The Role of Microorganisms in Biogenic Elements Cycling in the Dry Steppe Ecosystems of Central Asia

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Abstract

The following primary variables were studied in order to understand which part microbial decomposers play in biogenic elements cycle in the steppe ecosystems of Central Asia: species composition and productivity of plant communities; chemical composition of dead plant material; fungal abundance and abundance of various ecological trophic groups of bacteria (saprophytic, proteolytic, cellulolytic); degradation rate of model substrates and plant litter (protein and cellulose). The total stock of chemical elements (N, P, Ca, Mg and K) involved in the biological cycles in the steppe of Buryatia (Russia) amounted from 6.478 to 10.130 kg/ha, and from 8.826 to 31.802 kg/ha in the Mongolian steppe. The chemistry of elements’ cycles in the ecosystems under study is of a nitrogen type.

Materials and methods

The investigated forb-feather-grass communities of the dry steppes were located in Buryatia and Mongolia (Fig. 1).

These communities under study were located in the Involginskiy and Mukhorshibirskiy districts of Buryatia, and in Khentii, Sukhbaatar and Dornod provinces of Mongolia. A brief
description of each study site is given in Table 1.

Modified Kirshner–Ganek method was used to measure cellulose content, while fats were extracted using Soxhlet extractor. Protein levels were calculated from total nitrogen multiplied by the factor 6.25. Sugar and starch content was determined with anthrone reagent (Biochemical approaches to study plants, 1987). Fe, Cu, Zn, Mn, Co, Cr, Cd levels in mineralization products were calculated using atomic absorption spectrophotometer SOLAAR M6; Ca and Mg were determined following complexometry; N — following Kjeldahl titrimetric method; P — through vanadate-molybdate photometry; Na and K — following spectrophotometry (using spectrophotometer) (Ermakov, 1987; Yagodin, 1987).

Degradation intensity of plant material was

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**Table 1. Geographical coordinates, altitude, dominant and codominant plant species of the study sites.**

<table>
<thead>
<tr>
<th>Site</th>
<th>District / Province</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Altitude (m)</th>
<th>Dominant and codominant species</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mukhorshibirskiy</td>
<td>51°08’97”</td>
<td>107°24’42”</td>
<td>613</td>
<td><em>Stipa krylovii</em></td>
</tr>
<tr>
<td>2</td>
<td>Mukhorshibirskiy</td>
<td>51°08’16”</td>
<td>107°18’59”</td>
<td>598</td>
<td><em>Stipa krylovii, Agropyron cristatum, Artemisia frigida</em></td>
</tr>
<tr>
<td>3</td>
<td>Mukhorshibirskiy</td>
<td>51°11’25”</td>
<td>107°34’76”</td>
<td>698</td>
<td><em>Stipa krylovii, Poa botryoides, Artemisia frigida, Potentilla acaulis</em></td>
</tr>
<tr>
<td>4</td>
<td>Involginskiy</td>
<td>51°34’84”</td>
<td>107°03’93”</td>
<td>637</td>
<td><em>Stipa krylovii, Artemisia frigida, Cleistogenes squarrosa, Poa attenuate, Potentilla acaulis</em></td>
</tr>
<tr>
<td>5</td>
<td>Involginskiy</td>
<td>51°37’03”</td>
<td>107°07’70”</td>
<td>686</td>
<td><em>Stipa krylovii, Cleistogenes squarrosa, Poa attenuate</em></td>
</tr>
<tr>
<td>6</td>
<td>Khentii</td>
<td>47°33’81”</td>
<td>109°18’88”</td>
<td>1486</td>
<td><em>Stipa krylovii, Cleistogenes squarrosa, Poa botryoides</em></td>
</tr>
<tr>
<td>7</td>
<td>Khentii</td>
<td>47°33’59”</td>
<td>109°18’77”</td>
<td>1488</td>
<td><em>Stipa krylovii, Cleistogenes squarrosa</em></td>
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<tr>
<td>8</td>
<td>Sukhbaatar</td>
<td>47°37’56”</td>
<td>112°21’62”</td>
<td>978</td>
<td><em>Stipa krylovii, Cleistogenes squarrosa, Leymus chinensis</em></td>
</tr>
<tr>
<td>9</td>
<td>Dornod</td>
<td>47°49’68”</td>
<td>113°05’14”</td>
<td>939</td>
<td><em>Stipa krylovii, Cleistogenes squarrosa</em></td>
</tr>
<tr>
<td>10</td>
<td>Sukhbaatar</td>
<td>47°28’52”</td>
<td>113°24’23”</td>
<td>1012</td>
<td><em>Stipa krylovii, Cleistogenes squarrosa, Leymus chinensis</em></td>
</tr>
</tbody>
</table>
investigated with the help of mechanical isolation (Perel & Karpachevsky, 1968). Cellulose and protein degradation intensity was measured on model substrates (filter paper and photographic paper) following the application by Khaziev et al. (2005).

The abundance of different ecological trophic groups of microorganisms in sample of living and dead aboveground phytomass and roots was evaluated on selective media following limiting dilution culture approach with the help of McCready table (Tepper et al., 2004). A Sabouraud’s medium (Dudka et al., 1982) was used to evaluate the fungal abundance. The saprophytic bacteria were secured using glucose-yeast-peptone medium (Subba Rao, 1977). The abundance of cellulolytic and proteolytic bacteria was measured in Pfennig’s medium adding filter paper and peptone, respectively (Pfennig, 1965).

