

The influence of grazing load of different intensity on the state of zoo-microbial complex in the soils of Tuva dry steppes

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Abstract. The paper presents the results of a study of the features of the transformation of various components of the zoo-microbial complex during long-term use of the steppe ecosystem as a pasture under a strong load compared to pasture areas under a weak load. It was revealed that various components of the zoo-microbial complex are characterized by fundamentally different reactions to such a widespread anthropogenic factor in the steppe zone as grazing load. It was determined that when the constant grazing load changes from weak to strong, a reliable increase in the C-biomass of microorganisms occurs. It was found that areas of dry steppe that have been under a weak grazing load for a long time are characterized by significantly higher quantitative indicators of oribatid mite communities, such as species richness and total abundance, compared to an area of the dry steppe ecosystem that has been under a strong grazing load for a long time. As a result of the conducted acarological analysis, the statement is substantiated that under a weak but stable load, the oribatid communities have a moderately high number, while under a strong grazing load, the oribatid community is in a depressed state. The conclusion is presented that the indicators of soil microbial biomass, number and species richness of oribatid mites can be successfully used in the practice of environmental monitoring of steppe ecosystems under varying grazing loads.

1 Introduction

The destructive link in the biological cycle of underground components of terrestrial ecosystems is based on soil microorganisms, which are responsible for the mineralization of about 90% of the soil's organic matter. The remaining 10% is processed either by soil fauna or chemically, and it is the biomass of soil microorganisms that plays an exceptional role in the processes of matter and energy circulation in ecosystems [1]. Microorganisms produce various extracellular hydrolytic enzymes in the soil, which allows them to directly decompose organic matter, while the participation of soil animals in this decomposition occurs more indirectly [2]. A particularly significant group of soil organisms are oribatid

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mites. Their populations in various types of soil can reach hundreds of thousands or even millions of individuals per square meter. The rate of consumption of microbial biomass by smaller invertebrates such as oribatid mites is significantly higher, hundreds of times, than that of larger soil-dwelling animals such as earthworms and millipedes. Given their higher population density than other soil invertebrates, these animals play a critical role in regulating the metabolic activity of the soil microbial community. Consequently, oribatid mites influence both the growth and metabolic activity of microorganisms and the diversity and structure of microbial populations during succession during decomposition of plant materials. Oribatids gnaw leaf blades, within and on the surface of which microorganisms live. The gut of oribatid mites contains some important enzymes for the breakdown of fungal cells, some of whose cell wall substances are very resistant to decomposition [3]. Like microorganisms, oribatid mites make a significant contribution to the decomposition of organic matter by breaking down plant litter and facilitating its availability for microbial decomposition. The main role of oribatid mites in the destruction of plant litter is to crush it, but in addition to invertebrate excrement, a significant amount of liquid and gaseous metabolic products enters the soil, which are subsequently used by microorganisms. When assessing the contribution to the total respiration process of soil biota, it turned out that microarthropods and protozoa make the greatest contribution to this process. Studies show that the presence of soil fauna significantly accelerates the processes of litter mineralization and humus formation: the specific rate of microbial decomposition of litter components in the excrement of invertebrates increases by 1,5–4 times compared to the original litter, which is explained by a change in the composition of microorganisms when passing through the intestines of plant matter [4]. The effect of grazing load on the community of soil microorganisms has been studied in various natural zones of the planet. In the tallgrass prairie of Kansas, the effect of grazing cattle and bison on soil respiration was assessed. It turned out that the CO₂ flux from the pasture surface was 20–37% less than that from the surface of ungrazed prairie areas, which the authors attribute to a decrease in plant photosynthesis and a slowdown in the movement of carbon into the rhizosphere [5].

