Dörner et al. / Agro Sur 41(1): 1-9, 2013
DOI:10.4206/agrosur.2013.v41n1-01

Shrinkage properties of different managed Andisols as function of aggregate scale

Las propiedades de contracción de Andisoles bajo distinto manejo en función de la escala de los agregados

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ARTICLE INFO

Keywords:
Volcanic soils
Soil porosity
Soil shrinkage
Soil aggregates

Original Research Article,
Soil Science

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Running tittle:
Aggregate scale dependent shrinkage of volcanic ash soils

ABSTRACT

Andisols cover approximately 50-60% of the arable land in The high porosity of volcanic soils changes continuously due to mechanical and hydraulic stresses, which can lead to an increase of drought vulnerability in crops, even though precipitation exceeds 2,000 mm annually. The aim of this work was to describe the shrinkage behaviour of volcanic soils as function of land use and aggregate scale. To describe the effect of different land uses (Native Forest, 1 and 50 years old grassland) on the shrinkage behaviour of an Andisol at different scales, undisturbed soil samples (230 cm^3) and aggregates (between 2 and 20 cm^3) were collected at 5, 20 and 40 cm depth. The weight and deformation of aggregates and undisturbed soil samples were registered at different water contents. The aggregate shrinkage was measured using the Saran resin technique. The coefficients of linear extensibility (COLE) and pore shrinkage index (PSI) were used to characterize the shrinkage behaviour. The intensification of the land use induced a decrease in the total porosity (TP) and total PSI measured at 5 cm depth: TP by 7% and PSI by 38% from NF to P50. This soil deformation occurred not only due to soil compaction but also as consequence of an intense drying. When land use changes from native forest to pasture, soils dry out more intensively, leading to smaller shrinkage properties, e.g. COLE decreased as a result of the increasing bulk density, which is also related to the amount of allophane. The smaller aggregates presented higher bulk densities than soil cores. Finally, significant scaling relationships were not observed for initial soil volume and COLE, therefore, further conceptual and experimental development are required to understand these scaling effects.

RESUMEN

Los Andisoles cubren aproximadamente el 50-60% de los suelos arables en Chile. La alta porosidad de los suelos volcánicos cambia continuamente, debido a estreses mecánicos e hidráulicos, que pueden conducir a un aumento de la vulnerabilidad a la sequía en cultivos, a pesar de que la precipitación excede 2.000 mm anuales. El objetivo de este trabajo fue describir el comportamiento de contracción de los suelos volcánicos en función del uso del suelo y de la escala de muestreo. Para describir el efecto de los diferentes usos de suelo (bosque nativo, praderas de 1 y 50 años) sobre el comportamiento de contracción de un Andisol a diferentes escalas, se recolectaron muestras de suelo no disturbadas (230 cm^3) y agregados (entre 2 y 20 cm^3) a profundidades de 5, 20 y 40 cm. La masa y la deformación de los agregados y las muestras de suelo se registraron a diferentes contenidos de agua. La contracción de los agregados se midió usando la técnica de resina Saran. Para caracterizar la contracción se determinó el coeficiente de extensibilidad lineal (COLE) y el índice de contracción de los poros (PSI). La intensificación del uso del suelo induce una disminución de la porosidad total (TP) y del PSI registrado a 5 cm de profundidad: TP en un 7% y PSI en un 38% de NF a P50. Esta deformación del suelo se produjo no sólo debido a la compactación del suelo sino también como consecuencia de un secado intenso. Con el cambio de uso de suelo de bosque nativo a praderas, los suelos se secan más intensamente, lo que redujo la capacidad de contracción, p.ej. COLE disminuyó con el aumento de la densidad aparente, lo que está también relacionado con la cantidad de arcillas alófanas. Los agregados más pequeños presentan densidad aparente más alta que la matriz de suelo. Finalmente, no se observaron relaciones de escala significativas para el volumen inicial de suelo y COLE, por lo tanto, se requiere un mayor desarrollo conceptual y experimental para entender el efecto de escala.

