Spatial and temporal changes of soil physical properties of an Andisol in southern Chile as a consequence of grazing and wetting and drying cycles

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Abstract
Weather, human activity and different soil management are factors that lead to spatial and temporal variations in soil physical properties. The aim of this study was to study the effects of grazing and wetting and drying (WD) cycles on some time-space dependent physical properties of an Andisol (Duric Hapludand) in southern Chile. Temporal changes in soil water content (WC) influenced the penetration resistance (PR), and were also related to the aggregate strength (AS) and precompression stress (Pv). Soil compaction caused by livestock not only affected PR spatially, but also disturbed the pore continuity, thus reducing the air conductivity of the soil.

Key Words
Grazing, soil water content, mechanical strength, pore functions, spatial and temporal variability

Introduction
The water regime in soils is very important to aggregate formation, morphology of soil structure, processes occurring in the soil, plant-growth and the functioning of microorganisms. This, in turn, depends on the ability of soil to provide nutrients, gases, heat, water and a rootable pore system. These properties are exposed to continuous changes, whether due to natural phenomenon (WD cycles) or human activities (tillage-induced disturbance and grazing events). The latter often causes severe changes in soil structure which have a detrimental impact on soil functions, e.g. soil disturbance due to tillage or grazing that represents the most dynamic and influential modification (in time and space) of soil physical properties such as bulk density, water and air conductivity (Schäfer-Landefeld *et al.* 2004). Until now, temporal and spatial changes of soil physical properties are not well known in southern Chile. Therefore, the purpose of this study was to illustrate the spatial and temporal changes of soil's physical properties (WC, PR) measured in the field relating them to the grazing events, changes in WC and soil strength and pore functions measured in the laboratory.

Methods
Soil and management
The investigation was conducted in an experimental field located in Valdivia (Santa Rosa). Before starting the experiment, the soil (Duric Hapludand, Serie Valdivia) was cultivated and *Lolium perenne* and *Trifolium repens* were seeded in April, 2008. The grazing (2 animals/400 m^2) began in September, 2008 and was the same in all plots.

Soil sampling and measurements
The soil samplings and measurements were conducted from November, 2008 until April, 2009 (SR1- 03.11.08; SR2- 10.11.08; SR3- 09.01.09; SR4- 10.03.09; SR5- 15.04.09; SR6- 20.04.09; Figure 1) depending on the soil water content (WD cycles) and grazing. The experimental field consisted of 6 plots (20x20m). The water content (TDRs) and penetration resistance (Penetrometer) were measured on each plot, arranged along transects 3m apart with each transect divided into 13 points (separation: 1.5 m). When field measurements were done, undisturbed soil samples in metallic cylinders and soil aggregates were collected from 2 to 10 cm depths.

Laboratory determinations
Saturated hydraulic conductivity (Ks, cylinders of 250 cm^3, n: 10) was measured with a water permeameter using the constant head method. Ks was measured after 1 and 72 hours of continuous water flow. In order to define the pore size distribution, the water retention curve (cylinders of 220 cm^3, n: 7) was measured using sand tanks and pressure chambers. The precompression stress (Pv, cylinders of 110 cm^3, n: 6), determined in an odometer after equilibration of the soil samples at a matric potential of 60hPa, was calculated according to

the Casagrande method (Rico and del Castillo 1978). In order to define the structural and functional resilience of pores, the air conductivity (Ka) was measured before (bC) and after (aC) compaction. The crushing test (n: 20) was conducted in order to describe the aggregate strength (Dexter and Kroesbergen, 1985). For this purpose aggregates were saturated, equilibrated at -60, -330hPa and 30°C and then crushed between two parallel splints by adding water.

