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Impact of grazing on chemical, physical and biological properties of soils in the mountain rangelands of Sahand, Iran

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Abstract. The objective of this study was to characterise the effect of grazing on soil physical, chemical and biological properties of a semi-steppe rangeland grazed by goats and sheep in the Sahand Mountains (Iran) in order to develop effective soil conservation measures and sustain livestock production. Grazing was classified as light, moderate and heavy according to the stocking rate and utilisation rate of the vegetation. Soil sampling was conducted at depths of 0–10 and 10–20 cm for each grazing treatment. Soil physical and chemical properties were determined at both depths and soil microbial variables were evaluated at the surface layer. Increasing level of grazing significantly decreased all soil chemical properties at both depths except for pH and magnesium concentration. Increasing the level of grazing significantly decreased the soil moisture content and porosity at both soil depths. The highest values of microbial biomass carbon, total fungi and bacteria were observed on the light treatment. Grazing significantly affected soil properties unfavourably and reduced vegetation vigour and composition, jeopardising the sustainability of the ecosystem.

Additional keywords: grazing intensity, Sahand rangeland, soil properties, trampling.

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Introduction

Rangelands cover ~40% of the global terrestrial area (Suttie *et al*. 2005) and ~45% of the total area of Iran (Moghaddam 2007). Rangelands in many areas of Iran have been degraded and plant species, preferred by ruminants, have declined over time and been replaced by less desirable, sometimes toxic species (e.g. *Peganum harmala*, *Avena sativa*, *Cenchrus ciliaris* and *Sorghum* spp.) (Azarnivand and Zare Chahoki 2008). In many areas, cover of the desirable species has been lost and soil is exposed to wind and water erosion (Mesdaghi 2007).

Many rangelands in the world have become degraded as a result of heavy and inappropriate grazing pressures (Noellemeyer *et al*. 2006; Stavi *et al*. 2008; Radford *et al*. 2008). This has often resulted in a reduction in plant cover of plant species preferred by livestock and a reduction in plant productivity (Mohammad 2000). Reduction in plant cover can also make the soil more vulnerable to wind and water erosion (Bilotta *et al*. 2007). Trampling by livestock can compact the soil and increases its bulk density (Savadogo *et al*. 2007). As a result of large changes in vegetation cover and in nutrient cycling (Chaneton and Lavado 1996; Steffens *et al*. 2008; Jeddi and Chaieb 2010; Teague *et al*. 2011), inappropriate grazing pressures can cause a reduction in the physical, chemical and biological properties of soils, leading to rangeland degradation and desertification (Oztas *et al*. 2003; Steffens *et al*. 2008).

Many studies have been carried out on the effects of livestock grazing on the physical and biological variables of soil and on rangeland hydrology but the results have been variable (Lavado *et al*. 1996; Bisigato *et al*. 2008; Wood *et al*. 2008). The greatest effect of grazing on rangeland ecosystems is on the removal of the major portion of aboveground plant biomass by livestock (Shariff *et al*. 1994). As a result, the input of litter to the soil will decrease. For example, Frank *et al*. (1995) showed that grazing intensity affected soil carbon (C) and nitrogen (N) contents of Northern Great Plains grasslands and Su *et al*. (2004) found that heavy grazing pressures resulted in loss of soil organic C and N, and depletion in soil enzyme activities. Other results showed that the effect of dung and urine decomposition can alter soil pH and electrical conductivity, and increase CO_2 exchange rates over the grazing season (Lecain *et al*. 2000), affecting the rate of soil organic matter (OM) decomposition and increasing the rate of N mineralisation (Shariff *et al*. 1994).

Long-term ecosystem health and economic profitability are the goals of rangeland managers within an adaptive, goal-oriented management framework using a basic knowledge of plant and animal physiology, and ecology (Teague *et al*. 2011). To prevent continuing degradation and negative consequences, restoration operations are necessary to increase vegetation cover and to stabilise the soil surface by reducing wind and water erosion and to improve the status of these rangelands (Moghaddam 2007).

