Catena 149 (2017) 86–97

Contents lists available at ScienceDirect

Catena

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

Spatial patterns of soil resources under different land use in *Prosopis* woodlands of the Monte desert

Pablo A. Meglioli [a,*], Julieta N. Aranibar [a,b], Pablo E. Villagra [a,c], Cecilia Vega Riveros [a]

[a] Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), Consejo Nacional de Investigaciones Científicas y Técnicas (CCT-CONICET, Mendoza), Av. Ruiz Leal s/n, Parque General San Martín, CP 5500, Mendoza, Argentina
[b] Facultad de Ciencias Exactas y Naturales, Universidad Nacional de Cuyo, Ciudad Universitaria, Parque General San Martín, CP 5500, Mendoza, Argentina
[c] Facultad de Ciencias Agrarias, Universidad Nacional de Cuyo, Almirante Brown 500, Chacras de Coria, CP 5505, Mendoza, Argentina

ARTICLE INFO

Article history:
Received 8 April 2016
Received in revised form 26 August 2016
Accepted 3 September 2016
Available online xxxx

Keywords:
Grazing gradient
Livestock corrals
Nutrient balance
Piosphere
Soil resource distribution
Woodland soils

ABSTRACT

Changes in the spatial distribution of resources constitute an indicator of degradation of arid grazing lands. In arid and semi-arid ecosystems, the distribution of soil resources has been commonly associated with the structure and the spatial arrangements of the vegetation. Although the formation of "fertile islands" beneath vegetation patches is well documented, much less is known about the changes induced by grazing systems on the distribution of soil resources. We examine how pastoralist settlements are affecting the spatial distribution of soil resources and the soil nutrient balance in central-western woodlands of Argentina. We analyzed the distribution of soil water, chloride, nitrate, total nitrogen, and organic matter at increasing distances from livestock corrals and in undisturbed woodlands, at different soil depths. We also calculated variation indexes of soil organic matter and total nitrogen produced by livestock settlements, as an indicator of degree of deterioration or improvement of the soils. The transects located in pastoralist settlements demonstrated an increasing centripetal gradient in availability of soil water and nutrients compared to transects outside of these disturbed areas. Livestock corrals create local hotspots of nutrient enrichment, but when we analyzed the effects of livestock settlements at a higher spatial scale, we found net losses of soil organic matter and total nitrogen. We conclude that the coupling between nutrient and patch dynamics is disrupted by the pastoralist settlements, which caused a redistribution of soil resources, controlled by the location from the livestock corrals. The processes that promote nutrient losses, such as ammonium volatilization, denitrification, nitrate leaching, organic matter oxidation, manure exports, and soil erosion, are relatively higher than the extra inputs of dung and urine. Therefore, this study emphasizes the role of grazing systems as modulators of water and nutrient fluxes, and soil nutrient balance.

1. Introduction

Semi-arid woodlands contain rich biodiversity and provide soil-mediated ecosystem services, including carbon storage and nutrient cycling (MEA, 2005). However, as a result of disturbance, woodland structure and composition are changing, affecting ecological and hydrological processes (Wilcox et al., 2003), and consequently some ecosystem services (Foley et al., 2005). Changes in land use and land cover play key roles in hydrological and biogeochemical processes, including water, carbon, and nitrogen cycles (D'Odorico et al., 2010; McLauchlan et al., 2014). Particularly, livestock grazing has been recognized as an important factor affecting ecosystem function, altering the composition and structure of plant communities, modifying accumulation and spatial distribution of soil resources, and changing nutrient balance (Adler et al., 2001; Milchunas and Lauenroth, 1993; Piñeiro et al., 2009).

