Effect of land use changes on the dynamic behaviour of structure dependent properties of an Andisol in southern Chile

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Abstract

In order to describe the effect of land use changes on the dynamic behaviour of structure dependent properties of an Andisol in southern Chile, disturbed and undisturbed soil samples were collected in a native forest (NF), cropland (C) and 30 year old pasture (P). The soil cores were subject to mechanical (n: 4) and hydraulic stresses (n: 7) to evaluate their i) soil deformation (COLE: coefficient of linear extensibility calculated for mechanical and hydraulic stresses), ii) pore functions and iii) resilience. The hydraulic deformation was less ($COLE_{hd}$: 0.04-0.08) when compared to the effect of mechanical stresses ($COLE_{ml}$: 0.3-0.5). On the other hand, the volume recovered after the hydraulic (52% and 33% in 5 and 20 cm depth) stress was greater than after the mechanical stress (28% and 19% in 5 and 20 cm depth). The land use change affected the volumetric resilience of the soil, particularly after soil compression. The latter is related to the amount of soil organic carbon. Both mechanical and hydraulic stresses altered the bulk density of the soil. However, while the loading cycle induced a decrease of air conductivity as a consequence of a reduction of macro pores, the drying cycle caused an increase in air conductivity due to the formation of continuous macro pores between aggregates.

Key Words

Soil structure, consolidation, shrinkage, resilience, pore functions, volcanic soils

Introduction

It is well known that Andisols (Soil Survey Staff, 2006) exhibit very special natural properties like variable charge, high phosphate retention (Shoji *et al.,* 1993), low bulk density, large air and water holding capacity (Ellies, 1988; Dorel *et al.,* 2000), high hydraulic conductivity (Ellies *et al.,* 1997), stable soil aggregates (Hoyos and Comerford, 2005) and great shrinkage capacity (Dörner *et al.,* 2009). The volcanic soils in southern Chile cover a wide range of land uses (e.g. native forest, grasslands and croplands) allowing us to evaluate the effect of an intensification of land use on structure dependent properties and their resilience after different kinds of stresses. The structural changes are not only due to external forces like e.g. soil compaction (Ellies, 1988; Ellies *et al.,* 2000), but also to internal processes as a consequence of water menisci forces during wetting and drying cycles (Seguel and Horn, 2006; Dörner *et al.,* 2009). This study's objective was to describe the effect of land use changes on the dynamic behaviour of structure dependent properties of an Andisol depending on external and internal forces and their consequences on soil deformation, function and resilience.

Methods

Soil and land uses

An Andisol (Serie Los Lagos) was used to determine the effect of three land use systems (NF: native forest, C: crop, P: 30 years old pasture) on the dynamic behaviour of structure dependent properties (bulk density and air conductivity) as a function of load/unload (l/u) and drying/wetting (d/w) cycles.

Soil sampling and measurements

The sampling took place at the beginning of October 2008. Disturbed and undisturbed soil samples were collected at 5 and 20 cm depths at the three land uses of NF, C and P. In order to define the soil response to mechanical and hydraulic stresses, the undisturbed soils were sampled in metallic cylinders of 220 and 110 cm^3, respectively.

Laboratory determinations

General properties of the soil such as soil texture, organic carbon, and allophane among others, were measured as presented in Dörner *et al.* (2009).

In order to determine the soil shrinkage curve, the samples (n: 7) were first carefully saturated from beneath and then drained at matric potential values of -1, -2, -3, -6, -15, -33, -50 kPa. To characterize the shrinkage behaviour at matric potentials lower than -50 kPa, samples were shifted to dry air conditions (20 and 30ºC for 10 and 14 days, respectively). Thereafter, the samples were rewetted again and then dried at the same matric potential values as in the first drying cycle and shifted to dry air conditions (20 ± 2°C) for 14 d and then stepwise oven dried at 30, 60, and 105°C. From saturation and throughout the different matric potentials, dehydration temperatures and rewetting, the water content and vertical deformation (measured in 7 points for each soil sample) were recorded with an electronic balance and caliper gauge (0.05 mm accuracy). The air conductivity of each sample was recorded with an air permeameter at a matric potential of -60 hPa.

