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Temporal dynamics of the physical quality of an Andisol under a grazing system subjected to different pasture improvement strategies

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ABSTRACT

The south of Chile presents adequate conditions for the development of pastoral ecosystems in volcanic soils. The improvement strategies of these pastures consider soil tillage and fertilization. Andisols have special physical properties, however, their ability to support high stress levels affecting the soil physical quality should be defined. The aim of this study was to evaluate the evolution of the effect of different pasture improvement strategies on the physical quality of an Andisol. The study was carried out in the Estación Experimental Agropecuaria Austral (39°46′ S, 73°13′ W), on a Duric Hapludand. Four treatments were randomly distributed corresponding to a mixed binary species (T1: *Lolium perenne* L. + *Trifolium repens* L.), a multiple species mixture (T2: *Bromus valdivianus* Phil., *L. perenne*, *Dactylis glomerata* L. and *T. repens*) both of which were tilled, and another two that had no mechanical intervention of the soil, which was degraded naturalized pasture without fertilization (T3) and, finally, one that represented a naturalized degraded pasture with fertilization (T4). Additionally, a naturalized, degraded pasture without intervention was analyzed, which corresponded to the initial situation (IS) of the pasture. Undisturbed samples were taken between 1 and 10 cm in December 2010 and October 2011. The bearing capacity of the soil (*BC*), the water retention curve (*WRC*), the saturated hydraulic conductivity (*Ks*) and the air conductivity (k_l) were determined. Soil physical quality indicators were derived such as plant available water (*PAW*), pore continuity indexes (C_2 and C_3) and the *S* index for physical quality. The tillage of the soil separated the pastures, grouping them into either disturbed (T1 and T2) or non-disturbed (T3 and T4). In general, parameters that were derived from the pore volume never reached the critical levels (e.g., *PAW* > 20%, *S* Index > 0.035) proposed in the literature. On the other hand, parameters that define the functionality of the porous system (k_l), showed differences in one order of magnitude between pastures that maintained their structure (T3 and T4) compared to the tilled ones (T1 and T2), so that for T4 the pore continuity index (C_2 and C_3) increased by 300% and the volume of blocked pores (ε_b) did not reach 1%. At the same time, properties that define the performance of the pores evolved positively over time in a more intense manner in pastures that maintained their structure (T3 and T4). However, this does not mean that in the long term these pastures would not present conditions of physical degradation.

1. Introduction

The southern zone of Chile possesses 1.34 million ha of pastures. Of these, 8.7% are improved, while 91.3% of them are naturalized pastures (INE, 2007). In this area naturalized pastoral systems are developed, which present a high production potential and livestock relevance (López et al., 1997). This has occurred as a result of the intense changes in land use over the last 200 years (Martínez et al., 2008). These pastures are the principal source of feed for ruminants, due to low costs of production (Teuber et al., 2007). The improvement strategies implemented in these pastoral systems consider the sowing of

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new pastures, the regeneration of existing ones, and even the fertilization of existing pastures (Siebald et al., 1983).

One evaluation alternative for the implementation of these strategies is through the concept of soil quality proposed by Karlen et al. (1997): "*the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation*". This concept is determined by inherent and dynamic characteristics of the soil (Karlen et al., 2003), and is found valid when indicator parameters are present (e.g., air capacity, permeability, penetration resistance) that allows for evaluation of the level of soil quality (Reynolds et al., 2009; Horn and Fleige, 2009).

The studies of the changes that the physical properties of the soil suffer have been evaluated from a holistic point of view considering the mechanisms and dynamics of soil structure formation, pedogenetic processes, biotic and abiotic factors (Bronick and Lal, 2005), tillage effects (Pagliai et al., 2004; Dörner and Horn, 2006) and compaction (Weisskopf et al., 2010). Historically, this line of research has been developed comparing the strategies evaluated with reference patterns that can indicate "good" quality (e.g., Dexter, 2004a; Reynolds et al., 2009) as could be a climax condition, or of low intervention (Fuentes et al., 2004). In these terms, Dörner et al. (2012) indicate that research has commonly focused on the effect of animal treading on soil compaction (Rezkowszka et al., 2011b), so that little attention has been paid to the natural soil recovery (Drewry, 2006; Dec et al., 2012) and even less on the effect of different pasture improvement managements on soil physical quality, particularly, when the initial situation is a degraded pasture. The latter is a great concern in southern Chile, where the soils are developed from volcanic ash.

For soils derived from volcanic ash parameters of physical soil quality under grazing have been spatially (Dec et al., 2011) and temporally (Dec et al., 2012) evaluated and it has been demonstrated that these soils present special physical properties. Due to the low bulk density ($<0.9\,g\,cm^{-3}$), elevated levels of organic carbon (Matus et al., 2006) and of allophane (Dörner et al., 2009a,b, 2010), these soils present a high resilience capacity (Dec et al., 2012; Dörner et al., 2012). However, this does not mean that soils derived from volcanic ash present an infinite capacity to support high stress levels (e.g., increased grazing pressure in winter) which can affect their physical quality. In this context, medium and long-term studies are needed to consider the effects of grazing management on the physical quality of these soils and their evolution over time (Dec et al., 2012). The hypothesis of this study indicates that the properties which define the physical quality of an Andisol in the medium-term, will improve in pastures that maintain their structure compared to pastures that have been tilled. The aim of this study was to evaluate the temporal effect of the implementation of different pasture improvement strategies on parameters that define the physical quality of soil derived from volcanic ash.