In an analysis of changes in soil characteristics, nutrient availability, and microbial activity with grazing intensity in the Chaco region of northwestern Argentina (highly restored pasture, moderately restored pasture, and highly degraded pasture), it was found that soil moisture and microbial biomass decreased with increasing grazing intensity. Seasonal variations in microbial density and activity increased from the highly restored to the highly degraded plot, probably in response to increased moisture stress. Nitrogen fixation was more intense in the moderately restored plot, followed by the highly degraded plot. The authors conclude that overgrazing has a strong effect on soil fertility, as well as on the soil's ability to withstand water stress during the dry grazing season [6]. In a study of the effects of livestock grazing on soil CO₂ emissions in a shortgrass prairie in northeastern Colorado at three sites (heavy grazing, light grazing, and no grazing), it was shown that differences in soil CO₂ emissions were due to climate variability and differences in plant species composition resulting from long-term grazing and cessation of grazing. This study demonstrated that grazing intensity did not alter photosynthetic parameters of plant communities or soil respiration in shortgrass prairie [7]. In a study of the effects of soil fauna (enchytraeids) on the level of microbial biomass in pasture soils, the authors were unable to find convincing evidence for such an effect, suggesting that this relationship is mediated through the soil phosphorus cycle [8]. Changes in soil microbial biomass stock and other soil microbiological parameters have been analysed in a range of steppe ecosystems under different grazing pressures. A study conducted in the temperate steppe of northern China found that overgrazing reduced bacterial and fungal diversity. In particular, the negative effects of overgrazing on microbial richness were significant in typical steppe but insignificant in grassland steppe, which had higher plant diversity and higher soil

moisture. It was shown that the direct negative effects of grazing and its indirect negative effects through soil properties resulted in significant reductions in microbial richness in typical steppe, while in the grassland steppe, the indirect positive effects through plant properties offset the direct negative effects of grazing [9]. A study in a grassland steppe in Inner Mongolia under six different grazing intensities found that intensive grazing significantly reduced the carbon and nitrogen contents of microbial biomass in the surface soil layer. Soil bacterial diversity was higher under light grazing than under heavy grazing, and fungal diversity was higher under no grazing than under grazing, while overgrazing resulted in a reduction in the number of soil bacterial species [10].

In a 40-year field experiment investigating the effects of overgrazing on soil organic matter and microbial biomass in semi-arid grassland in China, soil organic matter and microbial biomass decreased by 20% in the soil of overgrazed grassland compared with moderately grazed grassland. Soil micromycetes abundance decreased by 40% under these conditions, and bacterial and actinomycete abundance also decreased, but urease activity increased under extreme grazing. These results indicate that overgrazing may impair nitrogen supply to belowground microbes, thereby stimulating microbial production of soil nitrogen-fixing enzymes [11]. In a study of the effects of grazing in four grassland ecosystems, it was demonstrated that the soil microbial community was transformed under the influence of grazing pressure mainly due to the decrease in the diversity of soil fungi. The diversity of soil bacteria remained almost unchanged. The analysis showed that climatic factors contributed 13.1% to the variation of the bacterial community, while grazing intensity contributed 3.01% to the variation of the fungal community. The study showed that the diversity of bacteria and fungi was affected by different ecological processes and can adapt to a certain grazing intensity over time [12].

An experiment was conducted in a desert steppe in Inner Mongolia to examine the effects of light and heavy grazing compared to a protected area (an enclosed paddock not disturbed by livestock) on microbial diversity. The results showed that heavy grazing dramatically reduced bacterial diversity only in non-rhizosphere soils but had no significant effect on fungal diversity in either rhizosphere or non-rhizosphere soils. Bacterial diversity in rhizosphere soils was higher than that in non-rhizosphere soils only under heavy grazing [13]. A study of the effects of different grazing intensities on the composition of soil microbial communities in different plots of a meadow steppe showed that grazing had a significant effect on soil microbial communities. The highest microbial diversity was observed under light and moderate grazing intensities. Grazing changed the microbial composition from fungal-dominated to bacterial-dominated and from slow-growing to fast-growing, thereby shifting from fungal-dominated food webs that primarily utilize stable organic matter to bacterial-dominated food webs that primarily utilize labile organic matter. Higher activity of fungi that are unable to decompose stable soil organic matter and higher activity of bacteria that decompose labile soil organic matter were observed in fungal-dominated and bacterial-dominated communities, respectively [14]. An experiment on the effect of grazing pressure on soil microbial properties conducted in the mountain meadows of the Chinese Altai demonstrated that basal respiration was highest under low grazing pressure. All other studied soil and microbial parameters remained virtually unchanged with increasing grazing load, except for the metabolic quotient, which decreased with increasing grazing load, indicating an old and dormant microbial community that directs less soil organic carbon to catabolic processes within its cells [15]. When assessing the effect of grazing of varying intensity and areas without grazing in typical steppe and desert steppe ecosystems in Inner Mongolia on soil organic carbon and microbial biomass carbon, it was found that higher values of the studied parameters are characteristic of grazed areas of the typical steppe compared to non-grazed ones. Over seven years of observations, there was an increase in soil carbon reserves in grazed areas of the desert steppe. The authors

