Geoderma 235–236 (2014) 30–38

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Seasonal changes in bulk density under semiarid patchy vegetation: the soil beats

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ARTICLE INFO

Article history:
Received 13 November 2013
Received in revised form 15 June 2014
Accepted 22 June 2014
Available online 5 July 2014

Keywords:
Soil microrelief
Plant–soil interactions
Feedback processes
Carbohydrates
Swelling
Shrinking

ABSTRACT

Objective: We investigated the temporal variation of soil bulk density (BD) in a semiarid *Macrochloa tenacissima* grassland where BD plays a key role in the soil–plant feedback mechanisms that are responsible for the patchy distribution of vegetation.
Methods: We used the core method to analyse the soil BD in two experimental sites in microsites that were representative of the spatial heterogeneity of soils and vegetation. The study was performed over two years, in winter (three times) and summer (twice). We studied the changes in BD in relation to the rainfall and to the soil properties that describe or affect the soil structural conditions, such as soil moisture, particle-size, clay mineralogy, the contents of various organic carbon fractions and certain microaggregation indices.
Results: We found a consistent temporal variation in BD, which was lower in winter (1.22 ± 0.02 g/cm^3, average ± SEM) than in summer (1.33 ± 0.02 g/cm^3) and depended on the rainfall in the weeks before sampling. The greatest change was observed during the first year of study, when the wettest winter and the driest summer occurred. The variation of BD was most pronounced in the mounds developed under senescent plants (+16.7% average increase from winter to summer), intermediate under adult plants and in the residual mounds (+8.9%) and was weak in the soils of the bare areas or under young plants (+5.1%). This implies that the microtopography should get steeper in winter and flatter in summer. The largest changes in BD were correlated with variables representing organic matter and its action in adhering soil particles.
Conclusion: We observed consistent temporal variations in BD that were spatially heterogeneous and related to wet conditions in the soils studied. Research is needed to establish the mechanisms responsible for the changes in BD, which may include greater activity of roots and fauna during the wet season and the enrichment in labile organic fractions that are hygroscopic and can bind soil particles into temporary aggregates.
Practice implications: Spatially heterogeneous temporal variation in BD must be taken into account in inventories of soil nutrients, water or carbon. Moreover, it implies an increased porosity under vegetated patches just when the soil receives the most rainfall, resulting in a positive feedback of plant growth and mound formation. This mechanism might be added to those already described for plant–soil feedbacks in dry lands.

1. Introduction

Bulk density (BD) is a measure of soil compactness and is calculated as the ratio of dry soil mass per unit volume (Grossman and Reinsch, 2002; USDA NRCS, 2008). BD is an important characteristic that affects key soil functions such as water-holding capacity, infiltrability, aeration and ease for plant germination and root growing. Furthermore, BD is needed to convert soil weight into volume, so it is a crucial component of assessing soil water, nutrients and carbon stocks (Grossman and Reinsch, 2002; Lal and Kimble, 2001; Throop et al., 2012).

BD depends on the size and density of soil mineral and organic particles and how they are packed together (USDA NRCS, 2008). BD is not a constant because it changes according to the structural condition of the soil, particularly in relation to its packaging. For this reason, it varies markedly through time in response to changes in land cover and soil management (Batey, 2009; Hamza and Anderson, 2005). It can also undergo significant oscillations on a within-year scale because of the seasonal impacts of cattle herding (Drewry et al., 2004; Wheeler et al., 2002) and tillage (Franzluebbers et al., 1995; Krzic et al., 2000) and the subsequent reconsolidation of the soil materials due to rainfall (Mapa et al., 1986) and/or irrigation (Angulo-Jaramillo et al., 1997; Zeng et al., 2013). Intra-annual variations can also be related to natural cycles of freezing–thawing (Hu et al., 2012; Krumbach and White, 1964) and of wetting–drying of

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http://dx.doi.org/10.1016/j.geoderma.2014.06.022
0016-7061/

smectite-rich soils (Pires et al., 2008; Sirvent et al., 1997). Seasonal variations hinder assessing soil BD from single, one-time measurements (Haines and Cleveland, 1981).

In dry lands, BD can be both a cause and an effect of the soil–plant interactions responsible for the typical mosaic distribution of the vegetation of arid and semiarid areas (Bochet et al., 1999; Maestre et al., 2005; Stavi et al., 2009). Underneath plants, BD decreases due to organic matter inputs and bioturbation, which lead to higher infiltration rates that in turn promote plant growth. These feedbacks in a water-limited environment contribute that the soil under plants becomes a resource island that accumulates nutrients and moisture and shows higher biological activity. These islands are surrounded by bare areas where soils are less fertile (Burke et al., 1998; Ehrenfeldt et al., 2005; Schlesinger and Pilmanis, 1998). The fertility islands often show a protruding microrelief resulting from bioturbation by plant roots (Biot, 1990; Bochet et al., 2000) and/or fauna (Tongway et al., 1989), wind dust deposition (Ravi et al., 2007; Shachak and Lovett, 1998), the capture of splash particles (Bochet et al., 2000; Parsons et al., 1992) and/or sediment redistribution due to water erosion (Bochet et al., 2000; Buis et al., 2010; Parsons et al., 1992; Saco et al., 2007).