INTRODUCTION

Volcanic ash soils are of great importance in southern Chile, since they cover between 50-60% of the arable land in this country (5.4 million ha, Besoain, 1985) an owing to their particular properties, are very productive (Soil Survey Staff, 2010). The development of agriculture leads to an intensification of land use, which can induce a degradation of soil structure in volcanic soils due to excessive traffic and lost of soil organic matter (Ellies *et al*., 2000; Tobón *et al*., 2010). The same is also true if these soils dry out intensely because, due to its shrinkage properties (Dörner *et al*., 2010), the soil contraction also results in soil deformation (Dorel *et al*., 2000; Gray and Allbrock, 2002; Bartoli *et al*., 2007). These volumetric changes in the soil due to external (e.g. tillage tractor) and internal (e.g. water menisci force) stresses modify pore size distribution, change water holding capacity, and increase the amount of coarse pores as a consequence of crack formation (Horn and Baumgartl, 2002). Thus, the magnitude of soil deformation depends on both the soil mechanical strength (precompression stress) and the hydraulic stress (preshrinkage stress) (Baumgartl and Köck, 2004), showing that the stress level can be loaded or drained without further irreversible deformation (Horn and Baumgartl, 2002).

When a soil is continuously exposed to dryness, four shrinkage stages can be defined from the shrinkage curve. The stages of the curve, which compare the void ratio (e) responses to moisture ratios (ϑ), are defined as structural, proportional, residual and zero shrinkage phases from saturation to a complete dry condition (Braudeau *et al*., 1999; Peng and Horn, 2005). In the first phase, the structure-dependent pores and biopores are emptied without a significant reduction in soil volume, allowing air to enter large pores (Cornelis *et al*., 2006). In the second phase, the proportional shrinkage is defined as the decrease in water volume equalling the decrease in bulk soil volume (McGarry and Malafant, 1987). In the third phase, air enters into the previous water saturated intra-aggregate pores and a further decrease in water upon drying exceeds the volume change of the aggregates (Cornelis *et al*., 2006). In the fourth stage, soil particles have reached their densest configuration and the volume of the aggregates remains unaltered as the water volume further decreases (Bronswijk, 1991).

The shrinkage of soils as a function of aggregate scale was previously investigated in different European Andisols (Bartoli *et al*., 2007). They found scaling relationships between final shrinkage and initial total soil volume, i.e. the smaller the sampling size, the greater was the shrinkage, ascribing this relationship to a greater mean rate of water loss of soil clods than soil volumes. Exceptions were the most porous Andisols horizons rich in Al-humus, i.e. the clods shrunk less than the soil core counterparts. These results showed that further investigations are needed to understand the scaling relationships, which can be relevant in Chilean volcanic ash soils, since it is well known that Andisols exhibit very special natural properties such as variable charge, low bulk density, large volume of pores at different water tensions, high hydraulic conductivity, the formation of stable soil aggregates and a great shrinkage capacity (Ellies, 1988; Shoji *et al*., 1993; Ellies *et al*., 1997; Dorel *et al*., 2000; Bartoli *et al*., 2007).

The soil deformation of Chilean Andisols as a function of mechanical stresses has been documented (e.g. Ellies, 1988; Ellies *et al*., 2000; Dörner *et al*., 2009; Dörner *et al*., 2011). On the other hand, results related to the pore dynamics in aggregated beds due to wetting-drying cycles of low intensity have been reported (Seguel and Horn, 2006). However, there is a lack of information about the magnitude of the deformation of different managed Andisols as a consequence of hydraulic stresses, both at soil core and aggregate scale. Therefore, the aim of this work was to describe the shrinkage behaviour of volcanic soils as function of land use and the scale.

MATERIAL AND METHODS

Sampling collection

The sampling took place at the end of October 2007 when the soil reached field capacity. Disturbed and undisturbed soil samples (aggregates and cores) were collected at 5, 20, and 40 cm depth at the three land uses of Native Forest (NF), a prairie used for permanent pasture during the last 50 years (P50) and another seeded in March 2007 (P1) after a previous permanent pasture. The soil cores (7 replicates for each soils and depth) were sampled in metal cylinders (230 cm^3; h: 5.6 and d: 7.2cm). The samples were covered with plastic caps to protect the soil from mechanical disturbances and evaporation. The soil aggregates were carefully collected from NF and P1 in plastic boxes to avoid water evaporation and mechanical disturbance (although aggregates from P50 were collected, they were not measured due to mechanical disturbances and soil shrinkage).

Laboratory determinations

The water retention curve (WRC), pore-size distribution and soil shrinkage were measured from undisturbed samples (7 replicates per horizon). For the determination of WRC, the saturated samples were drained at decreasing water potential values (-10, -20, -30, -60, -150, -330, -500 and -15,000 hPa). In order to describe the shrinkage behaviour at water potentials lower than -500 hPa, samples were shifted to air-dry conditions (20 ± 2°C) for 14 days. During this period, the water content and vertical deformation (measured in 7 points at each soil sample) were recorded 1, 7 and 14 days after the beginning of dehydration with an electronic balance and caliper gauge (0.05mm accuracy), respectively. The undisturbed samples were then stepwise oven dried at 30, 60, and 105 °C.