There is limited understanding of the impacts of grazing intensity on the physical, chemical and biological properties of the soils in the semi-steppe rangelands of Iran. Thus, the main objective of this study was to investigate the impact of different long-term levels of grazing on the soil physical, chemical and biological properties on a mountain rangeland in Sahand, Iran. It was hypothesised that an increased level of grazing would negatively affect soil physico-chemical and biological properties, which would result in a decline in soil quality and, therefore, decreased productivity of these rangelands. By identifying a suitable grazing intensity in this study, it will also allow the development of management strategies for these rangelands.

Materials and methods

Study area

The study was conducted on native rangelands, 30 km east of the city of Maragha (~37°27′N and 46°33′E) (Fig. 1) as a representative part of the Sahand Mountains rangelands of East Azerbaijan province, North-west Iran. The climate of the region is semiarid and its elevation is ~1900 m a.s.l. According to the nearest weather station (at 30 km), the long-term mean annual rainfall is 322.4 mm and the area generally has cold and snowy winters. Maximum and minimum monthly mean rainfall occurs in April and August with 64.6 and 1.6 mm, respectively. Maximum and minimum annual temperatures are 19.6 and 5.4°C, respectively, with a mean annual temperature of 12.5°C (Iranian Weather Organization 2012).

Based on soil analyses, the soil is very uniform throughout the study area and the soil texture of the area is clay loam. Current geological maps demonstrate that the geology of the study area is dominated by sedimentary rocks of Pliocene to Quaternary ages. The sedimentary sequence consists predominately of Tuff, poorly indurated clay stone with bon beds (Geological Survey of Iran 1975). The vegetation of the study area consists of cool-season grasses, *Agropyron trichophorum*, *Festuca ovina* and *Bromus tomentolus* with *Cousinia commutate*, *Euphorbia* spp., *Cirsium arvence*, *Artemisia aucheri* and scattered *Thymus* spp. and *Astragalus* spp. shrubs.

The area has been grazed mainly by sheep and goats and had not been subject to pesticide or fertiliser application. The rangelands are located in the Boulouk Abad watershed whose network of drainage streams flow west into Lake Urmia. Three grazing sites were distinguished in this representative rangeland area for evaluating the effect of grazing intensity on soil properties.

Grazing sites

The three sites had different levels of grazing according to the number of livestock grazing per grazing area unit (stocking rate) and frequency with which they were grazed. As much as it was possible, each of the three sites was carefully chosen to be similar, homogeneous and on the same soil series. All sites were located on the southern side of Sahand Mountains and had a slope of between 10 and 25%. The three selected sites covered an altitudinal range from 1900 to 1950 m a.s.l.

Based on interviews, it was established that all sites had been grazed by livestock for several decades and under approximately the same seasonal use and environmental conditions. Livestock were mainly sheep and goats. The sites were used by herders during the spring and summer. The grazing period was from March to August. During this period, the sheep and goats were on the rangeland all day, returning at night to be milked. The numbers of livestock per unit area were used as an indication of level of grazing to represent cumulative grazing intensity (Adler and Hall

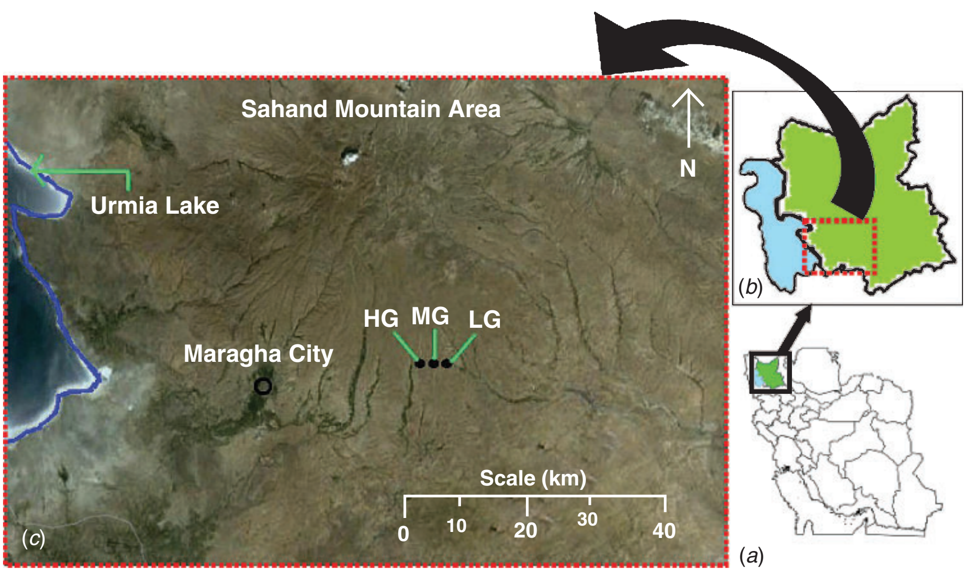

Fig. 1. Location of study sites in Iran (*a*), East Azerbaijan Province (*b*) and Sahand Mountains area (*c*).

