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Effect of pasture improvement managements on physical properties and water content dynamics of a volcanic ash soil in southern Chile

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A R T I C L E I N F O

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A B S T R A C T

The pastures in Chile are sustained on volcanic ash soils covering an area of 1,340,000 ha. Since 44% of these pastures are degraded, different strategies to improve these prairies have been implemented. This study examined the impact of the different pasture improvement managements (PIMs) on soil physical properties, water content dynamics and pasture productivity of a volcanic ash soil under sheep grazing. The experiment was established on a Duric Hapludand and considered four types of PIMs (fertilised-naturalised pasture, cultivated pasture, direct-drilled pasture, diverse-direct drilled pasture) including the initial situation (non-fertilised naturalised pasture). The effect of PIMs and grazing events on bulk density (BD), plant available water (PAW), air permeability (k_a), saturated hydraulic conductivity (Ks) and pre-compression stress (Pc) in the topsoil (0–10 cm) was determined taking undisturbed soil samples, whereas the penetration resistance (PR), field air permeability (k_l field) and herbage mass production were measured in the field. The volumetric water content, matrix potential and soil temperature were continuously registered at different depths. The fertilisation of degraded naturalised pastures, without soil structure disturbance, improved the pasture yield (140%), reaching values comparable to those improved with conventional systems. In the short term, the volume of macropores does not change significantly as a function PIMs. However, tilled soils presented less connected pores compared to the non-cultivated PIMs. The conservation of soil structure plays an important role in water accessibility by plants, so that fertilised-naturalised pastures were able to absorb water to depths of up to 60 cm. Compared to the improved pastures, the degraded non-fertilised pasture presented the lowest above ground herbage biomass as well as negative effects on soil physical properties (e.g. Pc increased by 57% and lower physical resilience) after grazing events.

1. Introduction

Sheep, beef and dairy cattle farming in southern Chile are based on grazing systems located mainly in the zone of volcanic ash soils (Balocchi, 2002). These pastures in Chile cover an area of 1,340,000 ha. However, 44% (594,000 ha) of these pastures are degraded or present low levels of productivity (INE, 2007), consequently different strategies to improve these prairies have been implemented (Zúñiga et al., 2015). The latter is a relevant topic in southern Chile, since naturalised pastures produce low annual accumulated herbage (less than 5000 kg DM ha^{-1}) and with a low nutritive value (Siebald et al., 2000). The pasture improvement managements (PIMs) mostly used directly on the increase of the low dry matter production of these degraded pastures in southern Chile are: i) the improvement of the chemical soil condition and grazing management; ii) sowing high production species through zero-tillage techniques plus an improvement of soil chemical conditions, and iii) new pasture establishment by traditional soil tillage, sowing high production species plus an improvement of soil chemical conditions (Cuevas, 1980; Balocchi and López, 1994; Chauveau et al., 2015; Zúñiga et al., 2015).

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It is well known that different tillage intensities generate different changes in soil physical quality (Strudley et al., 2008; Dörner et al., 2013a, 2013b; Ivelic-Sáez et al., 2015; Zúñiga et al., 2015). The more intensive the intervention of the soil structure, the more drastic the changes in pore functions will be, in comparison with the original status of the soil (Schwen et al., 2011a). Traditional tillage implies a destruction of soil aggregates, and then, soil structure formation processes will occur depending on wetting/drying cycles, cementation of the particles of the soil, and the stabilisation of the structure by the biological factors made by soil macro, meso and microfauna (Hartge, 2000; Bronick and Lal, 2005). This kind of tillage negatively affects the continuity of the functional pores of the soil (Dörner and Dec, 2007; Dörner et al., 2013b; Zúñiga et al., 2015) and generates a change in the relation between macro, meso and micropores by increasing total porosity but destroying the pore continuity at the same time (Reszkowska et al., 2011a; Zúñiga et al., 2015). On the other hand, less intensive tillage systems, like zero-tillage, maintain the soil structure, the architecture and the pore size distribution (Zúñiga et al., 2015) allowing preferential fluxes of water as well as a minor resistance to root growth and exploration of deeper soil depths (Xua and Mermoud, 2003; Uteau et al., 2013).

There is wide scientific knowledge related to the impact of traditional, zero and reduced tillage on mineral soils (Reynolds et al., 1995; Angulo-Jaramillo et al., 2000; Neves et al., 2003; Xua and Mermoud, 2003; Zibilske and Bradford, 2007; Strudley et al., 2008; Abid and Lal, 2009; Schwen et al., 2011a, 2011b), however, this does not hold true for soils derived from volcanic ashes (Dörner et al., 2012; Ivelic-Sáez et al., 2015; Zúñiga et al., 2015), which normally have very low bulk densities (< 0.9 Mg m^{-3}) and excellent physical properties (WRB, 2006). Dörner et al. (2013a) pointed out that the impact of tillage and of different botanical composition at these andic soils result in very different soil physical properties which also affect their relationships to soil water content dynamics. Considering that the physical properties of volcanic ash soils are specific and that animals graze pastures throughout the whole year in southern Chile (Dec et al., 2012), it is necessary to understand how the soil responds after the implementation of different pasture improvement managements (PIMs) under grazing conditions. The latter is relevant in order to: i) evaluate the interaction between the different managements (e.g. different kind of tillage and pastures) on soil-plant-water relationships, and, ii) determine how these different managements systems may affect the physical properties of the soil in the medium- and long-term. Therefore, the aim of this research was to analyse the impact of the implementation of different pasture improvement managements (PIMs) on soil physical properties, water content dynamics and pasture productivity of a volcanic ash soil under grazing.