Aggregate shrinkage (8 replicates per horizon) was measured using the Saran resin technique. Soil aggregates (between 2 and 20 cm^3 volume) were pending in cotton slings, then put on moist filter paper and saturated by capillarity. After saturation was reached, soil aggregates were coated with Saran resin. After the Saran was air dried, the coated aggregates were weighted and their volumes were measured following Archimedes principle (Gray and Allbrock, 2002). The determination of weight and volume were repeated at intervals of 6h, 12h, 24h and 48h until a constant weight was reached when they were dried at 30 °C. To determine the bulk density of soil aggregates, they were dried in the oven at 105 °C for 24 hours.

Calculations

Soil shrinkage curves

To characterize the shrinkage behaviour the void (e) and moisture (ϑ) ratios were used, which are defined as:

$$e = \frac{V_f}{V_s}\ [m^3/m^3] \quad (1)$$

$$\vartheta = \frac{V_w}{V_s}\ [m^3/m^3] \quad (2)$$

where V_f, V_w and V_s are the volumes of pores, water and soil, respectively. Since only the vertical deformation was measured, we assumed that an isotropic shrinkage occurred. We used a modified van Genuchten equation (Peng and Horn, 2005) to fit the shrinkage curve:

$$e(\vartheta) = e_r + \frac{e_s - e_r}{[1 + (\chi\vartheta)^{-p}]^q} \qquad 0 \le \vartheta \le \vartheta_s \quad (3)$$

where χ, p and q are dimensionless fitting parameters. Parameter p in Equation (3) is always a positive value. e_s and e_r are the saturated and residual void ratios, respectively, which can be obtained either by measurements or by fitting. In this work, we used the measured data. ϑ_s is the saturated moisture ratio. The characteristic shrinkage phases can be determined mathematically after following the method proposed by Peng and Horn (2005).

Soil shrinkage indexes

The shrinkage capacity was defined by the pore shrinkage index (PSI), which relates the shrinkage volume of the soil (ΔV_t) to the drained water-filled pore volume (ΔV_p) as follows:

$$PSI = \frac{\Delta V_t}{\Delta V_p}\ [m^3/m^3] \quad (4)$$

The PSI was defined for wCP (wide coarse pores, >50µm), nCP (narrow coarse pores, 50-10µm) and MP+FP (medium plus fine pores, <10µm) of the soil cores.

The coefficient of linear extensibility, which defines the one-dimensional variation of soils from wet until dry conditions (Grossman *et al*., 1968), was used by many authors (Gray and Allbrock, 2002; Peng *et al*., 2007) to quantify the shrinkage magnitude. We define the coefficient of linear extensibility for soil cores (COLE$_{SC}$) as follows:

$$COLE_{SC} = \frac{L_0 - L_{105°C}}{L_{105°C}}\ [-] \quad (5)$$

where, L_0 and $L_{105°C}$ are the length of the sample at saturation and after oven drying at 105°C, respectively. To define the COLE of soil aggregates we calculate the equivalent diameter of an irregular aggregate (d) defined by:

$$d = \left[\frac{6m}{\pi \cdot d_B}\right]^{1/3}\ [cm] \quad (6)$$

where m is the mass [g] of the aggregate and d_B the bulk density [g/cm^3]. The equation gives the equivalent diameter of a sphere having the same mass and density as the tested aggregate. Therefore, we define the coefficient of linear extensibility for aggregates (COLE$_{SA}$) as follows:

$$COLE_{SA} = \frac{d_0 - d_{105°C}}{d_{105°C}}\ [-] \quad (7)$$

Statistical analysis

In order to test the effect of the land use on structure dependent properties, statistical analysis was performed by analysis of variance. The differences of means were assessed by the Tukey-test (P ≤0.01).

RESULTS

General properties of the soil

The high organic carbon concentration, high clay and allophane contents, and large pore volume are typical characteristics of volcanic soils and are defined as the “andic” properties (Table 1 and 2). The organic carbon concentration and pore volume decreased with the land use from NF to P1 and then to P50, especially in the top 5cm layers. The amount of allophane increased

Table 1. General properties of studied soils.

Cuadro 1. Propiedades generales del suelo.