2005). These numbers were reported by owners of the livestock who also reported these sites had been used in such a manner for at least a few decades. The levels of grazing which described the sites were as follows:

Lightly grazed (LG): livestock were observed on rare occasions, the ground surface was almost completely covered by vegetation (over 85%) and stocking rates ranged from 2 to 2.5 livestock units per ha.

Moderately grazed (MG): this area was relatively far away from settlements but grazing took place on a regular basis; livestock density was ~3–4 livestock units per ha; vegetation cover was 60–75%. Its stocking rate was considered equal to the economic carrying capacity of the rangeland.

Heavily grazed (HG): this area was the rangelands surrounding villages and along pathways, being almost constantly grazed and trampled by livestock; vegetation cover was in most cases less than 35% and the soil showed signs of furrows caused by erosion. Its stocking rate was 4.5–5 livestock units per ha.

On each of the three sites, an area of 1 ha was selected for soil sampling.

Soil sampling and analyses

Sampling in each 1-ha area was conducted using a systematic randomised method. Five transects were located in each 1-ha area systematically and two soil samples at depths of 0–10 and 10–20 cm were taken randomly along each transect. The two samples at each depth along each transect were composited to create one soil sample from each transect at each depth. This yielded a total of 30 soil samples (3 grazing sites × 2 soil depths × 5 replications). Sampling for soil physical and chemical properties as well as microbial composition was done in early May when growing conditions were good to excellent and soil microbes would be most abundant. Samples were analysed in the laboratory of the Department of Natural Resources, Tehran University. The samples were passed through a 2-mm sieve before analysis. Electrical conductivity (EC) and pH was determined in 1 : 1 suspension with distilled water (Sparks 1996) and soil texture (sand, clay and silt per cent) using a hydrometer method (Gee and Bauder 1982). The organic C content was determined according to the Walkley and Black (1947) method, and total N using the Kjeldahl procedure (Bremmer and Mulvaney 1982). Contents of available phosphorus (P), exchangeable potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) were analysed according to Sparks (1996). Soil bulk density was determined by the clod method (Blake 1965); porosity and hydraulic conductivity was measured using a disc infiltrometer at suction values of 1- and 4-cm tension, as described by Zhang (1997), and moisture content was determined gravimetrically (Gardner 1965).

In each sampling area of 1 ha at two randomly selected points along each the five established transects, 5-cm diameter cores to a depth of 5 cm were taken for measuring soil microbial composition (Bardgett 2005). A total of 10 samples per site were taken. Total bacteria and fungi contents were determined by direct enumeration using microscopy as described by Van Veen and Paul (1979). Microbial biomass C content was measured by the chloroform-fumigation incubation method (Norwath and Paul 1994).

Statistics

Data were tested for normality before analysis using the Anderson Darling test (Steel and Torrie 1980) and homogeneity of variance (Levene's test) at the 5% probability level. A MANOVA using factorial analysis with two factors, level of grazing and soil depth, was conducted and Duncan's multiple range tests for the comparison and grouping of the data of different levels of grazing with regard to soil properties at the 5% probability level ($P < 0.05$). In this case, the first factor is grazing sites at three levels (LG, MG and HG) and the second factor is soil depth with two levels of 0–10 and 10–20 cm. Also a one-way ANOVA test was used for the analysis of soil biological properties. All statistical analyses for each of the measured variables were conducted using SPSS version 15 (SPSS Inc., Chicago, IL).