2. Material and methods

2.1. Geographic and treatment descriptions

The experimental field was located at the Universidad Austral de Chile's Estación Experimental Agropecuaria Austral (EEAA) (39°46′ S, 73°13′ W, 12 m a.s.l.) in Valdivia, Chile. The average annual temperature is 12 °C and yearly precipitation is between 1901 and 2005 mm, with a 2440 mm mean (González-Reyes and Muñoz, 2013), but with a major concentration of the rainfall in winter (Huber, 1970), as well as, a well-defined reduction in the rainfall in recent years (González-Reyes and Muñoz, 2013). Rainfall and average daily air temperature during the experiment (March 2013 till December 2015) were collected at the INIA station, located 40 km north from the study site (Fig. 1).

The soil is derived from volcanic ashes, classified as a Duric Hapludand (Valdivia Series according to CIREN, 2003) with a profile that can reach 3 m depth. The topography is complex, with dominant slopes of 3 to 8%, and sectors that are slightly curved from 2 to 5%. At the study site the slope was less than 2%. The soil presented pH_{water} of 5.6, organic matter levels of 13.1% as well as 8.6 mg/kg of P_{olsen} and aluminium saturation of 8.6%. Detailed information about the physical and chemical properties of the soil series under different land uses and soil management intensities can be found in Dörner et al. (2013a, 2013b, 2015); Zúñiga et al., (2015).

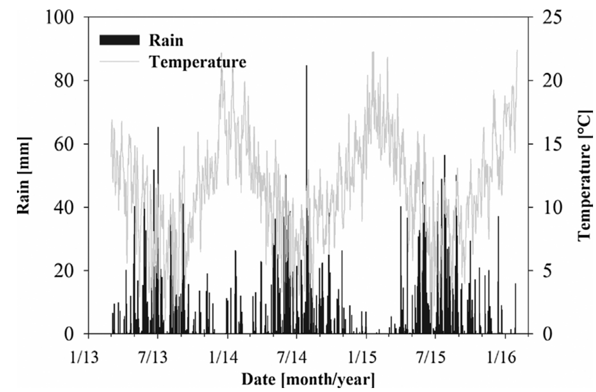

Fig. 1. Temperatures and rainfalls between December of 2012 and January of 2016.

The experiment considered five types of pastures, including the initial situation, defined as 'non-fertilised naturalised pasture (NFNP)'. This pasture was spontaneously growing in the utilised site and was not sown neither fertilised nor limed. The other four pastures corresponded to pasture improvement managements (PIMs, Table 1) that farmers can use in southern Chile: 1) fertilised naturalised pasture (FNP) without tillage treatment: the initial naturalised pasture was improved through fertiliser addition and liming to upgrade soil pH conditions. Fertiliser and lime were applied over the current pasture (improvement of the initial situation, NFNP) without tillage; 2) cultivated pasture (CP): the initial pasture was eliminated through two consecutive applications of glyphosate (3 weeks apart), after which the soil was ploughed, harrowed and a *L. perenne* and *T. repens* pasture was sown; 3) direct drill pasture (DP), zero-tillage treatment: the initial naturalised pasture received two consecutive glyphosate applications, as it was performed for CP, afterwards a *L. perenne* and *T. repens* pasture was direct drilled; 4) diverse direct drill pasture (DDP), zero-tillage treatment: the initial naturalised pasture was eliminated by herbicide application, as it was done for CP, subsequently a *B. valdivianus*, *L. perenne*, *D. glomerata*, *H. lanatus* and *T. repens* pasture was direct drilled. All the pasture treatments, except by NFNP, were annually limed and fertilised as follows: 180 kg nitrogen ha^{-1} year^{-1} (Nitromag 21%N); 52.3 kg phosphorus ha^{-1} year^{-1} (triple superphosphate, 20% P), 99.6 kg potassium ha^{-1} year^{-1} (potassium chloride, 60% K^+) and 800 kg calcium ha^{-1} year^{-1} (lime). The establishment of the PIMs were conducted in April 2013, when the soil water content was close to field capacity (soil water content ≤ 40%). The botanical composition was performed according to Grant (1981) and measured before the PIMs were implemented (March 2013) as well as during spring of 2014 as indicated in Table 1 (more information about this parameter can be found in Descalzi, 2017). The pastures were sown on April 17th 2013 and then were grazed by 25 sheep per plot (equivalent to 625 sheep ha^{-1}). The grazing criteria were sheep introduced at 2100–2300 kg DM ha^{-1} and removed at 1000–1200 kg DM ha^{-1} (Parga et al., 2007; Flores et al., 2017).

2.2. Soil physical parameters, water content dynamics and dry matter production: soil sampling and field measurements

In order to determine the effect of the different pasture improvement managements (PIMs) on soil hydraulic properties, undisturbed soil samples were collected in the topsoil (2–8 cm depth) in September 2013 by using metallic cylinders (230 cm^{-3}, with h = 5.60 cm and Ø = 7.15 cm). Additionally, samples were also collected before and