Site	Depth [cm]	Corg.	Sand	Silt [%]	Clay	Alloph.	db	dp [Mg/m³]	VR [m³/m³]
NF	5	16.4	9	48	43	8.0a	0.54a	2.06	2.79a
	20	7.4	9	57	34	10.5a	0.55a	2.03	2.71a
	40	3.4	7	62	31	11.6a	0.56a	2.07	2.69a
P50	5	11.1	12	49	39	7.9a	0.69b	2.12	2.04b
	20	12.2	10	50	40	8.0b	0.69b	2.08	1.99a
	40	2.9	4	76	20	13.4a	0.53a	2.08	2.92a
P1	5	7.3	6	59	35	9.3a	0.66b	2.12	2.21b
	20	6.8	8	57	35	10.7b	0.64b	2.08	2.26b
	40	2.8	6	75	19	13.3a	0.57a	2.03	2.58a

Different lowercase letters between samples collected on the same depth but different land use indicate significant differences (P ≤0.01). (Corg.= Organic carbon, Alloph.= Allophane, db= bulk density, dp= particle density, VR= void ratio).

Table 2. Total porosity (TP) and pore size distribution as function of land use and soil depth.

Cuadro 2. Poros totales (PT) y distribución del tamaño de poros en función del uso del suelo y profundidad.

Site	Depth [cm]	wCP (>50µm) [%]	nCP (50-10µm) [%]	MP+FP (<10µm) [%]	TP [%]
NF	5	12a	12a	49a	74a
	20	13a	18a	42a	73a
	40	13a	17a	42a	73a
P50	5	8b	10ab	54b	69b
	20	4c	14b	48b	69b
	40	12ab	18a	48b	72a
P1	5	5b	9b	50a	67b
	20	8b	17ab	46a	67c
	40	6b	20a	43a	74a

Different lowercase letters between samples collected on the same depth but different land use indicate significant differences (P ≤0.01).

with depth affecting the bulk density, especially in P50 and P1. The decrease in pore volume (TP) due to land use change was also observed for coarse pores. On the other hand, the amount of medium plus fine pores remains constant between NF and P1 and slightly increased from NF to P50 (Table 2). A detailed description of mechanical properties and pore functions of these soils can be found in Dörner *et al*. (2009).

Effect of land use on shrinkage behaviour

The soils, independent of the land use, shrunk. Two shrinkage phases can be well identified in Figure 1: structural and normal shrinkage. The residual and zero shrinkage were not clearly observed.

NF presented a wider range of shrinkage than the other two land uses in which the soil at P50 presented the shortest range of shrinkage. The shrinkage data was fitted with Peng and Horn's model (2005) well with a high coefficient relation (r >0.99). With this model, we defined the transition point from structural shrinkage to proportional shrinkage by the wet-side maximum curvature point (ϑ_{shw}, e_{shw}). The volume change ($e_s - e_{shw}$) during the structure dependent shrinkage was also calculated. The shrinkage parameters were listed in Table 3. Of the entire shrinkage, the structure shrinkage phase became narrower and the slope at the inflection point decreased gradually with the increasing intensity of land use from NF, P1 to P50. Such land use-dependent shrinkage was clearly observed in the top 20 cm, but at 40 cm these observed difference disappeared. Especially for the top 5 cm in P50, the structural pores were completed compacted due to the long-term cattle treading. From the fitted model, we could not find the structural phase due to its linear shrinkage behaviour. If we compared the three depths, the 40 cm depth soil showed largest void ratio due to the higher amount of allophane (Table 1) but also as consequence of the light mechanical and hydraulic stresses in the past. The range of structural shrinkage increased with increasing soil depth for each land use. The trend is more pronounced in pastures than in native forests. At the 40 cm depth, the soil deformation presented a well-defined change between the structural and proportional shrinkage, which started with lower moisture ratios (also pF values) in NF than P1 and P50.

Effect of land use on shrinkage capacity of soil pores

The pore shrinkage index (PSI) varied from 0.19 to 0.39 for the total pores (TP) in the three land uses (Figure 2). PSI of the total pores was greater in NF than P1 and P50 at 5 and 20 cm depths (P <0.01), but such difference was opposite at 40 cm depth. In some cases, the PSI of wCP and MP+FP were greater than those of the total pores. The shrinkage index values of coarse pores (wCP and nCP) did not differ as a function of the land use with the exception of the great values found in P50 and P1 at 20 and 40 cm depth, respectively.