Results

Chemical properties

Both level of grazing and soil depth had significant effects on all of the chemical properties of the soil. The pH of the soil was lower on the LG than the MH and HG levels of grazing at both soil depths (Table 1). The EC values were higher on LG than the other treatments when both soil depths were combined but not otherwise. The OM and N contents were higher on the LG than the other levels of grazing at both soil depths. The P content of the soil was higher on the LG than the other levels of grazing at the 0–10-cm depth. The K, Na and Ca contents were higher on the

Table 1. Soil chemical properties at two soil depths (0–10 and 10–20 cm) and at three levels of grazing (LG, MG and HG – see text for their description)
*Means of grazing treatments for each depth followed by different letters are significantly different at $P < 0.05$

Properties	0–10 cm			10–20 cm		
	LG	MG	HG	LG	MG	HG
pH	7.43 ± 0.06b*	7.66 ± 0.03a	7.73 ± 0.03a	7.27 ± 0.04b	7.50 ± 0.06a	7.66 ± 0.05a
EC (dSm^{-1})	0.66 ± 0.04a	0.59 ± 0.02a	0.57 ± 0.01a	0.59 ± 0.03a	0.51 ± 0.02a	0.50 ± 0.01a
OM content (%)	3.96 ± 0.37a	2.74 ± 0.27b	1.88 ± 0.30b	2.82 ± 0.18a	1.95 ± 0.33b	1.13 ± 0.13c
N (%)	0.23 ± 0.22a	0.16 ± 0.00b	0.08 ± 0.00c	0.098 ± 0.00a	0.052 ± 0.01b	0.28 ± 0.00b
P (ppm)	12.03 ± 0.52a	9.45 ± 0.41b	10.20 ± 0.28b	8.76 ± 0.50a	8.11 ± 0.49a	8.06 ± 0.46a
K (ppm)	182.55 ± 5.84a	131.04 ± 1.46b	126.24 ± 2.48b	121.82 ± 3.79a	108.54 ± 5.09b	95.89 ± 2.67c
Na (ppm)	11.98 ± 0.45a	8.22 ± 0.47b	5.38 ± 0.48c	4.12 ± 0.35a	3.86 ± 0.49a	2.55 ± 0.27b
Ca (meq/L)	26.56 ± 1.00a	19.16 ± 1.02c	22.32 ± 0.53b	13.44 ± 1.41a	10.06 ± 0.58b	11.60 ± 0.92ab
Mg (meq/L)	22.42 ± 1.00b	16.61 ± 1.28b	30.28 ± 2.85a	16.78 ± 1.43a	10.15 ± 0.64b	19.42 ± 1.61a

LG than the MG and HG levels of grazing although there were not always consistent differences between the MG and HG levels of grazing. The Mg content of the HG was higher than on the other grazing levels at the 0–10-cm depth. For all the chemical properties, the values were higher in the 0–10-cm depth than at the 10–20-cm depth.

Physical properties

Level of grazing had significant effects on all the physical properties of soil measured. Bulk density was lower on the LG level of grazing than on the other two levels of grazing at the 0–10-cm depth of soil (Table 2). At both depths, soil moisture content, and the porosity and hydraulic conductivity of the soil, were higher on the LG level of grazing than on the other two levels of grazing. Values of the MG level of grazing were higher than those on the HG level of grazing. Soil moisture content was significantly ($P < 0.01$) lower and hydraulic conductivity significantly ($P < 0.01$) higher at the 0–10-cm depth than at the lower depth.

Biological properties

Level of grazing significantly affected the soil biological properties at the 0–10-cm depth of soil. Total fungi and total bacteria were significantly higher on the LG level of grazing than on the other two levels of grazing and were significantly higher on the MG than the HG level of grazing ($P < 0.01$). Microbial biomass C content was higher on the LG level of grazing than on the other two levels of grazing. There was no effect of level of grazing on the ratio of total fungi to total bacteria (Fig. 2).

Discussion

Chemical properties

Level of grazing significantly affected soil pH, which increased with increased level of grazing at both depths. The lower pH values on the LG level of grazing can possibly be related to more root biomass, higher amounts of soil OM and denser root systems (Jeddi and Chaieb 2010) and more active metabolism by microorganisms in the rhizosphere (Jones *et al*. 2004). Hinsinger *et al*. (2003) stated that the organic acids secreted from the roots and release of CO_2 from roots and microorganisms could lead to the decrease in pH.