explain the higher value of microbial biomass carbon in the desert steppe than in the typical steppe mainly as a result of higher precipitation and temperature [16]. Studies of oribatids under grazing pressure on ecosystems are mainly descriptive, without taking into account the degree of pasture degradation and without comparison with undisturbed ecosystems. Publications considering the oribatid population under grazing conditions in a comparative aspect, whether it is a comparison of pastures with other biotopes or a comparison of different types of pastures with each other, are generally few in number [17–20], scattered and leave a vast field for research.

The aim of this study was to study the features of the state of the main components of the zoo-microbial complex (soil microorganisms and oribatid mites) under various grazing pressure regimes in the steppes of Tuva.

2 Objects and methods of research

The study was conducted in intermountain steppe ecosystems located in the Ubsunur Basin of the Republic of Tuva. Most of the territory of the Republic of Tuva is located in the dry steppe zone and the basis of agricultural production in Tuva is year-round transhumance. Soil samples for the analysis of the oribatid population and determination of microbiological indicators were collected in different years in 3 steppe biotopes on chestnut sandy soils under grazing loads of varying intensity. The main characteristics of the studied ecosystems are given in the table.

Table 1. Main characteristics of the studied ecosystems.

No.	Item geomorphological location	Ecosystem	Pasture load
1	Yamalyg Ridge, middle part of the foothill plain	Feather-grass dry steppe	Weak
2	Onchalan Remnant, northern slope	Feather-grass-Keleria dry steppe	Weak
3	Near the village of Erzin	Forb-grass dry steppe	Strong

To determine the microbiological parameters, samples were collected in July-August for three years from the upper 0-10 cm soil layer in 4-fold replication. The soil was prepared for analysis using the generally accepted method. Field moisture was determined in the soil samples [20]. The carbon content in the biomass of soil microorganisms (C-biomass) was estimated using the fumigation-incubation method [22], and the value of active biomass was estimated by the release of CO₂ from the soil for 10 hours of incubation after the introduction of a certain carbon substrate [23]. Based on the obtained values of the total and active biomass of microorganisms, the specific activity of the microbial biomass (the proportion of active biomass) was calculated as a percentage of active biomass in the total value of C-biomass. To analyse the population size of oribatids, soil samples were collected using a standard cylindrical sampler in 5 cm deep layers in 10-fold replication in each ecosystem. The expulsion of oribatids from the soil was carried out using the Tulgren-Berlese thermoelectric method, which is generally accepted for microarthropods. This method is based on a common feature of all soil inhabitants – going deep when the upper soil layers dry out [24]. Statistical processing of the results was carried out using the methods of variation and dispersion analysis [25-26].

3 Results and discussion

In steppe ecosystems, increased dryness is observed during cattle grazing, which leads to the depletion of the steppe flora and a shift in the species diversity of steppe plant communities towards a greater abundance of more drought-resistant species. In situations where vegetation in a steppe ecosystem becomes sparser due to mass trampling of plants and their consumption by cattle, the level of solar radiation and the temperature of the soil surface increase, the soil becomes compacted and the rate of moisture evaporation from the surface increases [25]. Our studies have shown that the moisture content of the studied soils did not exceed 4.3% at all stages of sampling (Figure 1). It is noteworthy that the soil moisture in pastures experiencing intensive grazing loads was generally somewhat higher compared to pastures in easier grazing conditions.

