ARTICLE IN PRESS

Applied Soil Ecology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Applied Soil Ecology

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

Soil properties in relation to diversionary feeding stations for ungulates on a Mediterranean mountain

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ARTICLE INFO

Keywords:
Ammotragus lervia
PLFA
Soil alteration
Wildlife management

ABSTRACT

Soil plays an important role in processes that maintain ecosystems function and support biodiversity. Physicochemical and biological soil properties can be altered by human activities, and through management tools that affect environment conditions. Diversionary feeding is a widely employed management tool to avoid human-wildlife conflicts. This practice could lead to concentrations of fauna in specific areas where food is deposited, which could affect physicochemical, biochemical and biological soil properties. We evaluated the effect of diversionary feeding on semiarid Mediterranean mountain soil in the Sierra Espuña Regional Park (SE Spain). The objective of diversionary feeding in this Regional Park is to mitigate crop damage caused by the aoudad (*Ammotragus lervia*), an exotic ungulate introduced for hunting interests in the 1970s. Three diversionary feeding stations were monitored with automatic cameras to verify their use by target and non-target species. We collected soil samples from the monitored feeding stations and compared soil characteristics from three areas: feeding stations soil, contour area soil (surrounding the feeding stations) and a reference soil (not influenced by feeding stations). Our results suggested no effects on soil physical properties. However, we found that diversionary feeding altered electrical conductivity, nutrient concentration, microbial activity and microbial communities at FS, but effects were weaker in the contour area. These alterations of soil dynamics contribute to change soil functionality and to reinforce global change. Not pouring food directly on soil is recommended to reduce these effects.

1. Introduction

Many crucial processes to maintain terrestrial ecosystems take place in soils (Roger-Estrade et al., 2010). Soils support high biodiversity (Young and Crawford, 2004) which, together with their physicochemical properties, provide important ecosystem functions and services, such as decomposition (Coleman et al., 2004), nutrient cycling, soil productivity sustainability (Roger-Estrade et al., 2010), and resistance and resilience to abiotic disturbance and stress (Brussaard et al., 2007). Microbial soil communities are the most sensitive and rapid indicators of perturbations and land use changes (García-Orenes et al., 2013). Indeed, growing interest is being paid to quantitative description of microbial community structure and diversity as a potential soil quality evaluation tool (Zelles, 1999; Zornoza et al., 2009). Given its relationship with soil functionality, the influence of soil microorganisms and soil microbial population and activity have been proposed as useful indicators to evaluate soil's response to different management practices (García-Orenes et al., 2013). The microbial community's response can be assessed by changes in phospholipid fatty acid (PLFA) patterns (Zelles, 1999). PLFA use lipids of microbial membranes as biomarkers for specific groups of microorganisms (Bacteria, Fungi, G− Bacteria, G+ Bacteria and Actinobacteria), which allows a profile of the community structure to be created (DeGrood et al., 2005; Zornoza et al., 2009).

Soil management practices due to anthropogenic activities can alter physicochemical and biological soil properties (Jangid et al., 2008), and can also affect soil function. For example, nutrient income in ecosystems may alter ecological processes and influence global change (Oro et al., 2013). These nutrient incomes may significantly alter soil characteristics by influencing changes in biological, chemical and physical properties (Macci et al., 2013). One form of nutrient inputs in the environment that can alter soil properties is supplementary feeding (Dunkley and Cattet, 2003). This practise drives the concentration of animals in small areas, which might modify the structural and chemical

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https://doi.org/10.1016/j.apsoil.2018.03.017
Received 5 February 2018; Accepted 29 March 2018

Table 1
Main characteristics of the reference soil (RS), feeding stations (FS) and contour (C) area of each sampled area (0–5 cm). Values are the mean ± standard deviation (n = 6).

