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IMPACT OF GRAZING ON SOIL BIOTA IN A MEDITERRANEAN GRASSLAND

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ABSTRACT

The effect of cattle grazing on the soil nematode and protozoan communities, and on microbial biomass, was measured in Israel's northern highlands. Three grazing areas were compared: (1) with 1·1 cow ha^{-1} y^{-1}; (2) 0·55 cow ha^{-1} y^{-1}; and (3) control—no grazing for almost 18 years.

Soil samples were collected from the upper 10 cm level of each area ($n = 24$), in autumn, before the onset of the rainy season, in order to analyse soil moisture, organic matter, total nitrogen, microbial biomass, soil respiration, soil free-living nematodes, as well as ciliate and flagellate populations.

Soil microbial biomass and soil free-living nematodes showed no clear differences in impact between heavy and moderate grazing. However, ciliates and flagellates showed a significant response to different grazing pressures.

KEY WORDS: soil; grazing; nematodes; protozoa; microbial biomass; Israel

INTRODUCTION

Grazing pressure and traffic load are the main causes for soil compaction and changes in herbage composition and cover. Proper grazing frequency can improve plant litter quality (Bardgett *et al*., 1998) and accelerate nutrient cycling and soil microbial biomass (Tracey and Frank, 1998). Grazing-induced soil biological activity can stimulate net nutrient mineralization and increase nutrient availability (Mawdsley and Bardgett, 1997). Excessive grazing, however, can affect total carbon, microbial biomass, enzyme activity, and reduce above- and below-ground biomass (Holt, 1997; Northup *et al*., 1999). Lower organic matter content will therefore affect soil biological activity, nutrient cycling, water infiltration and water storage (Willatt and Pullar, 1984).

Domestic livestock have grazed the Middle East for over 7000 years and were a major structuring force of plant and animal communities. Effects on vegetation structure and soil seed-bank dynamics were studied by Sternberg *et al*. (2000, 2003). However, further understanding of the abundance and activities of soil organisms involved in organic matter decomposition and nutrient turnover is needed.

In this study, the effects of different cattle (for meat production) grazing intensities on the soil free-living nematode community, soil protozoa population, and microbial biomass—the most important communities in soil for nutrient dynamics—were examined at the end of the dry season in a Mediterranean grassland.

We assumed that excessive grazing would negatively affect the soil biota community and, hence, soil nutrient turnover.

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MATERIALS AND METHODS

Study Site

The study was conducted at the Karei Deshe Experimental Farm, located in the northeastern part of Israel, latitude 32° 55′ N, longitude 35° 35′ E, altitude 150 m a.s.l. For full site characteristics, see Sternberg *et al*. (2000). The Mediterranean climate is characterized by wet and mild winters (7–14°C). The average rainfall is 570 mm, falling mostly in winter (beginning in October–November and ending in April). Summers are hot and dry, with mean temperatures ranging from 19 to 32°C. The soils are brown basaltic protogrumosols (Dan *et al*., 1970) with variable depth and a rock cover of about 30 per cent.

Experimental Design

The grazing experiment was begun in 1993 in an area of 250 ha, comprising two blocks of three fenced paddocks each. Stocking rates were 0·55 and 1·1 cow $ha^{-1}\,y^{-1}$, designated moderate (M) and heavy (H), respectively. Paddocks adjacent to these grazed plots, where no grazing had taken place for more than 18 years, were selected as controls (C). Replicate grazing systems were allocated in a randomized block design. Animals were given continuous access to the entire paddock during all of the grazing season, from January to October.

Sampling

Soil samples (7 cm diameter) from each paddock were collected from the upper (0–10 cm) soil layer in October 2003 ($n = 4$). They were placed in plastic bags, transported to the laboratory in an insulated container, and kept in cold storage (4°C) until processed. Subsamples were taken from each sample for estimation of nematode and protozoan populations, microbial biomass and soil abiotic parameters.

The following parameters were determined:

(1) Soil moisture was determined gravimetrically by drying samples at 105°C for 48 h.
(2) Soluble cations (K^+, Ca^{2+}, Na^+) were determined by an atomic absorption spectrometer (Rhoades, 1982).
(3) Total soluble nitrogen (TSN) was determined by chemical extraction and colur reactions using a Skalar-Autoanalyzer (SFAS, 1995).
(4) Soil organic matter was calculated from the percentage of organic carbon estimated by oxidization with dichromate in the presence of H_2SO_4, without application of external heat (Rowell, 1994).
(5) Soil microbial biomass and soil respiration were determined using both chloroform fumigation incubation and non-fumigation samples (Voroney and Paul, 1984). CO_2 production was determined using 10 g soil samples incubated in 250 ml Pyrex jars for 10 days at 25°C. A gas chromatograph device was used for CO_2 analysis.
(6) Metabolic quotient for CO_2 (qCO_2) was calculated as the ratio between the soil respiration rate and the microbial biomass (Anderson and Domsch, 1990).
(7) Nematode population was extracted from 50 g soil subsamples during 48 h using the Baermann funnel technique (Cairns, 1960). Nematodes were counted and preserved in formalin. The total nematodes extracted were used for identification, mainly to genus level, using a compound microscope. The classification of trophic groups was assigned to: (a) bacterivores; (b) fungivores; (c) plant parasites; and (d) omnivore predators, based on known feeding habitats or stoma and esophageal morphology (Steinberger and Sarig, 1993).