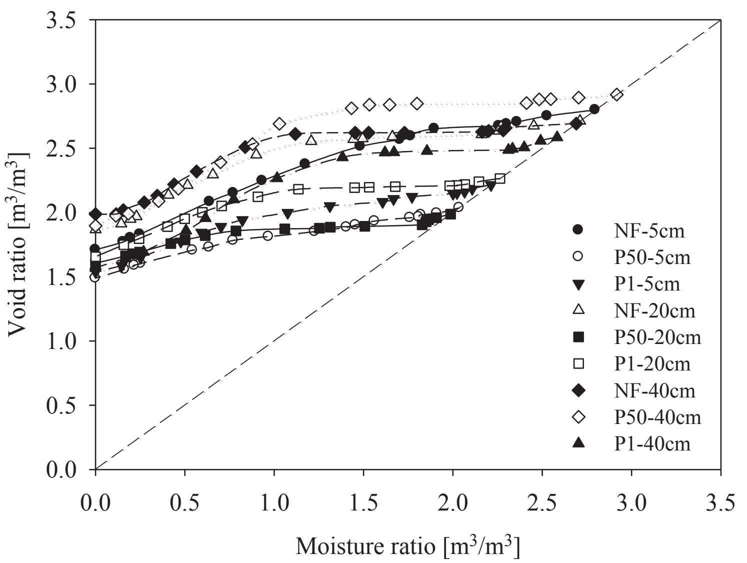

Figure 1. Shrinkage curves as function of land use and soil depth. The parameters are listed in Table 3.

Figura 1. Curvas de contracción en función del uso del suelo y profundidad. Los parámetros derivados de las curvas están indicados en el Cuadro 3.

Table 3. Parameters derived from the shrinkage curve according to the equation proposed by Peng and Horn (2005).

Cuadro 3. Parámetros derivados de la curva de contracción de acuerdo a la ecuación propuesta por Peng y Horn (2005).

Site	Depth	e_r	e_s	ϑ_{shw}	e_{shw}	$e_s - e_{shw}$	χ	p	q	r	Slope
	[cm]		----------[m³/m³]----------					------------------[-]------------------			
NF	5	1.71	2.79	1.57	2.55	0.25	0.57	3.69	0.30	0.99	0.62
	20	1.87	2.71	0.74	2.36	0.35	1.56	1.99	0.96	0.99	0.87
	40	1.99	2.69	0.68	2.42	0.28	2.49	2.15	1.80	0.99	0.98
P50	5	1.49	2.04	-	-	-	0.47	92.3	0.01	0.99	-
	20	1.61	1.99	0.42	1.76	0.23	1.61	1.52	0.89	0.99	0.41
	40	1.89	2.92	1.12	2.69	0.23	0.94	3.61	0.40	0.99	0.91
P1	5	1.54	2.21	0.91	1.96	0.25	0.89	2.51	0.47	0.99	0.53
	20	1.66	2.26	0.63	2.02	0.24	1.33	2.21	0.57	0.99	0.67
	40	1.57	2.58	1.06	2.28	0.30	1.01	2.79	0.59	0.99	0.87

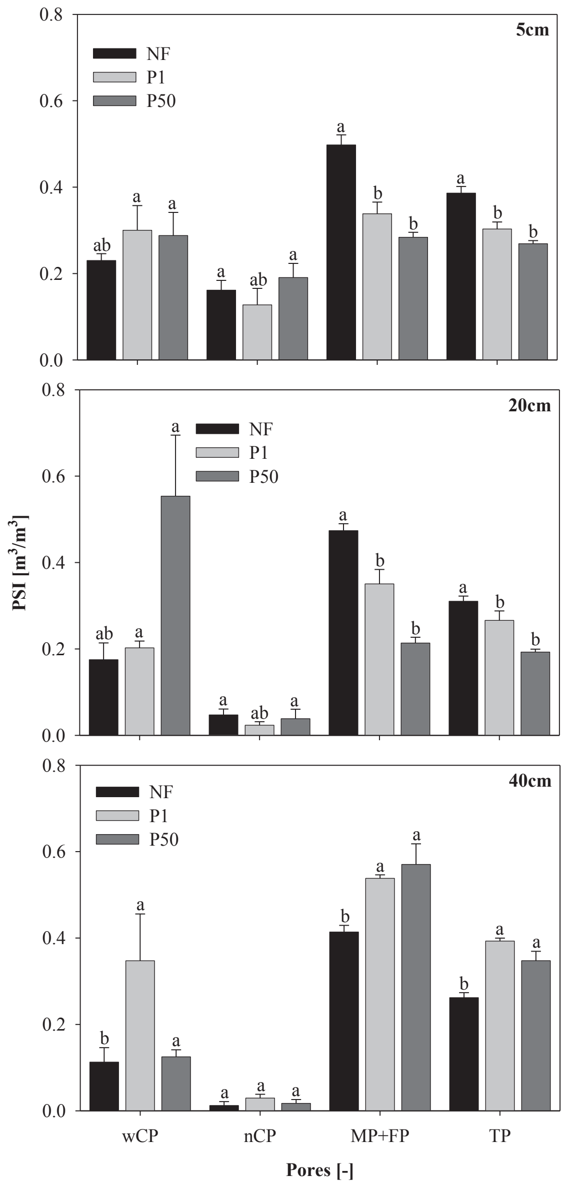

Figure 2. PSI of wide (wCP, >50μm) and narrow coarse pores (nCP, 50-10μm) and medium plus fine pores (MP+FP, <10μm) depending on land use and soil depth. Different lowercase letters on the bars indicate significant differences of each pore class as a function of land use (P <0.01).