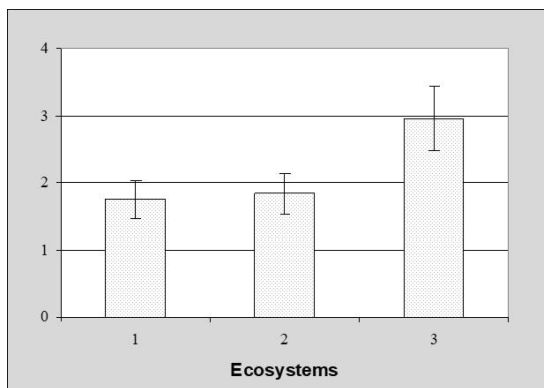


Fig. 1. The soil moisture content of the studied pastures at the time of sampling (%). LSD (5%) = 2.1.

The maximum values of C-biomass (29 mg/100 g) were noted in the soil of the pasture with a high grazing load (ecosystem 3), in the soils of the remaining ecosystems (1 and 2) the C-biomass was approximately 2 times lower (Figure 2). A similar effect was noted in studies carried out in the desert steppe of Inner Mongolia. The only explanation for this phenomenon proposed by the authors was associated with climatic factors [16].

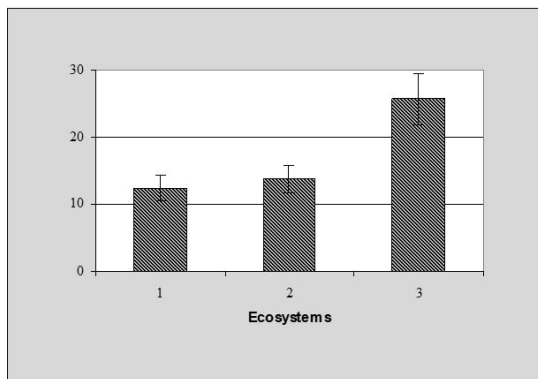


Fig. 2. C-biomass of microorganisms (mg C / 100 g) in the soil of different pastures. LSD (5%) = 2.2.

No reliable differences were found between ecosystems in terms of the level of metabolically active micro biomass (Figure 3); however, significant interseasonal fluctuations in this indicator are noted (variation coefficient 43%). That is, in the soil under

a degraded pasture (ecosystem 3), the content of total microbial biomass increases significantly, while the specific activity of this biomass generally remains at the level of pastures with a low grazing load (ecosystems 1 and 2).

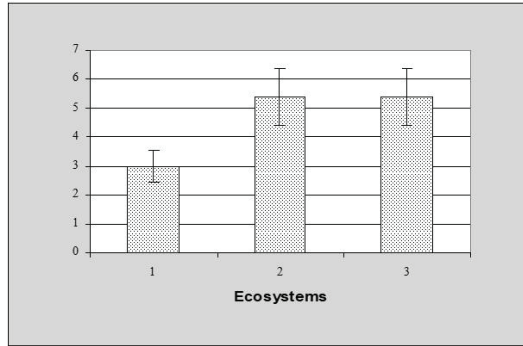


Fig. 3. Metabolically active biomass of microorganisms (mg C / 100 g) in the soil of different pastures. LSD (5%) = 3.5.

Changes in the concentration of total and metabolically active microbial biomass with changes in the pasture load may be associated with a decrease in root growth and an increase in the intensity of the root litter mineralization process. In this case, an increase in the mass of microorganisms with an increase in the pasture load can be considered as an indicator of changes in the intensity of destructive processes in the underground block of the steppe ecosystem.

In the studied biotopes, a total of 5 species of oribatids were found, the species list of which is given in the 2011 article [20]. Of these five species, two (*Latovortex laticuspis* and *Eporibatula prominens*) are common in many biotopes of Tuva, and in the presented material they occupy a dominant position in communities with a weak pasture load. Three other species in the presented material are few in abundance: *Proteremaeus chadaevae* – in a pasture with a weak load, and *Zygoribatula propinquus* and *Bipassalozetes* sp. – in pastures with a strong load. Data on the abundance of oribatid species in the studied ecosystems are shown in Figure 4. Steppe ecosystems with low grazing pressure are characterized by significantly higher species richness than ecosystems with intensive grazing pressure.