From the nematode community, we analysed: (a) total number of individuals 100 g^{-1} dry soil; (b) trophic groups; (c) species diversity: $H' = -\Sigma pi(\ln pi)$, where p is the proportion of individuals in the respective groups (Shannon and Weaver, 1949); (d) species richness: $SR = (S-1)/\ln(N)$, where S is the number of taxa and N is the number of individuals identified (Yeates and King, 1997); (e) maturity index: $MI = \Sigma v_i \cdot p_i$, where v_i is the c–p value assigned by Bongers (1990) to the genus in the nematode and p_i is the proportion of the genus in the nematode community; and (f) plant parasite index (*PPI*), calculated according to Bongers (1990).

(8) Protozoan ciliates and flagellates were counted using a direct method described by Mayzlish and Steinberger (2004).
(9) Amoeba biodiversity: Identification of free-living amoebae was accomplished after cultivation in non-nutritive agar plates. No live or dead bacteria were added to the medium in order to avoid the overgrowth of bacterial-feeder amoebae over those that feed on different sources such as yeast, fungi, algae, protozoa and/or other organisms. The initial cultivation was performed by homogenizing a 1 g soil sample in 10 ml working solution (1:5 dilution of soil extract) to a final dilution of 1:10. Homogenates were then left untouched for 30 min for particle sedimentation and the supernatant was gently transferred onto the bacteria-free non-nutritive agar plates. Amoebae were allowed to settle on the agar for 2 h before withdrawal of the excess water, avoiding ciliate and flagellate growth. Cultivates were identified under a binocular microscope after 15 days of incubation at 26°C. The strains were identified by morphology using a phase-contrast microscope according to the keys for fresh water and soil gymnamoebae and the guide to free-living freshwater protozoa (Page, 1976, 1988; Patterson, 1996).

All data were subjected to statistical analysis of variance (ANOVA). Differences at the $p < 0{\cdot}05$ level were considered significant.

RESULTS

Soil Parameters

Soil moisture was significantly affected by grazing for a period of ten years. Soil samples taken in this study showed that soil moisture under moderate grazing was 6·3 per cent, which was significantly lower ($p < 0{\cdot}05$) than under heavy grazing (8·7 per cent) and in the control plots (8·2 per cent) (Figure 1a).

The amount of Na^+ under moderate grazing was 559·4 ppm, which is significantly higher than in the control plots and under high grazing ($p < 0{\cdot}05$). Mean values of K exhibited a similar trend: under moderate grazing they were significantly higher (55·8 ppm) than in the control plots (21·2 ppm) and under heavy grazing (17·4 ppm). Values of Ca^{2+}, which differed slightly between the different plots, ranged from 61·1 ppm to 67·1 ppm (Figure 1b).

Under moderate grazing, total *N* was 2·8 per cent, which was significantly higher than under heavy grazing (1·7 per cent) and in the control plots (1·3 per cent). No significant differences were observed between control plots and under heavy grazing (Figure 1c).

The mean value of organic matter under heavy grazing was 1·1 per cent, which was significantly lower than in the control plots (1·6 per cent) and under moderate grazing (1·9 per cent), although no significant differences were observed between the control plots and under moderate grazing (Figure 1d).

Microbial Activity

No significant differences were observed in the values of soil basal respiration, microbial biomass, and qCO_2 for the different grazing intensities.

Values of microbial biomass (Figure 2a) were M > C > H. A similar sequence was found for soil basal respiration CO_2 values (Figure 2b). Under moderate grazing, values of soil microbial biomass ($970\,\mu g\,C_{mic} \cdot g^{-1}$) were found to be higher than under heavy grazing ($642\,\mu g\,C_{mic} \cdot g^{-1}$) and in the control plots ($707\,\mu g\,C_{mic} \cdot g^{-1}$). An inverse sequence was obtained for qCO_2 values (Figure 2c). The mean values of qCO_2 under heavy grazing were slightly higher than in the control plots and under moderate grazing.

Nematodes

Grazing intensity significantly influenced the number of nematodes (Figure 3). The highest total was 278 individuals per 100 g dry soil in the control plots and only 76 under heavy grazing. No significant differences were observed between the different grazing managements.

The numbers of bacterivores differed when comparing the plots, with values of M > C > H. Under moderate grazing, the bacterivores were the most abundant trophic group (51·9 per cent of the total nematodes). Under heavy grazing and in the control plots, the values were 37·9 per cent and 19·2 per cent, respectively.