Figura 2. PSI de los macroporos (wCP, >50μm), mesoporos (nCP, 50-10μm) y de los poros medios y finos (MP+FP, <10μm) en función del uso del suelo y profundidad. Diferentes letras minúsculas indican diferencias significativas para cada tamaño de poro en función del uso del suelo (P <0.01).

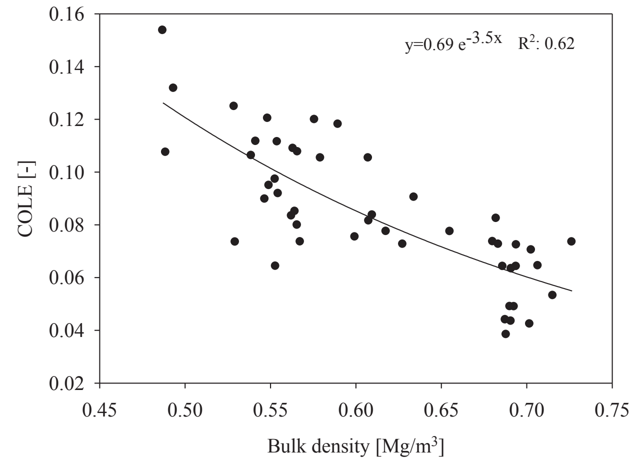

Figure 3. Coefficient of linear extensibility as function of initial bulk density of the soil.

Figura 3. Coeficiente de extensibilidad lineal en función de la densidad aparente inicial del suelo.

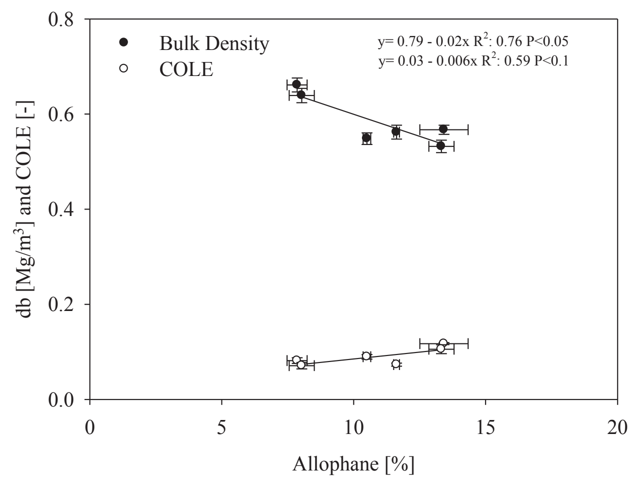

Figure 4. Bulk density (db) and COLE as function of allophane amount.

Figura 4. Densidad aparente (db) y COLE en relación al contenido de alofán.

The coefficient of linear extensibility (COLE) of soil cores decreased exponentially as the bulk density increased (Figure 3) which is strongly related to the land use (e.g. cattle treading increased the bulk density as shown in Table 1) but also to the amount of allophane (Figure 4).

The bulk density decreased as function of the initial soil volume, i.e. the smaller soil aggregates are denser than soil cores for each sampling site and soil depth (Figure 5).

The coefficient of linear extensibility and the initial soil volume measured from aggregates and soil cores collected in NF and P1 was used to characterize the scaling relationship (Figure 6). While COLE at 5 cm depth in NF increased by larger initial soil volumes the opposite was observed at 5cm depth in P1. On the other hand, the COLE at 20 and 40cm depth, in both sampled sites, presented the same tendencies, i.e. at 20 cm it tends to decrease and at 40 cm to increase with larger soil volumes.