The decrease in OM, N, P, K, Na and Ca contents with increasing level of grazing, as seen in this study, are likely to be mainly related to differences in the soil structure, with a well

Table 2. Soil physical properties at two soil depths (0–10 and 10–20 cm) and at three levels of grazing (LG, MG and HG – see text for their description)
*Means of grazing treatments for each depth followed by different letters are significantly different at $P < 0.05$

Properties	0–10 cm			10–20 cm		
	LG	MG	HG	LG	MG	HG
Bulk density (g cm^{-3})	1.33 ± 0.23b*	1.45 ± 0.01a	1.51 ± 0.02a	1.45 ± 0.03a	1.46 ± 0.01a	1.46 ± 0.01a
Soil moisture content (%)	6.05 ± 0.19a	4.96 ± 0.12b	4.36 ± 0.13c	7.11 ± 0.10a	6.45 ± 0.07b	5.67 ± 0.14c
Porosity (%)	48.79 ± 0.39a	45.12 ± 0.52b	41.89 ± 0.65c	47.30 ± 0.29a	44.32 ± 0.36b	42.76 ± 0.30c
Hydraulic conductivity (cm h^{-1})	0.29 ± 0.00a	0.19 ± 0.00b	0.09 ± 0.00c	0.19 ± 0.00a	0.16 ± 0.00b	0.08 ± 0.00c

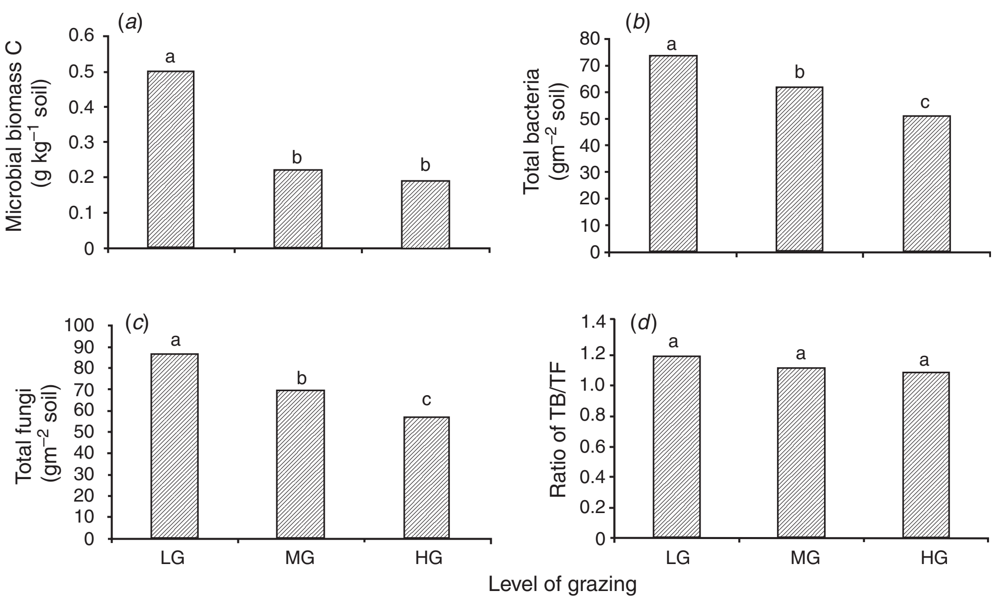

Fig. 2. Means of (*a*) microbial biomass C content, (*b*) total bacteria (TB), (*c*) total fungi (TF) and (*d*) ratio of TB to TC (TB : TC) at a depth of soil of 5 cm under three levels of grazing (LG, MG and HG – see text for their description) in Sahand Mountains area, Iran.

developed litter layer, a higher standing biomass and basal cover likely to have been found on the LG level of grazing. Moreover, the higher N content on the LG level of grazing might reflect the higher biological activities of soil microorganisms, and this higher microbial activity might increase the N and C contents in the soil (Lavado *et al*. 1996; Han *et al*. 2008). Increasing level of grazing is likely to have reduced the number of plants, plant basal area, and amount of deposited dead plant material that acts as protective mulch (da Silva *et al*. 2003). In addition, animal trampling strongly affects soil compaction (Hamza and Anderson 2005), and at the same time may stimulate OM decomposition, due to the destruction of soil aggregates by mechanical stress. A higher herbage mass also produces more root exudates and develops a wider branched root system in lighter grazing areas (Steffens *et al*. 2008), such as the LG level of grazing compared with the HG and MG levels of grazing in this study. The other difference that was observed among the levels of grazing was a higher content of Mg at the 0–10-cm depth in the HG level of grazing. It is not clear why this difference should have occurred with Mg content alone.