Spatial heterogeneity of soil resources, at large scales, affects the distribution and productivity of plant communities and, at smaller scales, influences plant establishment, growth and survival (Maestre et al., 2003), and modulates morphological and physiological plant responses (García-Palacios et al., 2012; Meglioli et al., 2016). In semi-arid environments, the distribution and availability of soil water and nutrients are usually associated with the spatial distribution of vegetation patches and rainfall variability (Austin et al., 2004; Breshears et al., 2009; Huxman et al., 2004). Vegetation patches tend to accumulate litter and plant material, and create a particular microenvironment that enhances carbon and nutrient cycling, and soil microbial activity beneath plant canopies (Alvarez et al., 2009; Carrera et al., 2009; Facelli and Brock, 2000; Rossi and Villagra, 2003). Canopy patches lead to higher soil moisture, nitrogen, and organic matter content compared with open intercanopy patches (Schlesinger et al., 1996; Titus et al., 2002). As a consequence, changes in the structure and spatial arrangement of vegetation patches have implications for ecosystem functioning (Aguiar and Sala, 1999).

* Corresponding author.
E-mail address: pmeglioli@mendoza-conicet.gob.ar (P.A. Meglioli).

http://dx.doi.org/10.1016/j.catena.2016.09.002
0341-8162/

In arid ecosystems, livestock grazing around pastoralist settlements represents a typical land use that changes vegetation structure (Bertiller et al., 2002), causing different plant spatial organization and heterogeneity (Bisigato et al., 2009). Vegetation changes modify the depth and distribution of plant roots, influencing the distribution of soil resources (Jackson et al., 2000; Jobbágy and Jackson, 2000). Understanding the effects of disturbance like grazing on vegetation patterns and soil water and nutrient dynamics is useful to understand ecosystem functioning, soil erosion processes, runoff and sediment fluxes in these landscapes (Bisigato et al., 2008; Ravi et al., 2010), and has implications on management programs of semi-arid zones, where extensive grazing is the main activity developed by human populations.

In water-limited ecosystems, the spatial distribution of livestock is restricted by water availability. Livestock frequently congregate around permanent watering points, generating areas of higher animal impact called 'Piospheres' (Lange, 1969). Multiple researchers have found grazing gradients, expressed as changes in vegetation cover (Brooks et al., 2006; Landsberg et al., 2003; Todd, 2006) and in the physical and chemical properties of soil (Shahriary et al., 2012; Smet and Ward, 2006) as a function of the distance from livestock watering points. These landscape focal points can concentrate soil resources from large foraging areas, which are carried and deposited by domestic animals. Goats and cattle consume plant and litter, reducing the local input of soil organic matter in grazing sites. However, livestock can transport and return the nutrients to the soil through urine and dung depositions, modifying carbon and nitrogen cycles, and soil nutrient balances (Adler et al., 2001; Mohamed Saleem, 1998). Urine and dung lead to increase in soil nitrate and ammonium, which are soluble and volatile forms of nitrogen that can produce high nitrogen losses via leaching and volatilization (Augustine, 2003; Wachendorf et al., 2005). Grazing by domestic livestock may also exert strong influences on microbial functional communities involved in soil nutrient cycling (Patra et al., 2005).

In central-western Argentina, open woodlands support the development of local communities and their traditional production systems (Jobbágy et al., 2011; Villagra et al., 2009). The low mean annual precipitation of <200 mm in this environment is a limiting factor for agriculture, but groundwater accessibility allows extensive livestock grazing. Recent studies of the Central Monte desert (NE, Mendoza) indicated that interdune valleys, characterized by woody legumes coupled to groundwater, have higher productivity and availability of soil resources than dune crests and flanks (Aranibar et al., 2011; Guevara et al., 2010; Jobbágy et al., 2011; Villagra et al., 2011). Groundwater provision for human and domestic animal consumption influences the spatial distribution of livestock, generating disturbance gradients.

The establishment of a new settlement involves the partial removal of the vegetation in 'sacrifice areas', including shrubs and trees, which are used for the construction of corrals, wells, and households, and to decrease the abundance of poisonous animals. Although these changes have direct effects aboveground, decreasing cover of shrubs, grasses and forbs (Goirán et al., 2012; Meglioli et al., 2014), they also cause other less obvious changes belowground, which can potentially affect hydrological and biogeochemical cycling. The reduced vegetation cover in livestock stations causes greater soil water content in surface and subsurface soils compared to undisturbed woodlands. Additionally, nutrient input from livestock dung and urine may increase nutrient leaching in the sacrifice zone (Meglioli et al., 2014). Livestock grazing alters spatial heterogeneity of vegetation and, consequently, disrupts mechanisms of resource concentration in vegetation patches (Bisigato et al., 2009). Therefore, woodlands with traditional livestock systems in these ecosystems offer an opportunity to study changes in the spatial distribution and availability of soil water and nutrients as a function of the position from corrals, where manure deposition is higher.