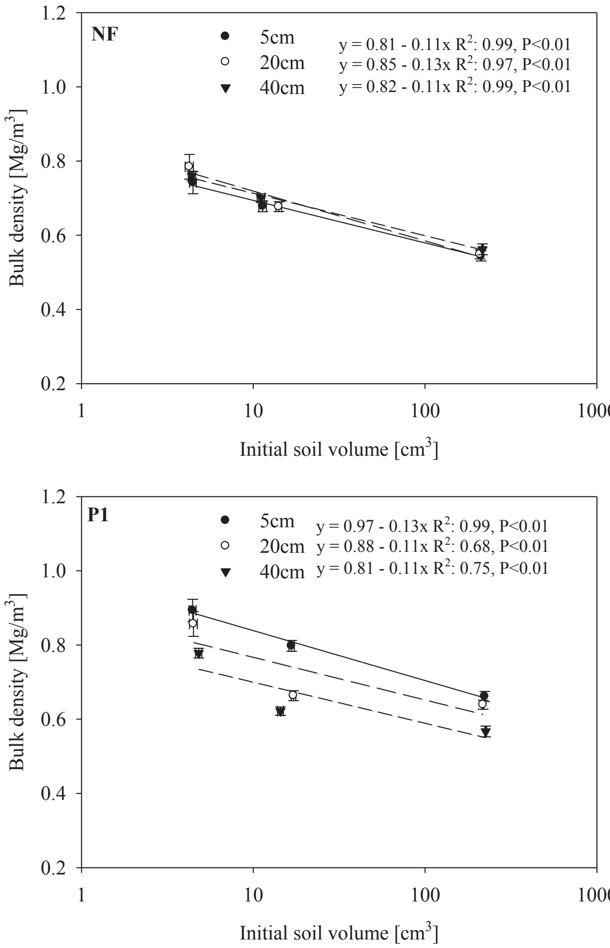

Figure 5. Initial bulk density as function of initial soil volume (NF: Native Forest, P1: one year old pasture).

Figura 5. Densidad aparente inicial en relación al volumen inicial del suelo (NF: Bosque Nativo, P1: Pradera de un año).

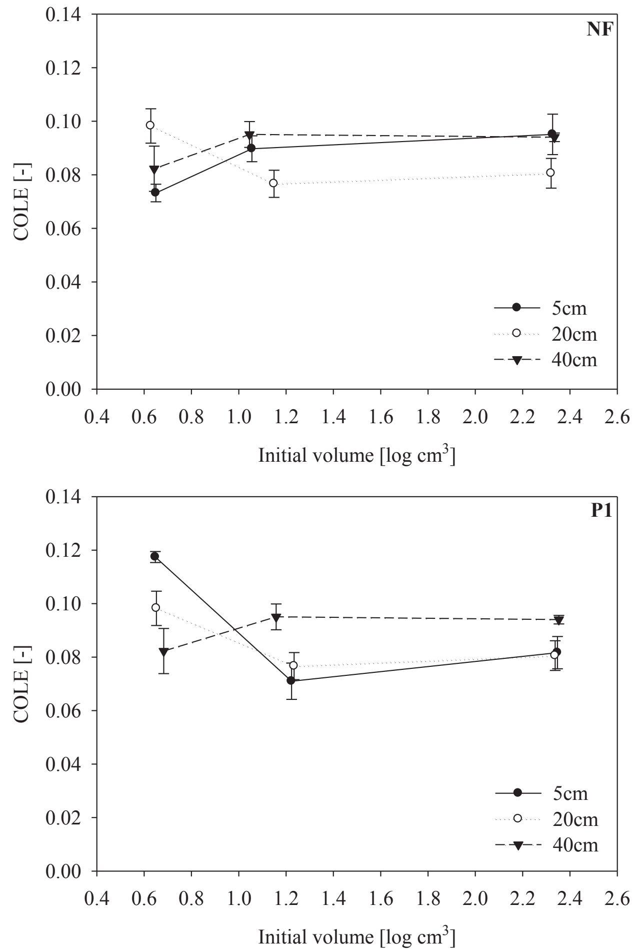

Figure 6. Coefficient of linear extensibility as function of initial soil volume (NF: Native Forest, P1: one year old pasture).

Figura 6. Coeficiente de extensibilidad lineal en función del volumen inicial del suelo (NF: Bosque Nativo, P1: Pradera de un año).

DISCUSSION

The shrinkage behaviour of volcanic soils showed a wide structural shrinkage and a pronounced proportional phase but lacked the residual and zero shrinkage. The coefficient of linear extensibility (COLE) of the three soils was characteristic for high shrinking organic soils (COLE >0.06; Peng *et al.*, 2007). In these terms, the high shrinkage capacity is also related not only to the amount of organic carbon, but also to the presence of allophane and the low bulk density (Figure 4). The latter was also supported by Bartoli *et al.* (2007), which reported an increasing shrinkage by lower bulk density as a result of the increasing amount of allophane. This type of clay mineral, composed of porous spheres, does not become aggregated as platy clay particles derived from phylosilicates do, leading to porous structures with a low cohesion between soil particles (Allbrook, 1985; Gray and Allbrook, 2002). Woignier *et al.* (2007) described that allophane aggregates as natural gels present the spongy structure that they build with allophane particles smaller than 5 nm.

