micro-basins of the region, which contribute significantly to the increase of flows, both surface water and infiltrated, which are the cause of landslides and mass erosion phenomena, are as follows:

- Increase in the change of land use from forests to paddocks. It has produced a drastic hydrological imbalance of micro-basins, significantly increasing the flows of surface and infiltrated waters.
- Excavation at the base of slopes and their over steepness, during the road construction processes.
- Deficiencies in road rainwater management works (transverse, without debris to stable and/or well-protected sites, and without internal structures to dissipate energy). Specific fillings in some areas of the road corridor, with low technical specifications and coinciding with sites of subsidence and settlements.
- Deposit of the materials resulting from the road cut, on the adjacent slopes, without any type of confinement. These "hillside fillings" coincide with the failed soils of some recent landslides.
- Specific problems of inadequate catchment, conduction, and delivery of surface water served in local homes (lack of channels and downspouts, deliveries of sewer networks to the hillside, soft areas without waterproofing, etc.).

The deforestation of the areas of interest for the protection of the micro-basins and the presence and increase of the areas in natural pastures in the study area are some of the causes of the decrease in water flows, which are associated with degradation of soils and aquatic and terrestrial flora and fauna and the alteration of the hydrological cycles of the basins, when climatic variables reach the most critical levels. The productive areas to intervene surrounding the micro-basins as ecosystems of strategic interest are also affected by climate change, which affects soils, reducing the supply of this environmental service to the beneficiary communities.

7. Technical support

According to PLA [15], amorphous clays, high in allophane, are the main determinants of the very particular physical and mechanical properties of Andisols. They are responsible for the development of low-density bulk floors, high porosity, high water retention (high saturation, field capacity, and tension of 1.5 MPa), and high limits (upper plastic limit or liquid limit—LPS and liquid plastic lower limit—LPI) of plasticity. The retention of available water (field capacity humidity at 1.5 MPa) is also usually high and limit liquid or water flow in the form of water is near, in soils not altered to the point of saturation.

Although the gravimetric water retentions are usually very high (up to 2–3 times the mass of dry soil when saturated), they are not so much on a volumetric basis due to the low apparent densities, although they are still higher than in other soils. The high retention of moisture even at high voltages and the poor connection between pores means that in humid climates, even with good drainage, conditions of poor aeration at shallow depths that restrict root development remain in the Andisols. In any case, to achieve such high moisture retentions requires a degree of weathering of volcanic ash, with formation of halloysite and accumulation of organic matter, since with very recently formed ashes, generally with sandy loam to gravel, the volumetric capacity Water retention is usually very low [15].

With drying, up to 30–50% of the water-retention capacity and a large part of its plasticity are irreversibly lost. It has been pointed out that the change of the plasticity indexes with the drying of the soil is the main property that distinguishes the Andisols from other soils where crystalline clays predominate.

The drastic and irreversible changes of properties of the Andisols derived from changes in humidity have much to do with the erosion processes in these soils.

The greater the inclination of the soils, the instability increases soils and, with it, the greater the susceptibility to mass movements, the more rainwater is infiltrated and less lost by runoff (accumulation). Mass movements depend on the interaction of several factors, especially slope; lithology; soil type; intensity, duration, and continuity of rainfall; surface and internal drainage conditions; vegetation cover; and management.

By virtue of the above, it is technically demonstrated that in Andisols, where a limiting layer has been formed for internal drainage at shallow depths and a high rate of surface infiltration is maintained, increases in moisture content negatively affect the stability of the soil material facing landslides by:

1. Increase in pore water interstitial pressure, which reduces the flow resistance in saturated soil over the restricted drainage layer.

2. Development of a hydraulic gradient or pressure in the direction of flow below the surface that can gradually lead to sub-surface erosion.

3. Lubrication of the limiting layer or sliding plane, which facilitates the movement of the material above it.

4. Increase in the mass of moist soil, sometimes 2–3 times its dry mass.

5. Decrease in the cohesion between particles and aggregates and once the soil is saturated, development of positive pressures in the pores [15].