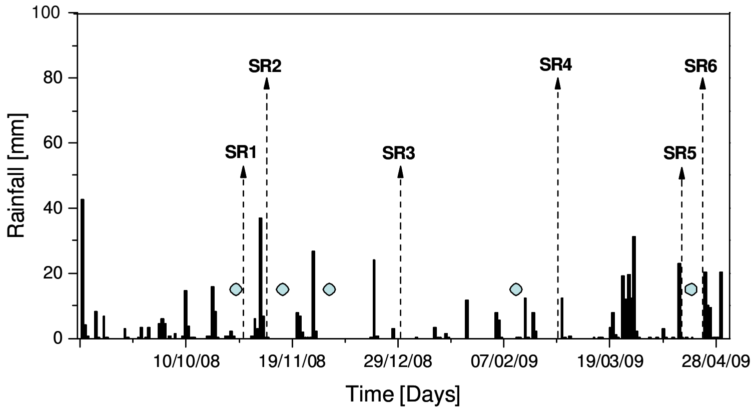

Figure 1. Development of rainfall during the experiment. SR indicates the soil samplings and circles the grazing events.

Results

Temporal and spatial changes in soil strength as a consequence of grazing events and WD cycles

The decrease in water content in the soil induced an increase in PR. The latter, however, is spatially dependent as a consequence of the grazing events. Animal trampling leads to the degradation of the soil's physical quality and the deterioration of soil structure through hoof action of the grazing animals. Compacted soil causes soil deformation and changes soil's physical properties such as e.g. PR (Reszkowska *et al.* 2009).

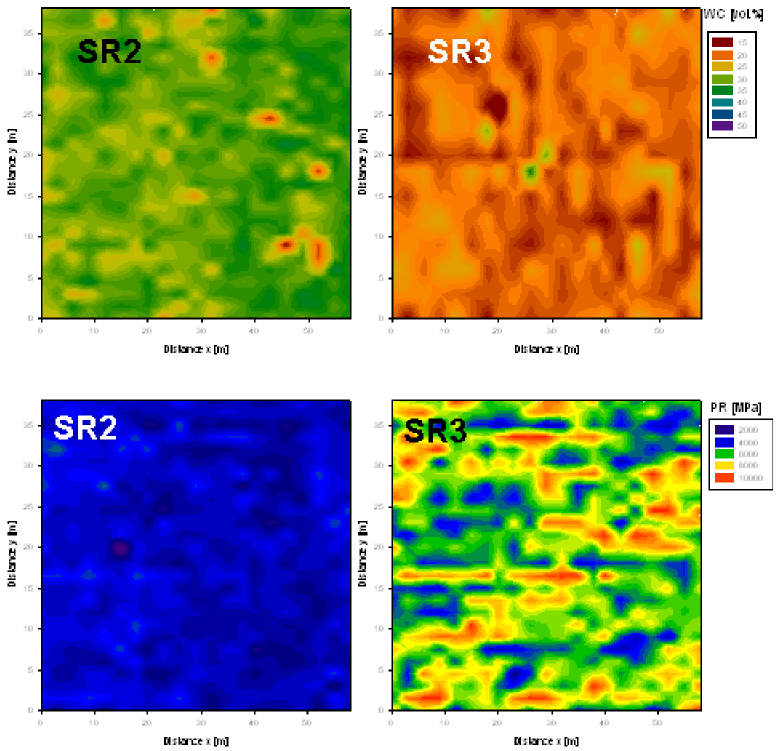

Figure 2. Spatial distribution of volumetric water content (WC) and penetration resistance (PR) in SR2 (10.11.08) and SR3 (09.01.09).

The observed values of PR in the present investigation are similar to those presented by Bachmann *et al.* (2006) in a Typic Hapludand under pasture. Soil penetration resistance is a mechanical property that has been used by many authors as an indicator of soil compaction (Draghi *et al.* 2005). In wet soils, where pore space is filled with water, the menisci forces cause the soil particles to loose contact between them. This, in

turn, increases the soil's susceptibility to compaction. The water menisci forces build up during drying induced and increase in PR, which exceeds critical values to root growth (2000 kPa, Bengamin *et al.* 2003). We believed, however, that this great PR do not affect the root growth because of the low bulk density (< 0.9 g/cm^3) caused by the great amount of organic soil carbon and the presence of allophane which are typical characteristics of Andisols (Dörner *et al.* 2009). The latter, however, need further investigation.
Temporal changes were also observed for other soil properties (Figure 3) which are related to the grazing events and WC cycles. The changes in mechanical strength registered by PR were also observed at the soil aggregate and core scales, i.e. an increase in penetration resistance also meant greater values of aggregate strength and precompression stress. After the grazing event occurred between SR5 and SR6 (17 April, 2009) both PR and AS increased.