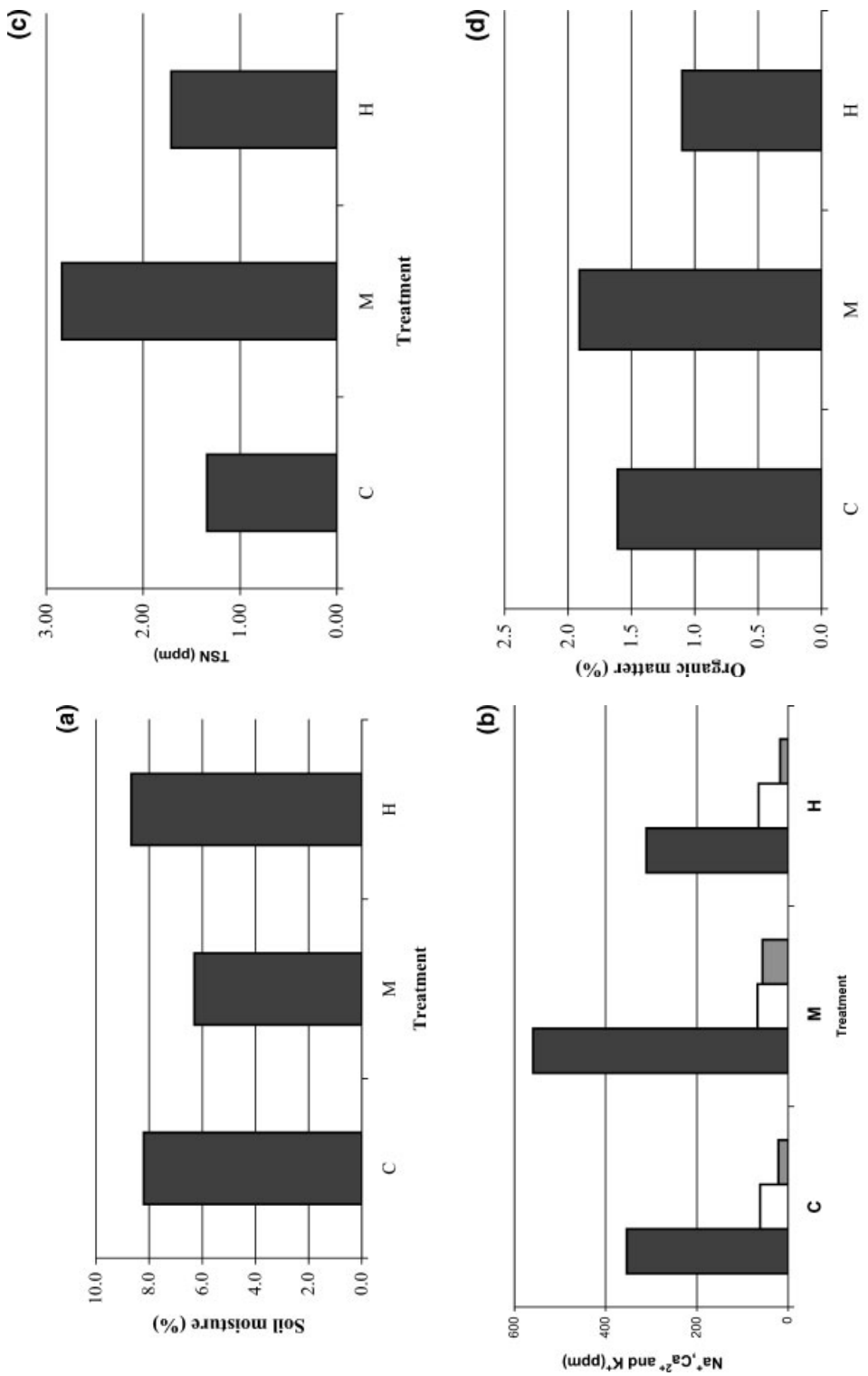

Figure 1. (a) Soil moisture (percent); (b) values of Na^+ ■, Ca^{2+} □ and K^+ ■ cations; (c) total soluble nitrogen (TSN); and (d) total soil organic matter (percent); under heavy grazing (H), moderate grazing (M), and control (C) conditions.