8. Studies and research

Chavarriaga (2014) studied and investigated the physical and chemical characterization of soil profiles. Reference: evaluation of causal factors, effects and feasible management alternatives, the problem of erosion and mass removal of soils in the Maltería—Las Margaritas road transect, right slope of the Chinchiná River, via Magdalena "Department of Caldas-Colombia."

The investigation was carried out to identify and diagnose the problem of soil erosion processes in the area of influence of the Maltería-Las Margaritas road transect via Magdalena, right slope of the Chinchiná River, to technically evaluate the factors involved and the causal relationships—intervening effect on the problem of erosion and mass removal of soils, weighing risks and impacts, investigated about the factors related to the technical nature of the problem of deterioration of the soil resource, and its alternatives for improvement or mitigation, of the general impacts and develop the physical-chemical knowledge of the problem of environmental deterioration of soils in the area of influence of the Maltería-Las Margaritas road transect via Magdalena, Municipality of Manizales; Secularly converted into a factor of great environmental and socioeconomic impacts, aggravated in the winter periods of the area, which lead to problems of large soil losses, landslides, road restrictions, and all kinds of risks, which compromise important resources of the region, as losses of landscape, biodiversity and human lives.

8.1. Methodology

For the purposes of sampling, the digital cartographic information provided by CORPOCALDAS (Autonomous Regional Corporation of the Department of Caldas), stratified in three altitudinal ranges: high, medium, and low, considered as representative of the study area, was taken as a basis. The type of sampling applied was of a random nature and was carried out using functions of the ArcGis program based on a number of four repetitions of each combination of the variables "coverage" and "altitudinal range," resulting in a total of 52 sampling points (52 pits, duly geo-referenced). The resulting systems are shown in **Table 1**. The soil samples were made by opening pits of 1 × 1 × 1.50 m and making samples in each of them by soil profile (2–4 samples per profile according to horizons and profile morphology), which were processed for analysis in terms of physical and chemical variables. By groups of pits according to their altitudinal position and vegetation cover (5 coverings), a format or spreadsheet for the description of soil profiles was prepared (52 profiles) taking into account the methodology of soil surveys described by Cortés and Malagón [3] and the FAO profile description guide [7], both references updated according to the description method of the Geographic Institute Agustín Codazzi (IGAC) [12]. Soil chemical analyses were carried out in the soil laboratory of the Caldas University and the analyses for the physical variables in the soil physics laboratory of the National University of Colombia, Palmira-Valle. Both the chemical and the physical information were processed by correlation analysis for their interpretation and mapping according to their geo-referencing.

Table 1 indicates the edaphic systems under evaluation with their respective coverage and altitude ranges. The information on soil cover are indicative and taken from CORPOCALDAS and verified in the field, were studied, sampled, and analyzed the soils by means of pits as

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No.	Coverage	Altitude range
1	Weedy grass	High: >2800 m above sea level
2	Secondary vegetation	High: >2800 m above sea level
3	Secondary vegetation	Medium: 2600–2800 m above sea level
4	Secondary vegetation	Low: 2400–2600 m above sea level
5	Mosaic of pastures with natural spaces	High: >2800 m above sea level
6	Mosaic of pastures with natural spaces	Medium: 2600–2800 m above sea level
7	Mosaic of pastures with natural spaces	Under: 2400–2600 m above sea level
8	Dense forest of high ground	High: >2800 m above sea level
9	High, dense forest of firm ground	Medium: 2600–2800 m above sea level
10	Dense forest of the mainland	Low: 2400–2600 m above sea level
11	Clean grass	Height: >2800 m above sea level
12	Clean grass	Medium: 2600–2800 m above sea level
13	Clean grass	Low: 2400–2600 m above sea level

Table 1. List of systems under evaluation (coverage and altitude range).

stipulated by the international guides of description of soil profiles. The altitudinal information was suggested by researchers to facilitate its analysis.