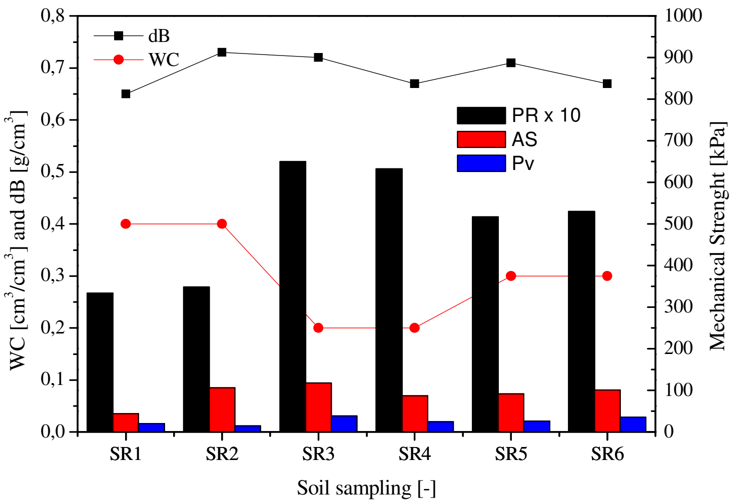

Figure 3. Temporal (soil sampling SR1-SR6) changes in penetration resistance (PR), water content (WC), bulk density (dB, SR1-SR4), precompression stress (Pv, SR1-SR5) and aggregate strength (AS).

Temporal changes in soil structure and pore functions as a consequence of grazing events and WD cycles
Temporal changes were also observed in air conductivity (Figure 4). Ka showed a slight decrease between the first and third soil samplings. The third sampling event (SR3) occurred 1 month after the last grazing event which did not allow enough time for the soil to recover its functional integrity. The changes in water content during summer and autumn induced crack formation due to the great shrinkage but low swelling capacity of these soils (Dörner *et al.* 2009). The latter explains the increase in Ka. After the consolidation experiment, Ka decreased; i.e. soil deformation and partial recuperation of the volume affect the continuity and efficiency of the porous system.

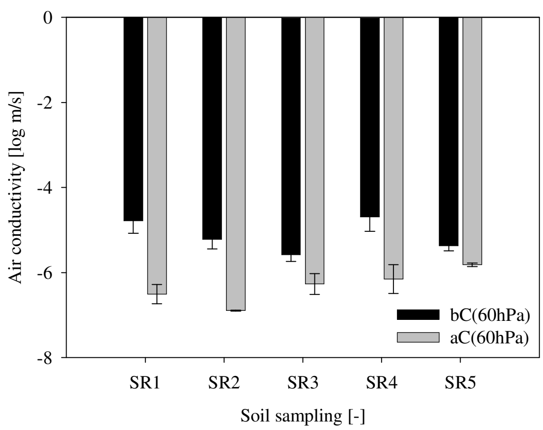

Figure 4. Air conductivity before (bC) and after (aC) compaction as a function of time (soil samplings SR1-SR5).

A redistribution of soil pores was observed during the experiment (Figure 5a). While the larger pores (wCP) remained constant, the narrow (nCP) and mesopores (MP) decreased 5.9% and 2.5%, respectively, and micropores (FP) increased 2.67% between SR1 and SR4. On the other hand, variations in water permeability (Figure 5b) reflect changes presented in PR (Figure 2, 3), bulk density (Figure 3) and pore size distribution

(Figure 5a). These dynamic changes in the soil's hydraulic properties are caused not only by WD cycles but also by grazing events where simultaneous compaction, shearing, kneading and homogenization (Warren *et al.* 1986) lead to intensive disruption of soil structure (especially topsoil) which, in turn, changes soil porosity and the connectivity of the porous system (Figure 5).