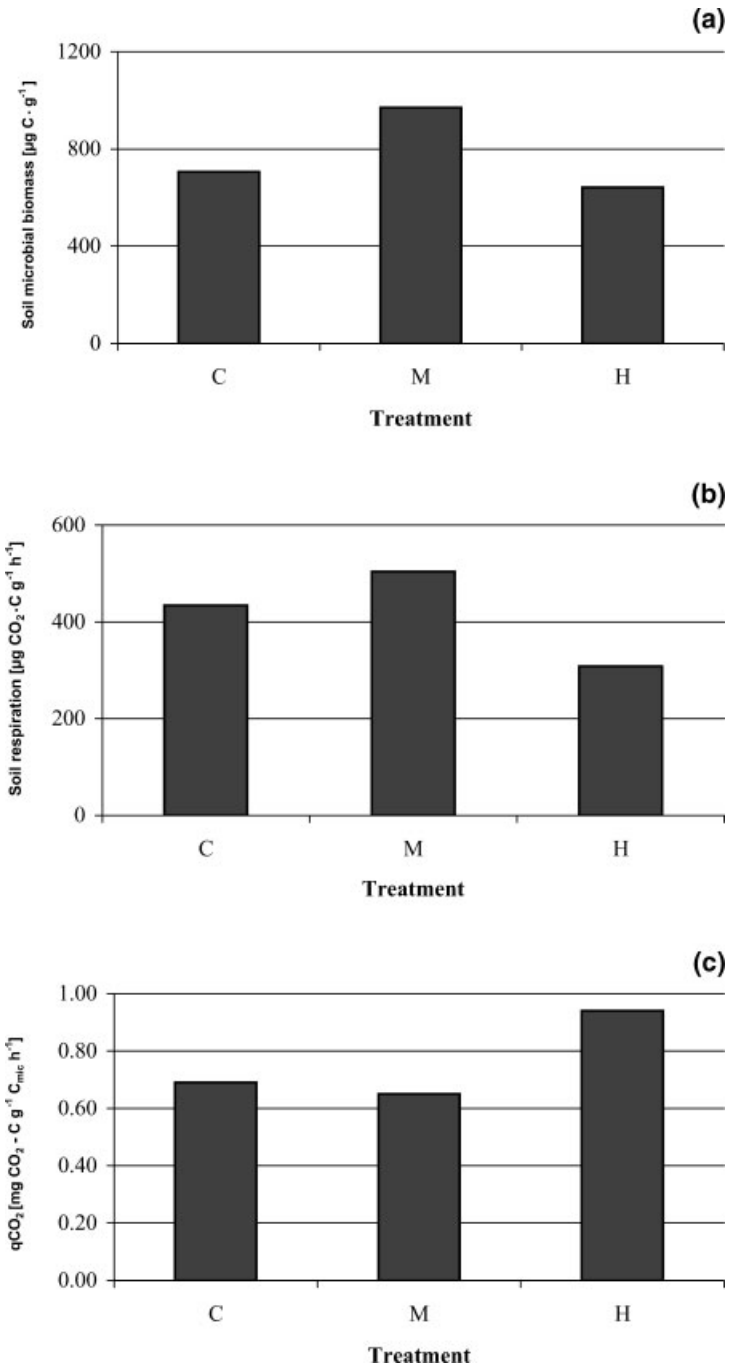

Figure 2. (a) Soil microbial biomass; (b) soil respiration; and (c) values of qCO_2 (the metabolic quotient for CO_2), under heavy grazing (H), moderate grazing (M), and control (C) conditions.

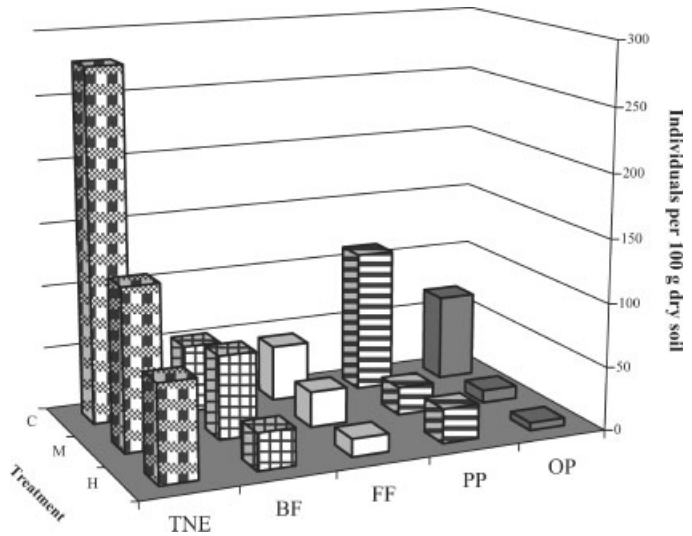

Figure 3. Total nematode population and nematode trophic group bacterivores (BF), fungivores (FF), plant parasites (PP), and omnivore predators (OP), under heavy grazing (H), moderate grazing (M), and control (C) conditions.

The numbers of fungivores differed slightly ($p < 0{\cdot}06$) between the plots, ranging from 14 to 44 per 100 g dry soil, with the highest value in control plots and the lowest value under heavy grazing.

The number of plant parasites in the control plots was 112 per 100 g dry soil, which was significantly higher than the values of 27 and 22 per 100 g dry soil found under heavy and moderate grazing, respectively.

The highest value of omnivore predators was found in the control plots, with 68 per 100 g dry soil and the lowest value (6) was found under heavy grazing. Differences between the control and grazing plots were significant ($p < 0{\cdot}03$).