Despite the importance of BD as an indicator of soil quality and key ecosystem functions (Lal and Kimble, 2001; USDA NRCS, 2008), there has been little research to date on the short-term changes in the BD of soils in natural areas (Hu et al., 2012), and there is notably little information on the seasonal behaviour of BD in dryland ecosystems that are spatially heterogeneous. Indeed, BD is often measured and used as a static characteristic of the natural soils and is not assumed to undergo temporal variations on the short term. The objective of this work is to investigate the temporal variation of BD in a semiarid ecosystem where BD is a main driver of the feedback mechanisms that are responsible for the patchy distribution of vegetation (Mora and Lázaro, 2013). Our null hypotheses were that (1) the BD did not seasonally vary and (2) the spatial heterogeneity did not affect the variation of BD.

2. Materials and methods

2.1. Study area

This work was performed in two experimental sites: Balsa Blanca (BB) and Las Amoladeras (AM) (Fig. 1a and b), located in the Natural Park of Cabo de Gata in Almeria (southeast Spain). The climate is Mediterranean semiarid, virtually free of frost, with mean annual temperatures of 18–19 °C and an average rainfall of approximately 220 mm y^{-1}. Soils are developed on alluvial fans and are classified as Mollic (Calcaric) Leptosols in BB and Lithic (calcaric) Leptosols in AM (Rey et al., 2011).

The vegetation is a patchy grassland dominated by alpha grass (*Macrochloa tenacissima*), a tussock-forming perennial grass. Rey et al. (2011) suggested that the BB and AM sites are actually representative of different degradation levels of the alpha grassland ecosystem. In AM, the plant cover is approximately 30% and frequently includes typical semiarid dwarf shrubs such as *Hammada articulata*, *Helianthemum almeriense*, *Thymus hyemalis* and *Sideritis pusilla* as well as opportunistic and seasonal annual plants. In contrast, the vegetation at BB has a cover of approximately 55% and certain shrub species are frequent, such as *Phlomis purpurea* and *Ulex parviflorus*. Others are sparse and related to the climax vegetation of the area, including *Chamaerops humilis*, *Olea europaea* var. *sylvestris*, *Pistacia lentiscus*, *Rhamnus lycioides* and *Quercus coccifera* (Mora and Lázaro, 2013).

The alpha grass growth in the study area is associated with the occurrence of mounds under the tussocks (Mora and Lázaro, 2013) due to the interception by plants of silt-rich eroded particles, the accumulation of organic matter and, possibly, bioturbation by roots and burrowing fauna. As mounds form, the BD decreases and the soil loosens and expands, while gravel is displaced towards the periphery of the tussock. After the plant dies, the mounds are eroded and the fertility islands tend to disintegrate (Mora and Lázaro, 2013).

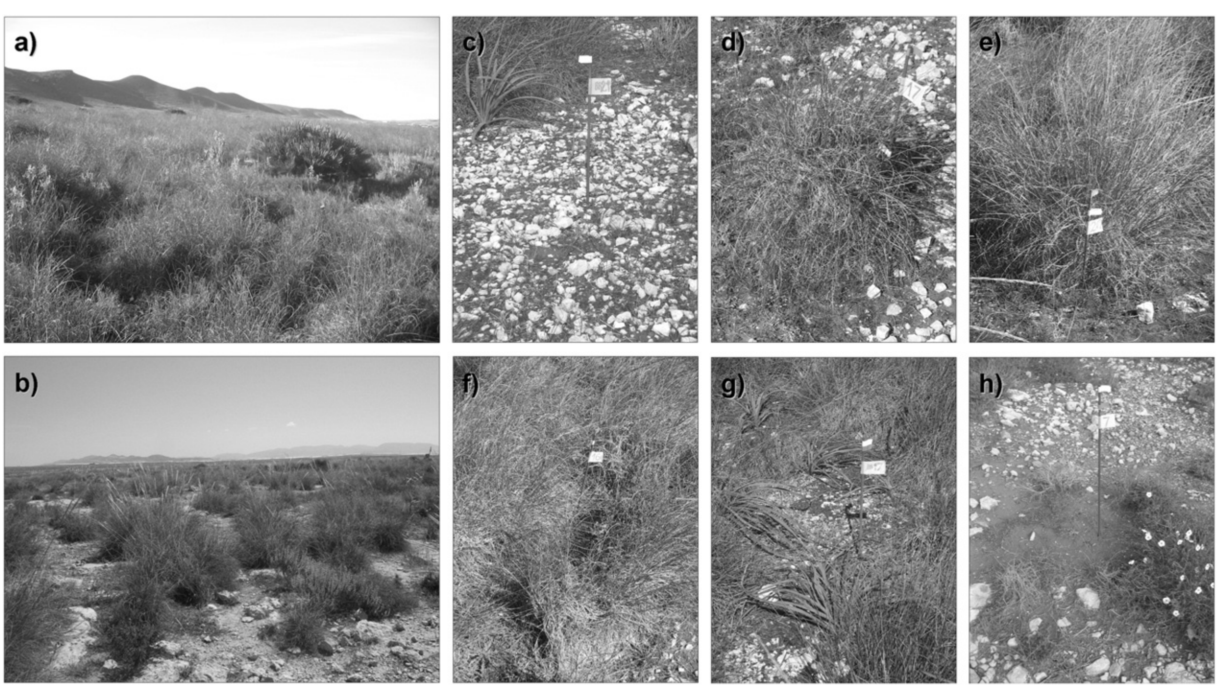

Fig. 1. General appearance of the experimental sites and microsite types: a) Balsa Blanca site, b) Las Amoladeras site, c) bare inter-plant space (I), d) isolated young plant, not yet associated with mound (II), e) adult plant, with mound (III), f) senescent plant, with mound (IV), g) well-preserved mound (V), and h) residual mound (VI).