To define the soil response to mechanical stresses, soil samples (n: 4) equilibrated at matric potential values of -60 hPa were placed in an odometer to define the consolidation curve. The samples were stressed uniaxially at 6, 12, 25, 50, 100, 200 and 400 kPa by static loading for 6 minutes. Thereafter, the loads (σ_n) were removed until 200, 100, 50, 6, 1 kPa were reached. The soil deformation was measured during the experiment (0.05 mm accuracy).

Calculations

The coefficient of linear extensibility (COLE) was used to evaluate the effect of the land use change on the dynamic behaviour of the soil volume as a consequence of a load/unload and drying/rewetting cycle. This index, which defines the one-dimensional variation of soils from wet to dry conditions (Grossman *et al.* 1968) has been used by many authors (Gray and Allbrook, 2002; Peng *et al.,* 2007) to quantify the shrinkage magnitude. The hydraulic COLE during rewetting (hr) after air drying at 30ºC and after complete drying (hd) was calculated as follows:

$$COLE_{hr} = \frac{L_{30°C} - L_0}{L_{30°C}} \qquad (1) \qquad\qquad COLE_{hd} = \frac{L_0 - L_{105°C}}{L_{105°C}} \qquad (2)$$

where L_0, $L_{30ºC}$ and $L_{105ºC}$ are the length of the sample at saturation and after air and oven drying at 30 and 105 ºC, respectively. We modified the index for the load ($COLE_{ml}$) and unload cycle ($COLE_{mu}$):

$$COLE_{ml} = \frac{L_0 - L_{\sigma_n}}{L_{400kPa}} \qquad (3) \qquad\qquad COLE_{mu} = \frac{L_{400kPa} - L_{\sigma_n}}{L_{400kPa}} \qquad (4)$$

where L_0, $L_{\sigma n}$ and L_{400kPa} are the length of the sample at the beginning, after different normal stresses and 400 kPa.

Results

General properties of the soils

The high SOC concentration, large TP and the presence of allophane are typical characteristics of volcanic soils (Table 1). SOC and allophane are depth-dependent properties. While allophane and particle density both increase, SOC decreases with soil depth in NF and P. SOC in C slightly increase as a consequence of soil ploughing. Among the three land uses the grain size distribution and the amount of allophane did not present large differences at the same depth. However, the shift from NF to cropland causes a decrease of SOC by 20% in C and 22% in P for the top 5 cm layer. On the other hand, the total porosity (TP) decreased by 5 and <1% when land use changed from NF to C and to P.

Table 1: General properties of the soils studied.

Land Use	Depth	Sand	Silt	Clay	Allophane	SOC	ρ_s	TP
[-]	[cm]	[g/kg]					[g/cm^3]	[%]
NF	5	354	531	115	70	93.9	2.05	66.9
	20	546	350	105	118	47.6	2.36	71.5
C	5	366	512	123	80	75.4	2.24	62.9
	20	480	407	113	105	80.0	2.30	64.7
P	5	377	493	130	94	73.1	2.24	66.5
	20	410	470	120	110	68.4	2.36	74.9

Sand: 2000 – 630 µm, Silt: 630 – 2 µm, Clay: <2 µm; SOC: soil organic carbon, ρ_s: particle density, TP: total porosity,

Effect of land use on soil deformation and resilience as a consequence of mechanical and hydraulic stresses

Both mechanical and hydraulic stresses induced soil deformation as expressed by COLE (Figure 1A). The hydraulic deformation was smaller as compared to the effect of mechanical stresses. The change in land use affected the mechanical COLE, i.e. as the soil was disturbed/ploughed and then compacted (soil under crop and pasture) the COLE decreased from NF to C 23% and NF to P 38% at the 5 cm depth. Similar tendencies were observed at the 20 cm depth and were also true when the drying intensity of the soil in the field increased as a consequence of the land use change (exception NF to P at the 5 cm depth).

The soil resilience was also evaluated with COLE (Figure 1B). All depths were able to recuperate partly as compared to the initial conditions. The volume recuperation after the hydraulic (π: 52% and 33% at 5 and 20 cm depths) stress was greater than the mechanical (π: 28% and 19% at 5 and 20 cm depths) indicating that the applied load largely exceeded the precompression stress while the preshrinkage stress probably did not. The land use change affected the volumetric resilience of the soil, particularly, after soil compression. The latter, which was not so clear after hydraulic stress, is related to SOC as also assessed by Ellies (1988).