The mosaic illustrates the different systems of coverage and their altitudinal position and allows to observe the little spatial variability of the soils, preserving similarities in their morphology and their genesis or their own genetic homogeneity or inheritance provided by the ancient deposits of pyroclastic volcanic materials. The ancient and recent volcanic events in a certain way have shaped the landscapes themselves where the profiles of exposed and supralying soils are located and studied to the lithological formations or litho-units dominated by igneous rock materials predominantly but with the participation of shales and other metamorphic materials. In general, this is the panorama of strata or horizons evidencing eminently volcanic features whenever an attempt has been made to discover the soil to such depths edaphologically speaking and that have enabled world literature to highlight the particularities of our soils known as volcanic or volcanic ash (volcanic ash soils).

On the other hand, the exposed mosaic allows a visual approach to obtain knowledge of reality in terms of the fragility of these edaphic ecosystems and therefore their immense susceptibility to erosion or mass removal and accompanying their physical attributes estimate in this study how are sandy and frank sandy textures, friable or loose consistencies, slightly plastic and slightly sticky, loose structures or those without structure in lower horizons markedly pyroclastic, not plastic and not sticky and without structure or loose consistency.

In this regard, the Geographical Institute Agustín Codazzi (IGAC) [12], in studies close to this research area concluded that the alternation of materials: ash-lapilli-pumice sands that have originated different horizons, A and C layers, show that a polycyclic development of these soils allow to deduce the different depositions of pyroclastic materials that have suffered degradation and reconstruct the history of their evolution; in effect, once the horizon was formed, it was buried by new materials, repeating in this way the different cycles of contributions of tephra or pyroclastic layers.

In any case, the presence of melanization, mineralization, humification, and structural development processes on the horizon indicates a pedogenic development slowed not only by the continuous rejuvenation of the materials but also by the very low temperatures.

The soils have originated from volcanic ashes alternating with sands, lapilli, and pumice. In superficial cases, well drained, they present several A horizons of dark colors with good structural development buried by volcanic sands that in turn are covered by lapilli and pumice; this indicates that they have suffered several periods of rejuvenation. In addition, the A horizon meets all the requirements of an umbric epipedon with andic properties, for which reason the soils have been considered as moderately evolved.

The physical-chemical dynamics of these soils is controlled by the presence of allophone, an amorphous material originating from the alteration of volcanic ash, constituted by Si in tetrahedral site, Al in tetrahedral and octahedral sites, and other octahedral ions with high variable load or high capacity of cationic exchange (CEC), 25–50 cmol(+)/kg of soil, anionic retention power (mainly phosphates), high affinity for humus and high porosity; and these allophones establish with it strong bonds that result in the accumulation of organic matter in the soil.

The humus-allophane interaction gives the soil particular properties such as high porosity constituted by many fine pores and medium observed in many cases and high retention of water or moisture at different tensions as a result of the high microporosity and the presence of allophane and organic matter.

The description and interpretation of the external and internal characteristics of one of the 13 modal profiles representative of the different coverages and uses and in accordance with the heights and their symbol are presented below. The methodology used follows the guidelines and procedures for description and interpretation of the 2013 IGAC in its semi-detailed study of Caldas soils.

8.1.1. External features of the SV24262 profile (2400–2600 m above sea level)

Taxonomy: Typic hapludand.

Cartographic unit: Cedral Consociation. Symbol: VS24262.

Geographical location: Department: Caldas. Municipality: Manizales Site: finca: El Cedral.

Geographical coordinates: X: 851051, 2843; Y: 1049817,0675; Height: 2444 m above sea level.

Landscape: mountain. Type of relief: Andean peaks.

Shape of the terrain: slopes, peaks, and troughs.

Lithology: alternating layers of volcanic ash, lapilli, and sands, on granitic lavas.

Environmental climate: cold and humid.