Cattle grazing did not greatly influence the Shannon Weaver diversity index (H'), which ranged between 3·5 and 3·6 (Figure 4a). The *SR* values were nearly stable for the different grazing intensities, with values ranging between 1·94 and 2·11 (Figure 4b). The maturity index (*MI*) was significantly higher in the control plots (2·65). However, no significant differences were found between the grazed plots (Figure 4c).

No clear differences were observed in the mean values of the plant parasite index (*PPI*) (Figure 4d). The highest value (2·34) was under heavy grazing and the lowest value (2·07) was found in the control plots.

Protozoa

There were great differences between ciliate and flagellate populations (Figure 5a), with a significant negative correlation (0·62).

Ciliates were significantly ($p < 0{\cdot}001$) more numerous under moderate grazing (1131 individuals per 1 g dry soil) (Figure 5a). Their number under high grazing (18 individuals per 1 g dry soil) and in the control plots (0 individuals per 1g dry soil), did not differ significantly. Significantly more ($p < 0{\cdot}05$) flagellates (1024 individuals per 1 g dry soil) were found under heavy grazing than in the other two grazing sites. The difference between moderate grazing (564 individuals per 1 g dry soil) and the control (554 individuals per 1 g dry soil) was not significant (Figure 5b).

The amoeba population in the soil samples was represented by a total of 28 species belonging to eight families. The results presented in Table I detail the families and species, with their relative frequencies between the different sampling sites. The Vannellidae was the most common family found in the samples, followed by the Hartmannellidae and Paramoebidae families.

The species diversity index (Shannon Index) was found to be higher in the grazing areas than in the control plot (Figure 6). The values obtained were M > H > C (4·1, 3·8 and 3·5, respectively).

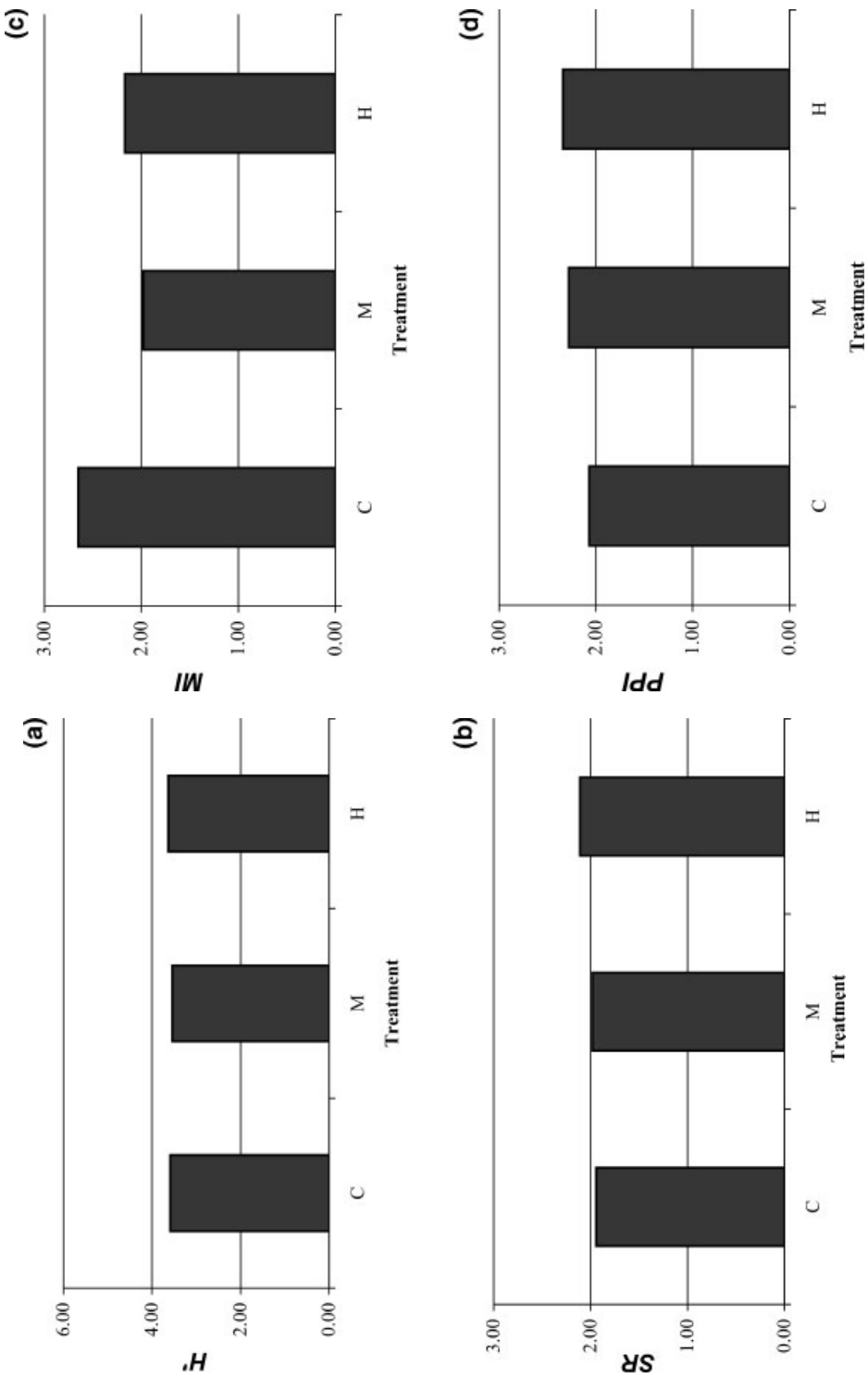

Figure 4. Ecological indices of soil nematodes: (a) species diversity-*H'*; (b) species richness-SR; (c) maturity index-*MI*; and (d) plant parasite index-PPI, under heavy grazing (H), moderate grazing (M), and control (C) conditions.