2. Materials and methods

2.1. Soil and management history

The experiment was carried out in the Estación Experimental Agropecuaria Austral (EEAA) (39°46′ S, 73°13′ W) of the Universidad Austral de Chile. The area around Valdivia presents a temperate rainy climate without a dry season (Cfb Kottek et al., 2006) with average annual temperatures of 12 °C, average rainfall of 2500 mm, distributed seasonally and winds with predominant origins from the North and West (Huber, 1970). The soil was developed from the deposits of volcanic ash over marine sediments called "cancagua". The soil characteristics and the water regimens permit this soil to be classified as Duric Hapludand (CIREN, 2003) or as a Petroduri-Silandic Andosol (Salazar et al., 2005; WRB, 2006), which is denominated "Valdivia Series" (CIREN, 2003). The topography is complex, with dominant grades of 3–8%, and sectors that are lightly curved from 2 to 5%. Table 1 shows the general characteristics of four horizons of the soil. In general terms the soil presents a larger predominance of silt in its horizons, and decreases in the levels of organic carbon (*OC*), and extractable aluminum (Al_{ext}) with depth, influencing the levels of bulk density of the soils (ρ_b).

The unit of investigation consisted of 12 plots of $400\,m^2$ (20×20), distributed in a randomized complete block design with three replicates for each treatment. The site was composed of 4 treatments plus a control situation (IS) that originated from a naturalized pasture subjected to 30 years of extensive grazing, but it was not grazed in this experiment. The dominant species corresponded to *Anthoxanthum odoratum* L., *Agrostis capillaris* L. and *Holcus lanatus* L. The 4 treatments corresponded to a mixed binary species (T1) composed of *Lolium perenne* ($25\,kg\,ha^{-1}$) + *Trifolium repens* ($5\,kg\,ha^{-1}$), multiple species mixture (T2: *Bromus valdivianus* ($27\,kg\,ha^{-1}$), *L. perenne* ($9\,kg\,ha^{-1}$), *Dactylis glomerata* ($4\,kg\,ha^{-1}$) and *T. repens* ($5\,kg\,ha^{-1}$), a naturalized pasture without fertilization (T3) and another naturalized pasture with fertilization (T4). T1 and T2 were sown in March of 2010. The preparation of the soil considered weed control operations with offset disc harrow (5 times) and field cultivator (1 time). The fertilization rate for T1, T2 and T4 corresponded to $120\,kg\,N\,ha^{-1}$, $120\,kg\,P\,ha^{-1}$, $120\,kg\,K\,ha^{-1}$ and $2000\,kg\,CaCO_3\,ha^{-1}$. The stocking density refers to the number of animals that graze in a determined moment on the surface of one ha. For this study, this load corresponded to $625\,sheep\,ha^{-1}$. The control situation (IS) was not grazed, tilled, or fertilized.

2.2. Soil sampling

A gouge auger (Eijkelkamp) was used to determine the homogeneity of the soil as a function of its effective depth and morphological variation. After that, a pit was made in which the soil was characterized, defining its horizons by depth, limits and morphological properties, collecting material from each horizon to

Table 1
General characteristics of the soil Valdivia Series (VAL).

(cm)	($g\,kg^{-1}$)			($Mg\,m^{-3}$)		($g\,kg^{-1}$)	($mg\,kg^{-1}$)
Depth	*Sand*	*Silt*	*Clay*	ρ_s	ρ_b	*OC*	Al_{ext}
0–12 A_p	230 ± 21.0 a	540 ± 23.0 a	220 ± 1.0 a	2.21 ± 0.13 a	0.67 ± 0.01 c	73.3 ± 0.8 a	1235 ± 24.0 a
12–26 B_1	300 ± 7.0 a	500 ± 11.0 a	200 ± 9.0 a	1.76 ± 0.14 b	0.70 ± 0.01 c	68.2 ± 0.7 b	1214 ± 27.0 a
26–50 B_2	270 ± 50.0 a	510 ± 49.0 a	230 ± 8.0 a	2.20 ± 0.05 a	0.80 ± 0.01 a	27.7 ± 0.5 c	994 ± 7.0 b
50–75 B_3	210 ± 47.0 a	580 ± 64.0 a	220 ± 22.0 a	2.38 ± 0.05 a	0.74 ± 0.02 b	14.7 ± 2.5 d	877 ± 7.0 c

Sand: ϕ = 2000–63 μm, *silt*: ϕ = 63–2 μm, *clay*: ϕ = <2 μm; ρ_s: particle density; ρ_b: bulk density; *OC*: organic carbon; Al_{ext}: extractable aluminium. Average values are presented ±1 standard error. Different letters indicate statistically significant differences among soil horizons ($p \le 0.001$; ρ_s: $p \le 0.05$).