Average annual rainfall: 1800–2000 mm. Average annual temperature: 8–15°C.

Edaphic climate: temperature regime: mesic. Moisture regime: udic.

Erosion: Class: pluvial water. Type: furrows. Degree: moderate.

Mass movements: Class: deformations. Type: cow's foot. Frequency: frequent.

Surface stoniness: there is none.

Rocky outcrops: there is none.

Floods: there is none.

Encharcamientos: there is none.

Water level: not found.

Natural drainage: good (good).

Effective depth: moderately deep.

Limited by: alternating layers of pyroclasts.

Diagnostic horizons: Epipedon: umbric. Endopedon: there is none.

Diagnostic characteristics: andic properties, mesic temperature regime, and umbric epipedon.

Natural vegetation: secondary vegetation.

Current use: forest.

Limitations of use: cold weather and slope.

Described by: William Chavarriaga Montoya. Date: April 2014 (**Table 2**).

8.1.2. Profile interpretation

The soils of the Consociación el Cedral formed of volcanic ash are moderately deep, well drained, with moderate structural development. These soils have brownish and yellowish brown A/C genetic horizons respectively and umbric diagnostic horizon with andic properties, for which the consideration is reiterated as moderately evolved soils (**Tables 3** and **4**).

8.1.3. Chemical characteristics

The results of the chemical analyses indicate that they are strongly acidic reaction soils with pH values between 4.7 and 5.3 with restrictions for K and Mg, whose Potencial De Hidrógenos (pH) is extremely low; they have medium to high values of S and high values of matter organic of soil (MO) and N, with MO being responsible for the CIC due to the low presence of clays. They do not contain aluminum contents that represent a toxicity hazard for many plant species.

VS24262	Depth horizon (cm)	Main characteristics
	(0–5 cm) Oe	Mattress of live and dead roots
	(5–65 cm) A	A dark brown (7.5YR 3/2); sandy loam texture; structure: large, thin, and weak angular blocks; friable wet consistency; consistency in wet conditions: not plastic and not sticky; abundant macropores; abundant medium, thin, and thick roots; little macroorganism activity, positive reaction to NaF, pH 5.3; diffuse and wavy boundary
	(65–80 cm) C	Yellowish brown color (10YR 3/4); Tuff: without structure (loose)
	(80–105 cm) Bb	Dark brown color (10YR 4/3); sandy texture; fine granular structure; weak, loose, moist consistency; consistency in wet condition: not plastic and not sticky; abundant macropores; scanty roots; positive reaction to NaF, pH 4.7; clear and wavy boundary
	(105–X cm) C1	Dark olive brown (2.5Y 3/3); sandy texture; without structure; coarse grain not consistent

Table 2. Profile no: VS24262 internal profile features.

The physical-chemical dynamics of this soil is controlled by the presence of allophane, caused by the alteration of volcanic ash; this component has an affinity for humus, and establishes with it strong bonds that result in the accumulation of organic matter in the soil.

The humus-allophane interaction gives the soil particular properties such as high porosity, high water retention, and high capacity for nutrient retention (CICA); however, most of the electrical charge is not available to retain nutrients at the soil pH; this load only appears when the pH rises, such as occurs when the floors are limed. The load, which depends on the pH, is called variable load (CICV) and is the one that is present in this soil. A feature that distinguishes soils of volcanic origin, due to the presence of allophane, is the low availability of phosphorus; however, the analytical results of this soil show average contents of this element, undoubtedly due to the presence of apatite in volcanic materials.