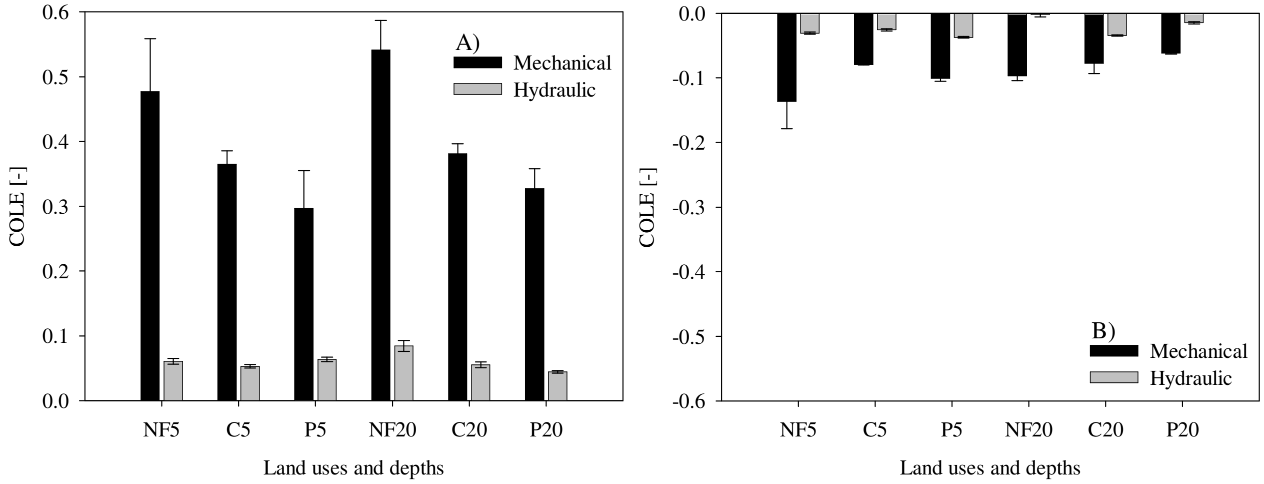

Figure 1. Effect of mechanical and hydraulic stresses on the coefficient of linear extensibility (COLE) after (A) load (0 – 400 kPa)/drying (0 hPa – 105°C) and (B) unload (400 – 0 kPa)/rewetting (30°C – 0hPa) for different land uses (NF: native forest, C: crop, P: 30 years old pasture) and depths (5 and 20 cm). Bars indicate ± 1 standard error.

Soil structure and its functional resilience after mechanical and hydraulic stresses

Both kinds of stress induced an increase in the bulk density (Figure 2). The mechanical stress induced the largest differences in bulk density before and after the compression cycle (NF: 34%, C: 29% and P: 19%).