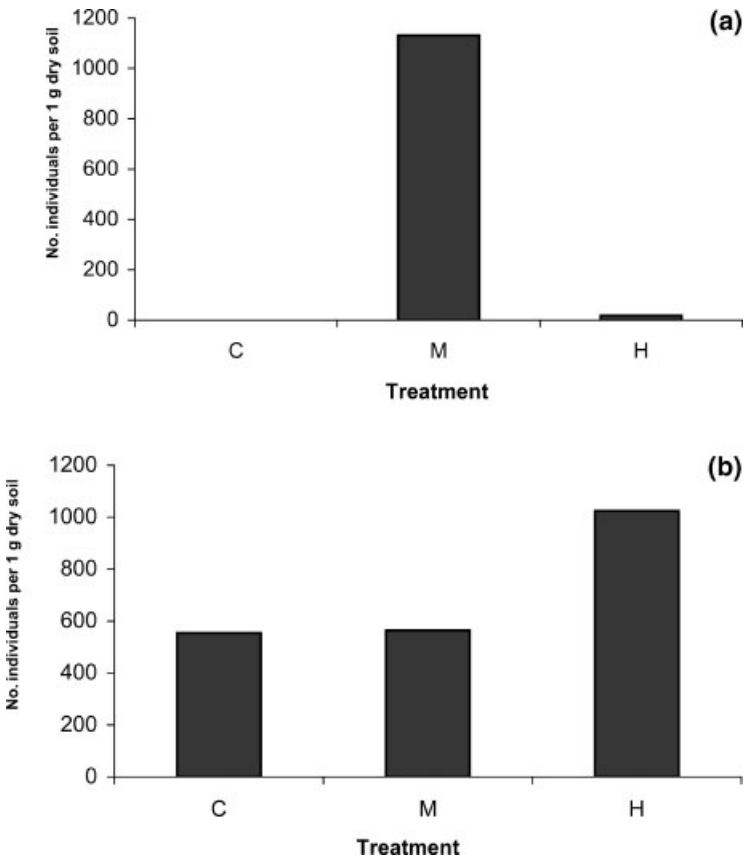

Figure 5. (a) Ciliate; and (b) flagellate populations, under heavy grazing (H), moderate grazing (M) and control (C) conditions.

The frequency analysis of the four morphotypes demonstrated different trends between the sampling plots. In the heavy grazing (Figure 7a) plots, types 1 and 4 frequencies were 35 per cent of the population followed by type 2, which represented 25 per cent of the population. Type 3 was found at a low percentage of less than 5 per cent. In the moderate grazing plots (Figure 7b), the most common type was type 1 with 39 per cent, followed by types 2 and 4, with no significant differences between their frequencies, having a mean value of 27·5 per cent. Type 3 frequency was found to be similar to the frequencies found in the high grazing pressure site, with a value of 6 per cent.

A different trend was found in the control plot (Figure 7c). Type 4 represented a little less than 39 per cent of the population, followed by type 2 with 35 per cent. Types 1 and 3 represented a mean of 13 per cent of the population, with no significant differences between them.

DISCUSSION

Our initial hypothesis, that soil biota are negatively influenced by excessive grazing, was not substantiated in this study for soil microbial biomass and soil free-living nematodes. However, the protozoans (ciliates and flagellates) showed a significant response to different grazing pressures, possibly as a response to changes in pore size.

Higher values of soil respiration and soil microbial biomass were obtained under moderate than under heavy grazing. These results are in agreement with Holt (1997), who found that microbial biomass values under heavy grazing were significantly reduced at the Cardigan and Hillgrove experimental sites. Soil microbial biomass responds rapidly to different management strategies (Jenkinson, 1988). Our results indicate a potential transition to

Table I. List of soil free-living amoebae in the present study and their frequencies