8.1.4. Physical characteristics

The dark brown color of these soils is generated by the accumulation and high levels of MO in the first horizon resting on clear materials. The texture is sandy loam, while the laboratory

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Reference	Horizon	Altitude (m)	Bulk density (g/cm^3)	Real density (g/cm^3)	Total porosity (%)	Macro (%)	Meso (%)	Micro (%)	Dispersión coefficient (%)
SV24262-A	A	2444	1.05	2.41	56.43	24.25	13.25	18.93	11.42
SV24262-Bb	Bb	2444	1.01	2.55	60.39	43.84	6.81	9.74	13.33

Reference	Horizon	Humidity retention							
		Saturation (%)	0.1 b	0.3 b	1 b	3b	5b	10 b	15 b
CG24262-A	A	85.30	69.95	34.12	33.48	31.04	27.91	23.34	20.07
PL24262-C	C	27.53	22.57	11.01	10.80	10.02	9.01	7.53	6.48

Reference	Horizon	Altitude (m)	Sieve (#10) (2 mm) (%)	Sieve (#20) (0.84 mm) (%)	Sieve (#35) (0.5 mm) (%)	Sieve (#60) (0.25 mm) (%)	Sieve (#>60) (<0.25 mm) (%)
SV24262-A	A	2444	87.8	3.48	2.88	1.48	4.36
SV24262-Bb	Bb	2444	92.8	1.52	3.36	1.24	1.08

Reference	Horizon	Altitude (m)	Stability index	DPM (mm)	State aggregation	Hydraulic conductivity (K) (mm/h)	Moisture of threat (m^3)
SV24262-A	A	2444	0.08	5.10	94.16	145.51	3,041,010
SV24262-Bb	Bb	2444	0.06	5.33	97.68	138.90	626,831

Table 3. Physical properties VS24262.

results obtained indicate coarser textures (sandy and sandy loam) due to difficulties that arise in the analysis by interference of the allophone. The structure is in subangular, thin, and moderately developed blocks. The porosity is high, (56.43 and 60.39%) for horizons A and Bb, respectively, with a large predominance of macro pores. The apparent density presents low values, normal for soils derived from volcanic ash. The conditions of aeration and drainage are good. The consistency is friable, not plastic, and not sticky in the described horizons.

8.1.5. Humidity retention

Figure 1 illustrates the moisture contents (%) and the soil moisture tension (Bars), information that indicates that as the soil tension increases, the moisture content decreases and what is related in this measure when the tension is zero (0) the ground is at the point of saturation.

Such soil water behavior is evident for both horizons: A and Bb. The humidity retention is high at different stresses as a probable result of the presence of allophane and high levels of organic matter.

Id. sample	Height (masl)	pH	Aluminum (cmol(+)/kg)	Nitrogen (%)	O.M cold weather (%)	Phosphorus (mg/kg)	Potassium (cmol(+)/kg)	Calcium (cmol(+)/kg)	Magnesium (cmol(+)/kg)	Sodium (cmol(+)/kg)	Sulfur (mg/kg)
SV24262-A	2444	5.3		0.59	16.46	22	0.05	1.43	0.14	0.319	16.67
SV24262-Bb	2444	4.7	0.2	0.54	14.36	104	0.06	0.93	0.09	0.235	8.32

Table 4. Chemical properties VS24262.