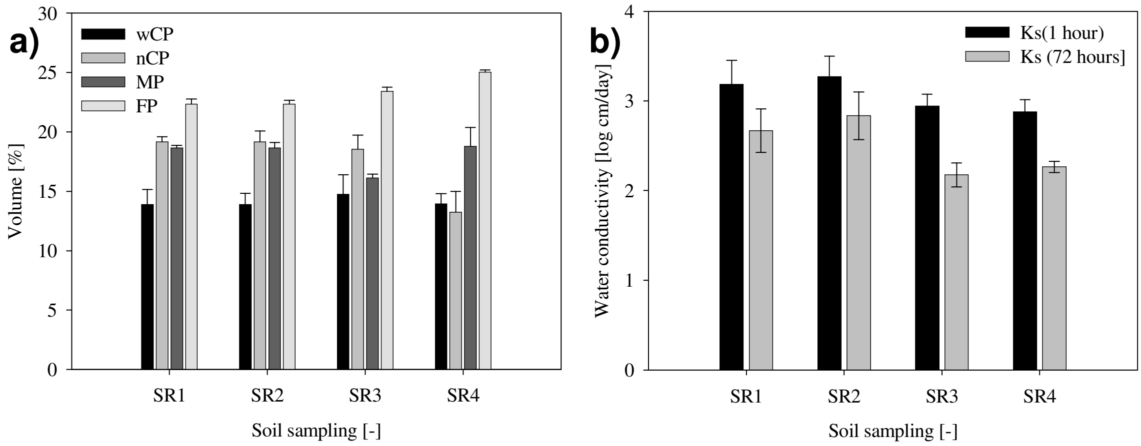

Figure 5. a) Pore size distribution (wCP:>50µm, nCP:50-10µm, MP:10- 0.2µm, FP:< 0.2µm and b) saturated water conductivity as a function of time (soil samplings SR1-SR4).

Conclusion

The penetration resistance changed in time and space in relation to soil water content and the grazing events. Changes in penetration resistance reflected the aggregate strength and the precompression stress. The pore system and its distribution were dynamic, changing temporarily as a consequence of internal and external forces. The latter also induced changes in mechanical strength and pore functions as observed in water and air conductivity, e.g. soil compaction caused by livestock disturbs continuity of pores and, consequently, reduced the air conductivity in the soil.

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References

Bachmann J, Contreras K, Hartge KH, MacDonald R (2006) Comparison of soil strength data obtained in situ with penetrometer and with vane shear test. *Soil and Tillage Research* **87**, 112-118.

Bengamin JG, Nielsen DC, Vigil MF (2003) Quantifying effects of soil conditions on plant growth and crop production. *Geoderma* **116**, 137-148.

Dexter A, Kroesbergen, B (1985) Methodology for Determination of Tensile Strength of Soil Aggregates. *Journal Agricultural Engineering Research* **31**, 139-147.

Dörner J, Dec D, Peng X, Horn R (2009) Change of shrinkage behavior of an Andisol in southern Chile: Effects of land use and wetting/drying cycles. *Soil and Tillage Research* **106**,45-53.

Draghi LM, Botta GF, Balbuena RH, Claverie JA, Rosatto H (2005) Diferencias de las condiciones mecánicas de un suelo arcilloso sometido a diferentes sistemas de labranza. *Revista Brasileira de Engenharia Agricola e Ambiental* **1**, 1415-4366.

Reszkowska A, Peth S, Horn R (2009) Cyclic compressibility of grassland soils as affected by grazing in inner Mongolia, China. In 'ISTRO 18th Triennial Conference Proceedings' (Izmir: Turkey).

Rico R, del Castillo H (1978) 'La Ingeniería de Suelos en Vías Terrestres, Carreteras, Ferrocarriles y Aeropistas'. (Limusa: México).

Schäfer-Landefeld L, Brandhuber R, Fenner S, Koch HJ, Stockfisch N (2004) Effect of agricultural machinery with high axle load on soil properties of normally managed fields. *Soil and Tillage Research* **75**, 75-86.

Warren SD, Nevil MB, Blackburn WH, Garza NE (1986) Soil response to trampling under intensive rotation grazing. *Soil Science Society of America Journal* **50**, 1336-1340.