The void ratio (VR) decreased from NF to P1 and then to P50, especially for the top 20 cm. The dense soil structure with increasing intensity of soil management is certainly owe to soil compaction, which, in turn, leads to a small amount of wide coarse pores (wCP, >50μm) as presented in Table 2. However, the medium plus fine pores (MP+FP, <10μm) are independent of soil management (e.g. no differences were assessed at 5 cm depth between NF and P1). Pore dependency of soil management agrees with former reporter (Richard *et al.*, 2001; Kutílek *et al.*, 2006; Peng *et al.*, 2012) who addressed that structural pores can be compacted while the textural pores are not. As a result, the range of structural shrinkage phase decreased with the increasing intensity on soil management (Figure 1 and Table 3).

Small shrinkage capacity for the wide coarse pores as indicated by PSI is in accordance with findings of other researchers (Braudeau *et al*., 2004, Peng *et al*., 2007, 2012) reporting large pores in general have less shrinkage than the medium and fine pores. Theoretically, soil management (e.g., land use) cannot change soil shrinkage capacity of MP+FP. In this study, however, the COLE (data not shown) and PSI values of MP+FP show that land use intensity reduced soil shrinkage in the top 20 cm, although the land use could not modify the volume of medium and fine pores (Table 3). We assume that this change is not due to the intensity of land use, it is owing to the different intensity of wetting and drying cycles as affected by the three land uses. This agrees with studies conducted by Mordhorst *et al*. (2012), they indicated that not only the combination of hydraulic and mechanical stresses but also the aggregation level influenced the soil deformation by drying (as assessed by COLE). The latter also agrees with the findings of Dörner *et al*. (2012), which assessed that after tillage and due to aggregate destruction the COLE increased, which is also related to a decrease in the soil mechanical stability.

Soil aggregates presented higher bulk density than the soil matrix, showing the effect of macro structure formation build up by denser soil aggregates. Similar relationships were observed by Seguel and Horn (2006) in southern Chile. The same authors found out as well that the aggregate strength generally increased with decreasing aggregate diameter. Some discrepancies, however, were observed in deeper soil horizons when aggregates were air-dried ascribing these phenomena to the presence of chemical structural agents as Fe and Al.

Since the bulk density decreased with increasing initial soil volume, we expected an increasing shrinkage as Figure 2 showed for the same sampling sizes but different land uses. The latter, however, was not always assessed as also presented by Bartoli *et al*. (2007) i.e. they presented decreasing and increasing scaling relationships as function of initial soil volume. They found that the smaller the sampling size, the greater was the shrinkage, ascribing this relationship to a greater mean rate of water loss of soil clods than soil volumes; however, exceptions were found for the most porous Andisols horizons rich in Al-humus, i.e. the clods shrunk less than the soil core counterparts. Hallet *et al*. (2000) mentioned that aggregate strength increased with decreasing aggregate size (as also observed by Seguel and Horn, 2006 in similar sampled sites), which can be related to the reduction of crack sizes available for fracture, therefore, we can expect a decreasing shrinkage as well. However, if we considered that allophane is composed by porous spheres, which leads to porous structures with a low cohesion between particles, it is possible to conclude that no significant scaling relationships has to be found. In order to understand this scaling relationship a further experimental development has to be done as proposed by Bartoli *et al*. (2007).

CONCLUSIONS

The three volcanic soils (Andisol) showed a very high shrinkage being strongly related to the presence of allophane. Their general shrinkage curves include a wide structural shrinkage phase and a clear proportional shrinkage, but the residual and zero shrinkage phases are not obviously observed.

The intensity of land use affects the amount of large pores and the structural shrinkage range. At the same time, the intensity of previous wetting/drying cycles depending on the land use influences pore shrinkage capacity significantly and finally presents soil shrinkage behaviour differently.

Scaling relationships were observed for initial soil volume and bulk density, i.e. smaller aggregates presented higher bulk density than soil cores. However, the same was not observed for initial soil volume and COLE. Further conceptual and experimental developments are required to understand these scaling results.

ACKNOWLEDGEMENTS

This study was sponsored by FONDECYT 11060130 and 7070332. The first author also thanks Claus Prehn for allowing us access to sampling sites on his farm.

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