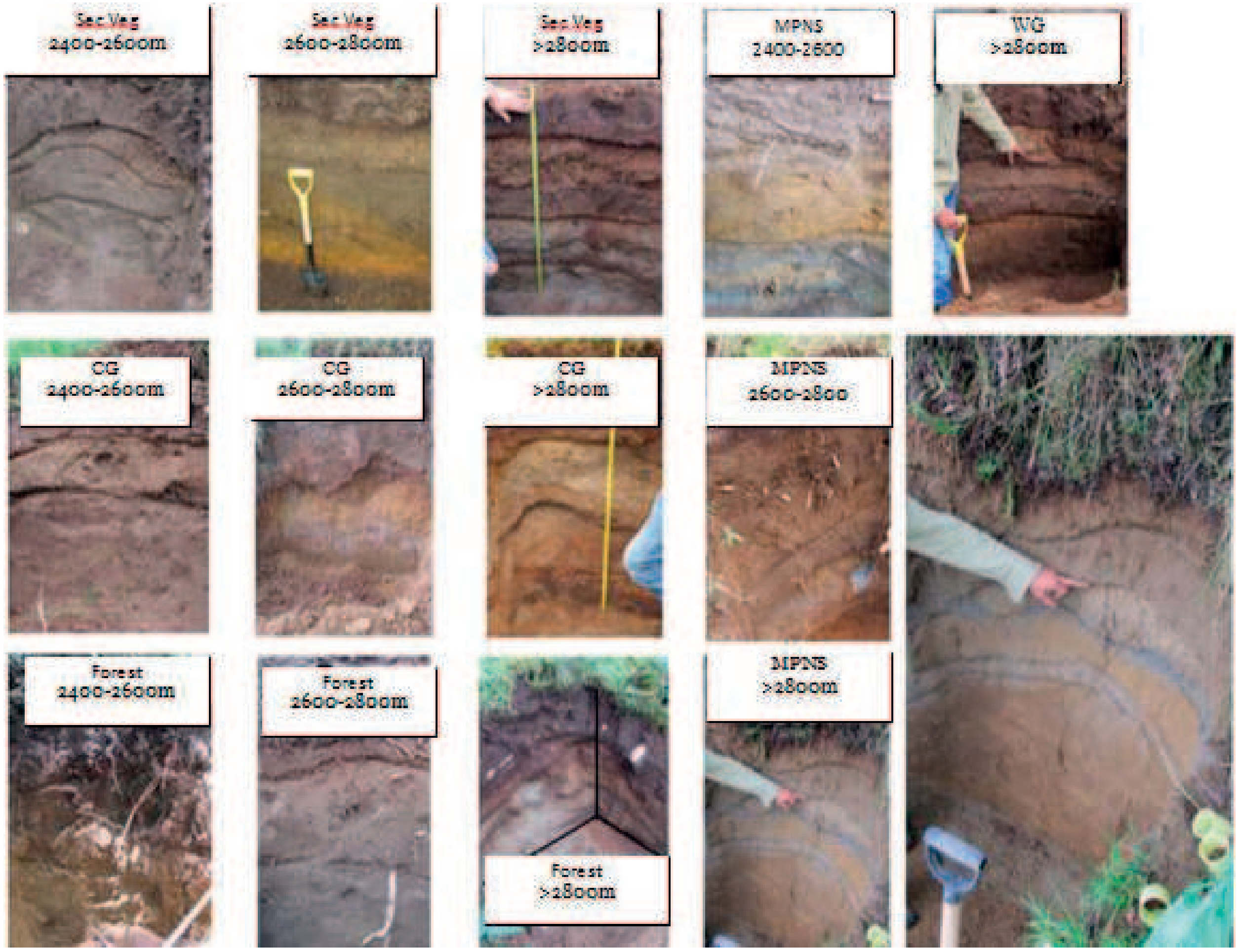
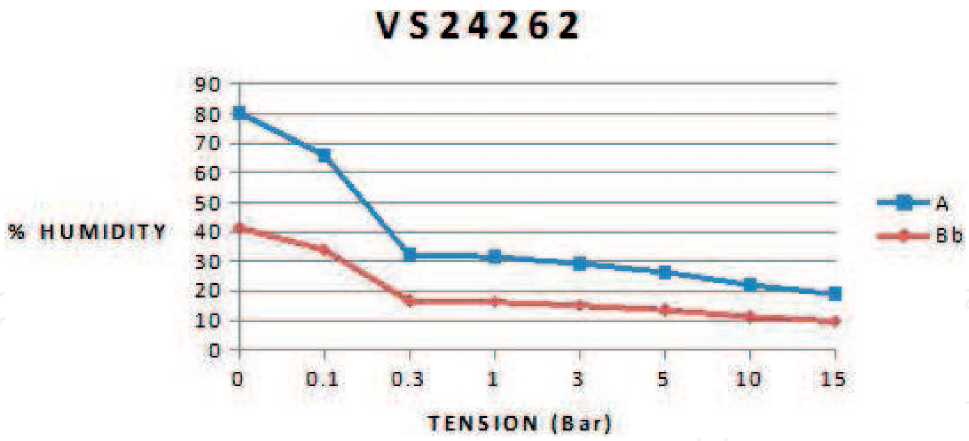