Taxa	Type	High	Moderate	Control
Acanthamoebidae	1			−
Acanthaboeba sp.		+ + +	+	−
Acanthamoeba castellani		+	+	−
Echinamoebidae	1			
Echinamoeba exudans		+	+ +	+
Echinamoeba silvestris		+	+	−
Filamoeba nolandi		+	+	−
Paramoebidae	1			
Dactylamoeba bulla		+	−	−
Dactylamoeba stella		+ +	+ +	+
Mayorella penardi		+	+ +	+ +
Mayorella vespertilioides		−	+	−
Vexilliferidae	1			
Vaxilifera bacilipedes		+	+	−
Vaxilifera gratensis		+	+	−
Hartmannellidae	2			
Hartmannella cantrabrigiensis		+ + +	+ + +	+ +
Hartmannella vermiformis		+ + +	+ + +	+
Sacamoeba sp.		−	+	−
Sacamoeba limax		−	−	+ +
Sacamoeba stagincola		−	+	−
Cashia limacoides		+ +	+ +	+
Glaeseria mira		−	−	+ + +
Amoebidae	2			
Trichamoeba sinuosa		+	+ +	−
Vahlkampfidae	3			
Vahlkampfia sp.		+	+	+
Naegleria sp.		+ +	+ +	+ +
Stachyamoeba lipophora		+	−	−
Vannelidae	4			
Platyamoeba placida		+ +	+ + +	−
Platyamoeba stenopodia		+ + +	+ + +	+ +
Vannela lata		+ + +	+ + +	+ +
Vannela simplex		+ + +	+ + +	+ + +
Vannela platypodia		+ + +	+ + +	+ + +
Vannela cirifera		+ + +	+ + +	+ + +

+ low frequent.
+ + mediate frequent.
+ + + very frequent.

another nutritional status. Reduction of microbial biomass and soil basal respiration may have been influenced by a lower rate of supply of organic matter and other nutrients due to grazing (Holt, 1997). The qCO_2 represents a specific physiological indicator of the soil microbial community (Sarig *et al*., 1999). Anderson and Domsch (1993) reported that qCO_2 values increase with environmental stress. We also found an increased qCO_2 value under heavy grazing, representing the more severe conditions obtained in these plots.

In our study, the values of total N, organic matter, and Na^+ and K^+ amounts were significantly higher under moderate than under heavy grazing. Similar results were reported by Bardgett *et al*. (2001), who found the highest values of soil C and total N under light grazing compared to heavy grazing and control. In a Mediterranean rangeland ecosystem, the higher values of total N, organic matter, and soluble cations under moderate grazing may positively influence soil biota composition. Due to enhanced recirculation of nutrients within the ecosystem, ecosystem productivity, especially primary productivity, seems to reach a maximum at moderate levels of herbivory (Loreau, 1995).

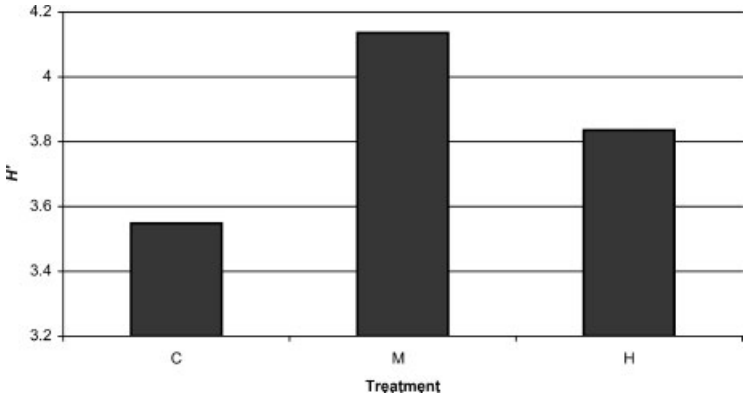

Figure 6. Ecological indices of soil amoebae: species diversity (H').

Long-term absence of grazing was found to have a positive influence on nematode community composition. In the control plots, the total nematode number and the plant parasite and omnivore predator populations were significantly higher than under heavy and moderate grazing. These results are inconsistent with the findings of Bardgett *et al*. (1997), who found that nematode abundance was significantly higher in grazed than ungrazed plots in a hill grassland ecosystem. We attribute these differences to the significantly lower soil moisture in the moderate grazing plots. This lower soil moisture might suppress the response of the total nematodes and nematode trophic groups to the different grazing regimes. Nevertheless, the bacterivore population increased more under moderate grazing than in the control and heavy grazing plots.

The results obtained in this study were found to differ from the results reported by Freckman *et al*. (1979), who compared the nematode community in grazed and ungrazed grassland, and found that the numbers of nematodes were higher in grazed than ungrazed annual grassland. This finding has been attributed to reductions in the abundance of soil microorganisms. The bacterivores were the most abundant trophic group under moderate grazing, comprising 51·9 per cent of the total nematodes. This indicates that the bacterial decomposition pathway was more important under moderate grazing than under heavy grazing and control. The higher maturity index in the control plots indicated that the rangeland ecosystems were affected by grazing pressure, while no differences were observed between heavy and moderate grazing.

The protozoans were found to be most affected by grazing, according to their size. The small protozoa, i.e. the flagellate population, were found to be more diverse under heavy grazing with high soil compaction. The small pores in the soil were suitable for flagellates but not for ciliates, which require bigger pores (Bamforth, 1997). We found that the ciliate population was more numerous under moderate grazing, where fewer cattle caused less soil compaction (Holt, 1997).