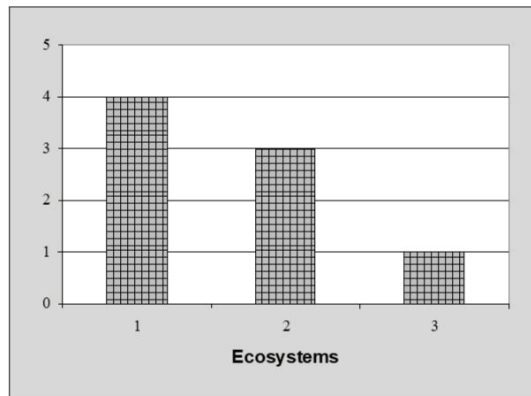


Fig. 4. Species richness of oribatid mites in the studied ecosystems

Data on the abundance of oribatids in the considered series of ecosystems are shown in Figure 5. It is evident that in a series of biotopes the abundance varies from 0,16 to 10,8

thousand specimens / m². At the same time, the range of fluctuations in variants with a weak grazing load is 8,0–10,8 thousand specimens / m². That is, oribatid communities with strong grazing react to high grazing intensity with a sharp decrease not only in species richness, but also in total abundance.

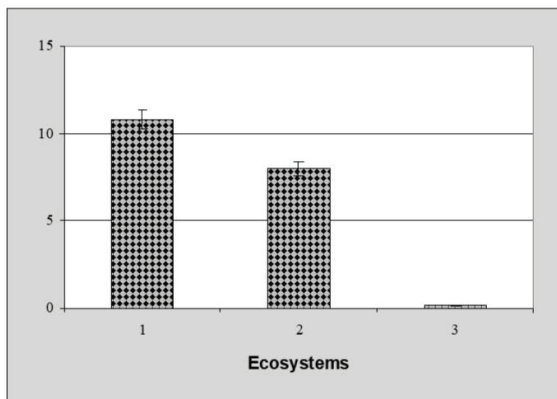


Fig. 5. Numbers of oribatid mites in steppe biotopes of Tuva under varying pasture load (thousand specimens / m²).

Thus, the grazing intensity factor has a significant impact on oribatid communities. With weak but stable grazing, oribatid communities have moderately high quantitative community indicators: species richness and abundance. With strong grazing, the oribatid community is in a depressed state. Moreover, it was previously shown that with strong grazing, the oribatid community is practically not restored within three years [20].

4 Conclusion

Thus, our study demonstrated that different components of the zoo-microbial complex of the steppe ecosystem in the dry steppe zone are characterized by fundamentally different reactions to such a common anthropogenic factor in the steppe zone as grazing load. Microorganisms and oribatids also showed different reactions during pioneer soil formation in a sandy ridge [26]. When the constant grazing load changes from weak to strong, there is a reliable increase in the C-biomass of microorganisms and a tendency towards an increase in the metabolically active microbial biomass is noted, but the specific activity of this biomass remains at the level of pastures with a weak grazing load. Steppe ecosystems with a weak grazing load are distinguished by a significantly higher species richness of oribatid mites compared to the ecosystem with a strong grazing load. At the same time, oribatid communities under heavy grazing respond to a high grazing load with a sharp decrease in their total numbers. That is, with a weak but stable load, the oribatid communities have a moderately high number, and with strong grazing, the oribatid community is in a depressed state. The results of the study show that the indicators of microbial biomass, abundance and species richness of oribatids in soils can be successfully used in the practice of environmental monitoring of steppe ecosystems with different grazing intensities. These parameters can be used in monitoring practice due to their simplicity and a sufficiently high degree of variability depending on the strength of the anthropogenic load on the natural ecosystem. Biological methods of environmental monitoring are of particular importance in the context of global climate change on the planet as a whole and in the dry steppe zone in particular, when the measured parameters of the steppe ecosystem are affected by both factors associated with the level of anthropogenic load (pasture load) and climatic factors

associated with an increase in average annual temperatures and a decrease in the moisture level in the dry steppe zone.

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