	RS	Sampled area 1		Sampled area 2		Sampled area 3	
		FS 1	C 1	FS 2	C 2	FS 3	C 3
AS (%)	58.58 ± 7.47	51.45 ± 8.75	64.06 ± 10.26	64.06 ± 14.32	68.17 ± 10.26	68.77 ± 2.11	65.59 ± 6.71
BD (g/cm^3)	1.04 ± 0.13	1.27 ± 0.17	1.17 ± 0.21	0.99 ± 0.23	0.91 ± 0.21	0.91 ± 0.17	0.90 ± 0.13
pH (extract 1:5, w/v)	8.15 ± 0.36	8.12 ± 0.21	8.18 ± 0.24	7.72 ± 0.18	8.25 ± 0.24	7.22 ± 0.20	7.92 ± 0.15
EC (mS/cm)	0.17 ± 0.07	0.42 ± 0.13	0.33 ± 0.21	0.79 ± 0.24	0.17 ± 0.21	0.70 ± 0.28	0.51 ± 0.17
Corg (g/kg)	23.90 ± 13.69	38.22 ± 21.54	35.89 ± 17.99	41.65 ± 8.16	35.77 ± 17.99	38.92 ± 9.94	55.47 ± 6.44
N (g/kg)	2.31 ± 0.90	3.29 ± 1.71	3.67 ± 1.77	4.56 ± 0.89	3.39 ± 1.77	3.61 ± 1.18	4.53 ± 0.57
Na (mg/kg)	2.97 ± 1.90	8.49 ± 5.73	3.76 ± 2.56	12.26 ± 8.16	7.28 ± 2.56	5.48 ± 2.27	7.49 ± 2.86
K (mg/kg)	12.52 ± 1.87	18.89 ± 6.73	6.80 1.43	19.63 ± 4.02	9.81 ± 1.43	25.37 ± 7.42	13.45 ± 2.13
P (mg/kg)	4.76 ± 0.73	8.14 ± 4.90	4.69 ± 2.42	22.34 ± 13.01	4.19 ± 2.42	8.70 ± 4.63	4.03 ± 0.44
C/N	9.34 ± 3.29	11.37 ± 2.38	9.77 ± 1.29	9.13 ± 0.36	10.51 ± 1.29	11.05 ± 1.39	12.27 ± 0.74
Cmic (g/kg)	0.60 ± 0.35	0.91 ± 0.73	0.42 ± 0.13	0.22 ± 0.07	0.35 ± 0.13	0.46 ± 0.35	0.44 ± 0.14
BSR (C-CO_2 (μg/h/g))	1.43 ± 0.76	6.59 ± 6.15	1.75 ± 0.71	3.53 ± 2.37	1.30 ± 0.71	3.81 ± 2.63	2.12 ± 0.65

AS: aggregate stability, BD: bulk density; BSR: basal soil respiration; EC: electrical conductivity; Corg: organic carbon; Cmic: microbial biomass carbon; C/N: carbon:nitrogen ratio; Mg: magnesium; Ca: calcium; K: potassium; N: nitrogen; Na: sodium; P: phosphorus.

properties of soil (Hiernaux et al., 1999; Martínez and Zinck, 2004; Savadogo et al., 2007), including organic matter turnover, nutrient capture and cycling (Van der Heijden et al., 2008), and the formation and stabilisation of soil aggregates (Chenu and Cosentino, 2011). Supplementary feeding is practised globally and as a wildlife management tool for several reasons. This practise is used to conserve threatened species (Cortés-Avianza et al., 2016; González et al., 2006; Krofel and Jerina, 2016; López-Bao et al., 2008; Piper, 2005), to facilitate wildlife observations as tourist attractions (Corcoran et al., 2013; Orams, 2002; Robb et al., 2008), and to promote human connectedness to nature (Leger, 2003). One of the most widespread uses of supplementary feeding is to manage game species (Inslerman et al., 2006; Putman and Staines, 2004; Vicente et al., 2005), particularly to improve trophy quality, and to increase population density, productivity and survival, but also to mitigate conflicts.