The grazing treatments also affected amoeba biodiversity. The grazing itself increased the diversity in the moderate and high plots and created a heterogeneous population of the different types in the moderate plot more than in the high plot. In the control plot, a more homogeneous population was found, suggesting that proper grazing intensity can improve soil quality and population diversity.

Our results indicate that a more diverse community can be maintained under continuous moderate grazing. A reduction of grazing intensity may destabilize this community, as observed in ungrazed exclosures, where the complete exclusion of grazing for 18 years generally led to lower numbers of different functional groups compared to moderately grazed areas. Thus, the exclusion of grazing in areas with a long history of grazing can be considered as a disturbance (Milchunas *et al*., 1988). These grasslands probably evolved to a state of balanced persistence and productivity under moderate grazing. However, they can change to an alternative, less diverse and productive state under either very heavy grazing pressure or in the absence of grazing.

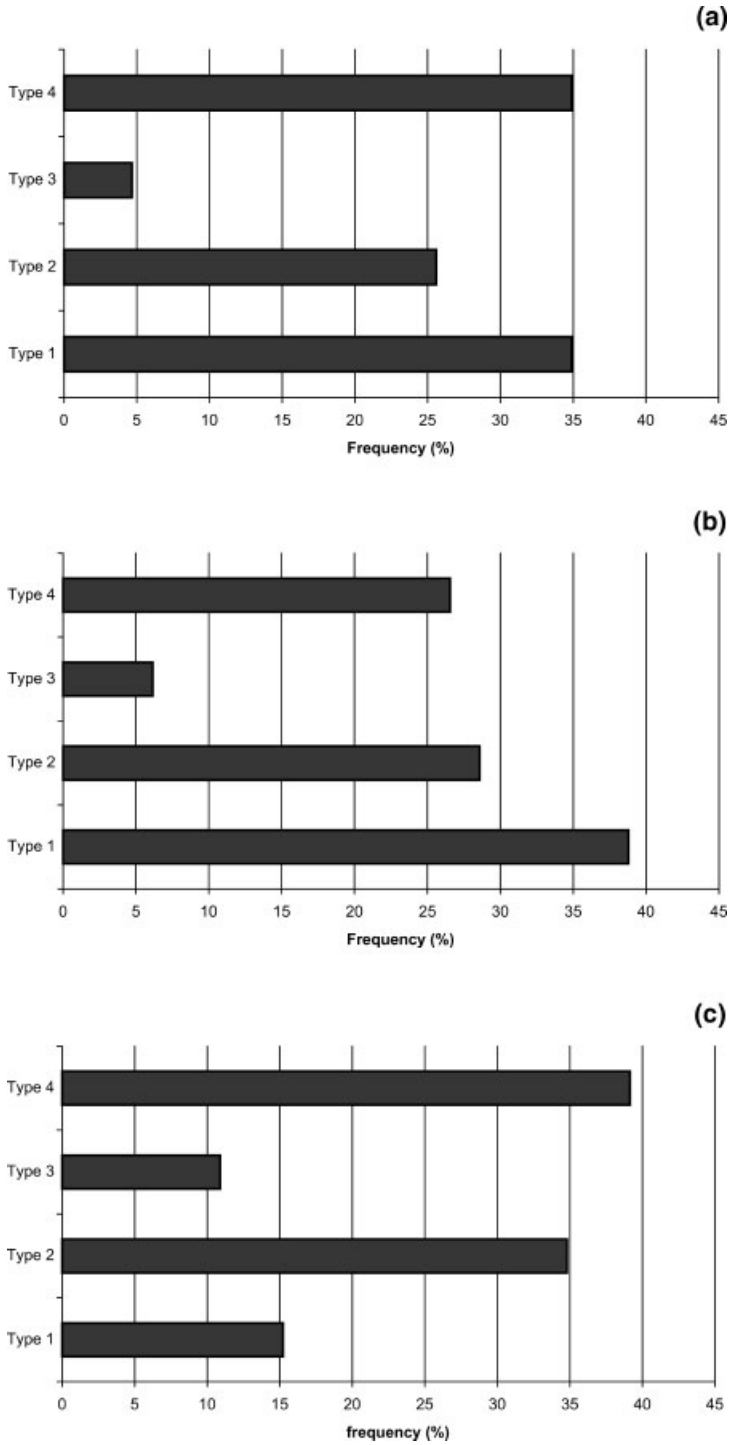

Figure 7. The four amoeba morphotypes under (a) heavy grazing; (b) moderate grazing; and (c) control conditions.

In conclusion, in our region, heavy grazing intensity can negatively influence soil organic matter, total N, and soluble cations, which might in turn affect soil biota in the ecosystem. This experiment was conducted in the autumn before the rainy season. Therefore, further study of the seasonal dynamics of soil biota is needed in order to better understand the effect of different grazing intensities on soil biota and nutrient cycling.

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