Figure 1. Mosaic of soil profiles in pits for different cover systems and at different altitude ranges in volcanic soils in Colombia (secondary vegetation; pasture mosaic with natural spaces; weeds; weedy grasses; clean pastures; and high, dense forest mainland).

8.1.5.1. Humidity threat

This measure is considered to be of great value in the study and in correspondence with the studied problematic as it is the mass removal of the soils; its meaning allows us to understand the capacity of these soils to retain water and to increase in volumetric and gravimetric terms the natural condition of the soil, that is, its volume of water content and its corresponding weight. The analysis starts from the consideration of the apparent density expressed in dry weight (1.05 and 1.01) and that allows to calculate the weight of a surface of soil (1 hectare). Determining its saturation point (80.35 and 41.38%) allows to quantify the water that can hold the soil in each horizon and that correspond to values of 3,041,010 and 626,831 m^3; this in sum equals 3,667,841 m^3 of water per hectare in the investigation of moisture threat.

By virtue of the above findings, water or humidity threat allows us to suggest the potentiality of moisture retention at the time of sampling and the determination of the saturation



point for a soil that was not in rainy weather conditions. Such values constitute a powerful argument to estimate the extraordinary erosive capacity of the soil water storage and retention factor in the study and the increase of the soil susceptibility to the mass removals the pending factor is added to this, mountain relief, gravity, geomorphology, lack of protection of the soil of the natural or wooded vegetation cover and poor pasture management due to overgrazing.

In other words, the difference between the water retained to saturation and field capacity is the water that intervenes mainly in the phenomena of mass removals. Another implication is that: 3667.8 tons of water migrate from horizon A, toward C constituted by pyroclastics; there increases the speed of infiltration and in contact of moisture with the buried soil or horizon Bb the water hangs (drain hanging) thanks to the slope of the slope and the horizon becomes a plane of sliding.

The dispersion coefficients of 12.38% on average for the sampled horizons qualify the soil as stable. The variables DPM (weighted average diameter) with average value (5.22) as well as the state of aggregation (95.92%) allow one to assess the soil as very stable or in its defect state of very high aggregation (>90%). Conversely, the stability index < 1.0 warns of the presence of large aggregates that determine and indicate instability with aggregates greater than 5 mm, as confirmed by the DPM (5.22), and susceptibility to soil mass removals. Stability indexes greater than 1 would be ideal and would indicate predominance of intermediate aggregates well distributed in the soil. The usable humidity (12.8%) however for the soil is an average value of available water or useful water or vegetable water supply.

On the other hand, the saturated hydraulic conductivity (Ks) determined in the laboratory with values of 145.51 and 138.9 mm/h allows to identify the speed with which the water permeates the soil; therefore, it is a measure of the permeability as an intrinsic character of the soil. Such values indicate a very fast hydraulic conductivity and/or permeability.

9. Conclusions

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

Inter-variable correlations were found that facilitate explaining the phenomenon of mass removal in the area, among them some of significant order referring to the association between the variable "Humidity-Threat" and the organic matter for all the coverages analyzed. There is a negative effect of intervention on forests on the stability of soil aggregates.

There is a significant and positive relationship between the stability of the soil structure with the OM content and the degree of soil cover.

It is possible to explain the variations in the stability of aggregates, by the combined action of OM content and the degree of soil cover; however, this last variable is the most significant of the two.

The management of soils against mass removal should consult systems that involve minimal disturbance of the soil and the greatest possible protection through forest coverings, as ways to promote a stable structure and, consequently, promote the resistance of soils to water erosion.

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