Results

The floristic composition of the investigated plant communities is typical for steppe ecosystems of Central Asia; it is rather limited, with 11–15 families, among which the most speciose of which are Asteraceae, Poaceae and Rosales. Buryat steppe plant community is of a moderate familial diversity (11) and fewest of species (34). Species composition of the flora of the Mongolian communities under study is more diverse, represented by 51 species from 15 families.

The total stock of aboveground phytomass in the plant communities under study ranges from 2.7 to 17.3 dt/ha. Measuring the yearly amount of mineral elements received from litter-fall is one of significant intensity factors of the minor biological cycle. To a certain extent, elementary chemical compositions of the steppe ecosysytems under study are of a similar content. N, K and Ca are being dominant, and their levels in plant residues are 0.99-1.87%, 0.74-2.16% and 0.33-1.00%, respectively. Our study on macro- (N, K, Ca, Mg, P, Na) and microelements (Cu, Zn, Mn, Pb, Cd) levels in the plant samples of the steppe communities under study compared to concentration levels of the same elements in forage plants in terms of meeting animals’ need for these elements, showed the deficiency of P and Zn in almost every sample, and partial Mn and Mg deficiency. Ca levels are within normal range and slightly exceed the limits. The levels of highly toxic Pb and Cd heavy metals in the plants are within maximum permissible concentrations, due to protective barriers that prevent plants from accumulation of these elements. According to their biochemical parameters (protein, cellulose and water-soluble carbohydrates levels), the herbage of Mongolian and Buryat steppe plant communities have relatively sufficient forage value.

As primary decomposers of organic matter, microorganisms play a critical role in the accumulation and transformation of biogenic elements, as evidenced by the previous data about carbon isotopic composition of plants and soil of the ecosystems under study (Dambaev et al., 2016).

Limiting dilution culture in selective media enabled us to measure fungal abundance, as well as the levels of different ecological trophic groups of bacteria, such as saprophytic, proteolytic and cellulolytic in our plant samples, namely, in the living and dead aboveground phytomass, and roots of the steppe plants (Table 2).

Saprophytic bacteria turned to outnumber other microbial decomposers, and their levels in living aboveground phytomass of all plants under study are amounted to $10^5–10^7$ cells/g. There were from ten to hundred times as much of saprophytic bacteria in the dead plant material and roots, amounting to $10^6–10^8$ cells/g. Cellulolytic bacterial abundance in the plant residues of the communities under study was minor, with $10–10^3$ cells/g. Proteolytic bacteria counts in the plant samples ranged from $10^2$ to $10^6$ cells/g. Fungal abundance in the aboveground phytomass of the plant samples varied from $10^5$ to $10^7$ CFU/g.

The study of microbial abundance highlights certain consistency in their dispersal across all the plant communities. In terms of abundance, they fall into the following ascending order: living aboveground phytomass, dead aboveground phytomass, and roots. Lower bacterial and fungal counts in living aboveground phytomass can likely be explained by high phytoncide levels that are destructive to microorganisms. Roots and dead aboveground phytomass are the most favorable environment for microorganisms.

Degradation rate of plant litter is one of the
importance of parameters of destruction processes. Comparisons to literature addressed to rate measurement of plant residues degradation in steppes ecosystems (Striganova & Kozlovskaja, 1985; Grishkan, 1995; Belyakova, 1996; Buyantueva, 1999; Sandanova, 2007; Oorzhak, 1985; Grishkan, 1995; Belyakova, 1996; Buyantueva, 1999; Sandanova, 2007; Oorzhak, 2007) showed that degradation of plant residues in the Buryat and Mongolian steppes is a slower process.

Over a year, only from 22.1% to 29.7% of the plant residues underwent microbial degradation, amounting to 1.54–2.83 dt/ha. The reason for this is likely to be high content of decomposition-resistant grasses, as well as natural and climatic characteristics of the regions: low temperatures for a long annual period, average annual temperature below zero point, dry soil for long periods, and unequal distribution of precipitations throughout a year, are visibly inhibit microbial destruction rates.

Degradation intensity of the model (protein and cellulose) substrates were studied in the field in the Buryat steppe ecosystems of interest to understand how environmental factors influence the fermentation (protease and cellulase) capacity of microbial decomposers.

Protease and cellulase capacity of microorganisms has been observed to naturally be of an exponential kind. During cold periods, in winters and early springs, low temperatures and, consequently, low microbial metabolism results in moderate microbial destruction of model substrates. Degradation intensity was 0.0005–0.01% a day for protein, and 0.048–0.097 mg a day for cellulose. During spring and summer (first half) periods, from 0.020 to 0.160 % of protein, and from 0.05 to 0.16 mg of cellulose a day underwent degradation.

Summer (second half) and early fall show degradation of 0.05–0.32% of protein, and 0.05–0.46 mg of cellulose a day. Thus, the direction and rate of biological cycle of matter within Buryat steppe ecosystems under study are significantly determined by summer and early fall period, hydrothermic characteristics of which are most favorable for microbial activity.

The intensity of biological cycle is one of the most representative factors of an ecosystem’s stability. Studying the productivity of the aboveground phytomass and the processes of microbiological destruction enabled us to evaluate the rate and intensity of release of the food compounds accumulated in green plants in the Buryat and Mongolian steppe ecosystems. The total stock of chemical elements (N, P, Ca, Mg and K) involved in the biological cycles in the steppe ecosystems of Buryatia amounted from 6.478 to 10.130 kg/ha, and from 8.826 to 31.802 kg/ha in the Mongolian steppe. The chemistry of elements’ cycles in the ecosystems under study is of a nitrogen type.

Acknowledgements

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References


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