This study examines how pastoralist settlements are affecting the spatial distribution of soil resources in the horizontal and vertical planes, and the soil nutrient balance in the Monte desert. Most studies on nutrient cycling are on the upper layers of the soil where the greatest biological activity occurs (Jobbágy and Jackson, 2001). However, we know very little about nutrient and carbon cycling from deeper soil layers of desert ecosystems (Jin et al., 2015). Soil analysis from deeper samples (up to 200 cm in depth) can be useful to identify possible rainwater percolation and nitrate leaching through the soil, depletion of soil nutrients, and redistribution of solutes.

We hypothesized that spatially heterogeneous distributions of soil resources associated with the structure and spatial arrangements of the vegetation in the central Monte desert are modified by pastoralist settlements, which redistribute soil water, nutrients, and solutes over the landscape due to centripetal transport of nutrients towards the corrals by livestock grazing and to the decreased plant demand given by the partial removal of vegetation. In addition, we proposed that the soils of livestock stations increase net losses of total nitrogen and organic matter due to increases in ammonium volatilization, nitrate leaching, organic matter oxidation, soil erosion, and the export of manure to outside areas, compared to the soil of relatively undisturbed control woodlands (Fig. 1). In order to evaluate these hypotheses, we analyzed the contents of soil water, chloride, nitrate, total nitrogen and organic matter at increasing positions from corrals and in control woodlands, at three soil intervals (shallow, intermediate and deep). Spatial patterns in soil resources were investigated comparing linear mixed models, considering the effect of land use and location of soil profiles along the transects in the interdune valleys. We expected to find edaphic changes related to the proximity to the corrals in the livestock stations (slope of regression line different from zero). However, the slope of regression line along the transects in the control woodlands should not be significantly different from zero due to natural spatial heterogeneity. We then analyzed the relationships between soil characteristics, land use, and vegetation patches, at different soil depth intervals.

2. Material and methods

2.1. Study area

The study area is the Telteca Natural and Cultural Reserve, located in the central plains of northeastern Mendoza River, Argentina (32–33 S; 67–68 W; 500–550 m elevation), on the alluvial plain near the lower Mendoza river. Geomorphologically, this region comprises a system of transverse dunes oriented NNW–SSE separated by discontinuous valleys. The plain is composed of Holocene deposits (Tripaldi and Forman, 2007), including soils with poorly developed horizons of recent origin (Entisols).

The climate is arid with a mean temperature of 18.5 °C and large daily and annual temperature ranges (48 °C absolute maximum and −10 °C absolute minimum). The mean annual precipitation is 156 mm (1972–2014 average), occurring almost exclusively during the spring and summer (from October to March) (Meglioli, 2015). Because rainfall is scarce and permanent rivers are not present in the region, groundwater is the most important source of water in the lowlands. The water table is located 6–15 m below the surface (Gomez et al., 2014). Shallow groundwater is used by phreatophyte vegetation in the interdune valleys, although groundwater is inaccessible to plants in dune crests and flanks (Jobbágy et al., 2011). Stable isotope composition of groundwater indicates that the aquifer is remotely recharged by precipitation in the Andes, >100 km away, with a negligible local recharge by drainage of summer rainfall (Jobbágy et al., 2011).

The vegetation is representative of the central Monte Biogeographic Province, with open woodlands of *Prosopis flexuosa* accompanied by xerophytic shrubs such as *Larrea divaricata*, *Capparis atamisquea*, *Trichomaria usillo*, *Lycium tenuispinosum*, *Atriplex lampa*, and *Suaeda divaricata* (Villagra et al., 2004). Dunes have a lower vegetation cover and are dominated by shrub species such as *T. usillo* and *L. divaricata* coexisting with small trees of *P. flexuosa*, and the grass *Panicum urvilleanum* (Villagra et al., 2004).