The increase in soil OM and nutrient contents, which accompanied the LG level of grazing, could have been a result of an increase in the amount of plant litter on the one hand and a decrease in soil compaction and exposure to the sun on the other hand, which obviously result in favourable living conditions for those organisms vital for the incorporation of the humus into the soil (Liu *et al*. 1997; Jeddi and Chaieb 2010). Consequently, soil nutrient content, and hence soil fertility, would have been significantly affected.

Physical properties

Based on the results of the present study, bulk density was reduced and the moisture content, hydraulic conductivity and porosity were significantly higher on the LG level of grazing (Table 2) compared with the other levels of grazing. Lower bulk densities and higher moisture content, hydraulic conductivity and porosity, as a result of decreased grazing intensity by livestock, have been observed for different grazing species in different grassland ecosystems (Daniel *et al*. 2002; Binkley *et al*. 2003; Stavi *et al*. 2008). Our results are, therefore, consistent with previous research which implies a reduction in plant inputs of OM to the soil at higher levels of grazing resulted in higher soil bulk densities and lower moisture content (Stavi *et al*. 2008).

Van Haveren (1983) found that the soil texture and moisture content at the time of grazing, as well as the level of OM in the soil surface, determine the degree of soil compaction. Soil compaction decreases the infiltration rate while increasing runoff and sedimentation, and, therefore, soil erosion.

Biological properties

Soil microbial communities play a critical role in ecosystem processes, such as C cycling, thus determination of microbial biomass C content and microbial activity of soil has been an important factor in determining soil quality and these parameters could be used as biological indicators of soil quality and health (Maková *et al*. 2011). The LG level of grazing had in general the highest biological activity. The greater microbial biomass C content in the surface soil of the LG level of grazing compared with the MG and HG levels of grazing was expected because of the differences in soil properties, root density and microbial activity between the levels of grazing. Soil CO_2 efflux is often positively related with variables such as moisture content, soil OM content and microbial activity (Yong-Zhong *et al*. 2005). Vegetation recovery and litter accumulation on the LG level of grazing is likely to have had a positive effect on soil biological properties. High microbial activity is favourable to the decomposition of the plant residues deposited on the soil surface and thus release of nutrients from litter (Jeddi and Chaieb 2010). This was attributed to the increased OM content and improved soil environment in this study. Patra *et al*. (2005) noted that increased levels of grazing, due to changes in the composition and structure of these plant communities, change the activity and composition of soil microbial communities.

Conclusions

Overall, the effects of high grazing intensity on physical and chemical properties of the soil were a higher soil bulk density, lower extractable base cations and P, and higher soil pH. These effects may have important consequences for these valuable ecosystems. We attribute these changes to the combined effects of animal trampling, reduced above- and belowground biomass and erosion as a consequence of grazing.

It can be concluded that reducing the level of grazing is an essential step to improving the rangeland conditions of Sahand. Controlling grazing time and decreasing level of grazing during the grazing season should lead to improved soil properties, increasing vegetation cover, and decreasing runoff and soil erosion. More studies are needed to better evaluate the time scale of reduction in the level of grazing required to achieve improvements in the properties of the soil in order to better understand the functioning of rangeland ecosystems. Future research to examine the influence of providing a recovery period, as discussed by Müller *et al*. (2007) and Teague *et al*. (2011), would likely yield positive results.

Appropriate reforms concerning the proper use of the grazing areas are needed, e.g. a reduction of high grazing intensity to a lower intensity. The aim of decreasing the intensity of grazing activities can only be achieved by the introduction of laws to govern the rights of use of communal grazing areas. Heavy grazing pressures may be prevented by distributing the livestock more uniformly and by ensuring that an appropriate carrying capacity is not exceeded.

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