Increasingly growing human activities, along with the expansion of ungulates, might cause interactions between them and lead to human-wildlife conflicts (Redpath et al., 2013). Conflicts, such as forest damage (Sahlsten et al., 2010), crop damage (Dunkley and Cattet, 2003) or vehicle collisions (Snow et al., 2015), are some relevant human-wildlife conflicts (Kubasiewicz et al., 2016). Supplementary feeding is often used as a tool to avoid these conflicts, in which case it is generally referred to as diversionary feeding (Kubasiewicz et al., 2016).

Publications about the effects of animal concentration on soil have focused mainly on livestock species (Betteridge et al., 1999; Castellano and Valone, 2007; Yong-Zhong et al., 2005). Several studies have also focused on wild boar (Cellina, 2008; Wirthner, 2011), especially in relation to rooting behaviour. Studies about effects of diversionary feeding stations (FS) on physicochemical and biological soil characteristics are scarce (Miranda et al., 2015; Oja et al., 2015; Selva et al., 2014). In this study, we evaluated the effect of FS on soil in the Sierra Espuña Regional Park, the Murcia Region, in SE Spain. There, the regional government uses diversionary feeding as a management tool for aoudad (*Ammotragus lervia*), an African ungulate introduced into SE Spain in the 1970s for hunting interests. FS were placed in the area in the 1990s after sarcoptic mange outbreak, which caused the aoudad population to drop by more than 90% (Eguía et al., 2015). The aim of food inputs was to initially help species to recover from such outbreaks. However, the aoudad population recovered in 2000–2010, and the regional government continues to practise diversionary feeding to keep animals within the park's boundaries and to avoid damage to surrounding crops in summer. Our objective was to study how diversionary food inputs could alter soil characteristics in FS.

We hypothesised that the effects on soil would be: 1) compaction around feeding areas due to trampling; 2) higher nutrient concentrations at FS; 3) alterations of the soil microbial community structure because of food inputs and wildlife activity.

2. Material and methods

2.1. Study area

The study was conducted in the Sierra Espuña Regional Park in SE Spain (37°47′–37°56′N 1°27′–1°40′W). It covers 17,800 ha and includes meso- and supra-Mediterranean habitats, which range from 500 to 1500 m.a.s.l., with *Pinus halepensis* woods, scrublands and pasture dominating the mountain range landscape (Sánchez-Zapata and Calvo, 1999). Rainfall ranges from 277 mm in lower mountain areas to 510 mm in the park's upper parts. Average annual temperatures also follow an altitudinal gradient, which ranges from 12.8 to 18.4 °C. The main soil found at the Sierra Espuña Regional Park is classified as Lithic Leptosol (WRB, 2014) with loam texture (37% sand, 50% silt and 13% clay). These soils are characterised by being shallow soil on rock (characteristic of many mountain soils) and they are rich in coarse fragments. They are only recognised at the subgroup level, which groups together all soils that are less than 50 cm thick to bedrock. The physicochemical and biochemical soil characteristics are described in Table 1 and the microbiological measures are provided in Table 2.

2.2. Experimental design

2.2.1. Feeding stations

Sixteen diversionary FS (average size 350.0 ± 129.6 m^2) were located in the regional park (Fig. 1). These FS consist in clear cut areas where forestry agents can access them by car to deposit supplementary feeding. In summer 2015, 35 kg of fodder and about 10 kg of lucerne were deposited weekly at each FS on bare ground, with no measures taken to prevent use by non-target species. This fodder was composed of a mixture of corn, barley, oats, pelleted lucerne meal and pelleted sugar beet pulp. The analytical fodder components included crude protein (10.4%), crude fats (2.8%), fibre (10.5%), ash (4.2%), sodium (0.05%) and phosphorus (0.28%).

We monitored three FS using automatic cameras, activated by movement (Bushnell HD), to assess their use by wildlife. Cameras were located in a nearby tree, about 3 m from the FS, and operated from 24 July 2015 to 6 October 2015 (75 days). They were programmed to record one picture every minute after detecting movement, and to operate 24 h/day. Pictures provided information about the species that fed at the FS, as well as the number of individuals, date and time. We downloaded the pictures taken by the automatic cameras weekly. The