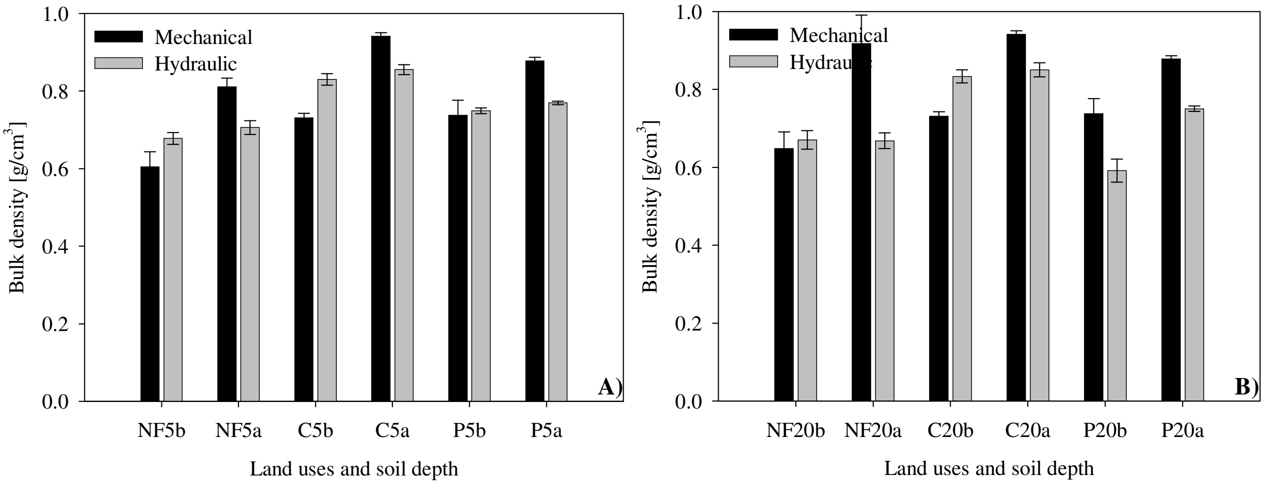

Figure 2. Effect of mechanical and hydraulic stresses (b and a: before and after compression or drying cycle, respectively) on the bulk density for different land uses and depths (A: 5cm and B: 20 cm depth). Bars indicate ± 1 standard error.

The soil deformation altered the soil structure (Figure 2) and consequently the pore functions as expressed by the air conductivity (Figure 3). However, the effect of both kinds of stress differed, i.e. while the air conductivity decreased as a consequence of soil compaction, the same property increased when, due to water menisci formation, soil shrinkage and crack formation took place.

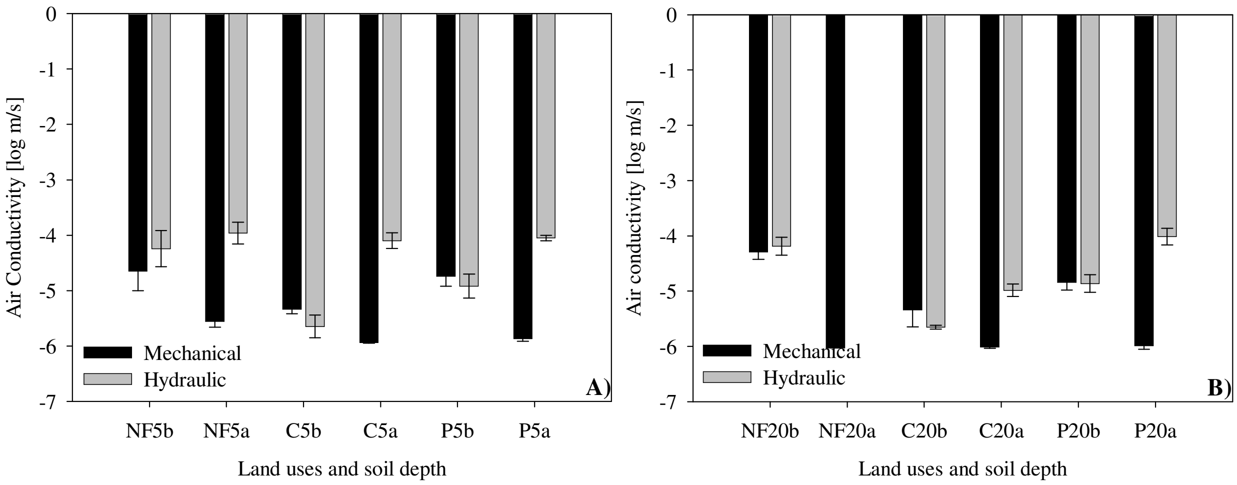

Figure 3. Effect of mechanical and hydraulic stresses (b and a: before and after compression or drying cycle, respectively) on air conductivity for different land uses and depths (A: 5cm and B: 20 cm depth). Bars indicate ± 1 standard error.

Conclusion

The soil structure (e.g. bulk density) of the studied Andisol presented a dynamic behaviour and changed as a consequence of drying/rewetting and load/unload cycles. An intensification of the land use induced greater mechanical and hydraulic stresses in the soil. The latter meant improved structure stability (e.g. lower COLE) but lower resilience. Both mechanical and hydraulic stresses altered the bulk density of the soil. However, while the loading cycle induced a decrease of air conductivity as a consequence of a reduction of macro pores, the drying cycle caused an increase in air conductivity due to the formation of continuous macro pores between aggregates.

Acknowledgements

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