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SYSTEMATIC STUDY OF ARID TERRITORIES

Changes in Properties of Alas Soils in Central Yakutia Caused by Pasture Degradation

A. A. Danilova[a], P. P. Danilov[b], G. N. Savvinov[b], L. D. Gavrilyeva[b], A. A. Petrov[b], and G. A. Alekseev[b]

[a] *Institute of Soil Management and Chemicalization of Agriculture, Russian Academy of Agricultural Sciences, p/o box 356, Krasnoobsk, Novosibirsk oblast, 630501 Russia*

[b] *Institute of Applied Ecology of the North, Northeastern Federal University, ul. Lenina 1, Yakutsk, 677027 Russia*

e-mail: Danilova7alb@yandex.ru, DanPP@mail.ru

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Abstract—The biological properties of alas soils influenced by pasture degradation at a load of five to six livestock units per hectare have been studied. It has been shown that manure in the amount of about 2 t dry substance/ha per year under cryoarid conditions allows for the studied characteristics to be maintained in a 0–20-cm soil layer at the level of background values for alas soil. The stability of the microbial community established in degraded alas soils has been estimated.

Keywords: Central Yakutia, alas soils, biological properties, pasture degradation, permafrost

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INTRODUCTION

Livestock pasturing in wildlife grass ecosystems is necessary for their sustainable function. Excess or insufficient pasturing leads to the degradation of the ecosystem (Bazilevich and Semenyuk, 1983; Abaturov, 2006; Abaturov et al., 2008). It has been demonstrated that the pasture ecosystem can stably function in the central chernozem region under a load of 0.5 livestock units/ha (Bazilevich and Semenyuk, 1983) and in Eastern Mongolia, it can function under a load of 0.3 livestock units/ha (Abaturov et al., 2008). Taking into account the low productivity of the natural alas meadows in Central Yakutia, the limit pasture load should not exceed 0.5 livestock units/ha (Davydov, 1982). However, this load in the alas pastures adjacent to settlements significantly exceeds the recommended level. Naturally, the grass cover there is considerably damaged.

The problem of pasture degradation has been most widely studied from a geobotanical perspective, and the alas meadows of Central Yakutia are no exception (Gavrilyeva et al., 1998; Ivanov et al., 2004). The soil prospects associated with this issue are usually considered to be the unidirectional removal of elements from the ecosystem (Asner et al., 2004; Martinez and Zinck, 2004; Milne and Haynes, 2004; Kotenko, 2011; Merkusheva, 2012; etc.). However, the relevant literature provides convincing evidence that the contribution of pasturing animals to the matter turnover in these ecosystems should be taken into account (Bazilevich and Semenyuk, 1983; Abaturov and Kulakova, 2010). Correspondingly, the goal of this work was to clarify the role of grazing animal excrements in formation of the properties of cryoarid soils during pasture degradation.

MATERIALS AND METHODS

Alases are geomorphological structures only characteristic of cryolithozone. A specific ecosystem has established in the thermokarst hollow, which is represented by a set of biomes from marsh (lower hydrothermal zone) rangng from meadow (middle zone) and steppificated (upper zone) to a typical forest.

Low plant productivity in the Central Yakutian alases is associated with the continental cryoarid climate in this region. The annual precipitation reaches 247 mm, including 162 mm during May–September and 85 mm in October–April at an evaporation of 420–500 mm. The average annual temperature varies from –7 to –10°C, while summer temperatures frequently reach 30–35°C and the soil surface is warmed to 50°C. However, the close permafrost layer makes these soils the coldest in the Northern Hemisphere (*Alasnye ekosistemy*, 2005).

According to the aboveground phytomass stock, the productivity of these grass ecosystems in an undamaged state is close to that of the Tuva and Transbaikalian dry steppes (*Stepi...*, 2002).

We have examined two typical mature hollow thermokarst alases with different degrees of human impact localized to the Tyungyulyun terrace (the fifth above-floodplain terrace of the Lena River) in the northern part of the Lena–Amga interfluvial area. The coordinates of the considerably degraded Uolen alas are 62°33′24.3″ N, 130°54″01.4″ E and of the back-

Table 1. Content of organic matter in studied alas soils

Alas name and degree of degradation	Hydrothermal zone	Organic carbon, %		Carbon in aqueous extract, mg/kg	
		0–20 cm	20–40 cm	0–20 cm	20–40 cm
Uolen, degraded	Lower	1.73	1.02	529	53
	Middle	2.51	1.77	940	835
	Upper	1.32	0.83	384	400
Toburuon, background	Lower	4.04	2.95	460	325
	Middle	2.47	0.97	200	580
	Upper	5.58	1.00	534	110
0.95 confidence interval		0.9		100	

ground Toburuon alas, 62°28′29.7″ N, 130°56′40.5″ E. The grass of the background alas is used for hay making and animal grazing is limited, whereas the grass cover of the Uolen alas is damaged due to excess pasturing. With a recommended pasturing level of 0.5 livestock units/ha, pasturing in this alas reaches six livestock units. This is a typical situation for most Central Yakutian alases located in the vicinity of settlements.

The studies were conducted in 2009–2011 and involved all hydrothermal zones of alases. According to the classification (Elovskaya, 1987; Desyatkin, 2008), the soils of the lower zone are identified as permafrost sod–gley, soils of the middle zone are classified as permafrost meadow, and soils of the upper zone are identified as permafrost steppificated. The soils of the Uolen alas are additionally characterized as altered by human activity. All of the examined soils are salty (sod–chloride types) with water pH reaching 9.5.

The functional range of the soil microbial complex was assessed using a multisubstrate test, MST (Gorlenko and Kozhevin, 2005). This test estimates the activity of soil microbial complex according to the utilization intensity of various carbon sources, where the intensity is assessed by the color reaction with tetrazolium salts. A unified assessment of the utilization intensity allows one to apply multivariate statistics when analyzing the experimental data.

Colony-forming units (CFUs) were counted conventionally (*Metody...*, 1980); the rate of nitrification was assessed by composting under optimal hydrothermal conditions; nitrate nitrogen was assessed according to Grandval–Lajoux with modifications by Iodko and Sharkov (1994); and field assay of cellulose decomposition was assessed according to Mishustin and Petrova (1963).

RESULTS AND DISCUSSION

The pasture degradation, which was assessed according to botanical criteria as stage 3, significantly changed the botanical composition and productivity of the phytocenoses localized to the Uolen alas. The average phytomass stock over the vegetation period of 2010 in this alas was 0.31 t/ha for the lower zone, 1.29 t/ha for the middle one, and 0.25 t/ha for the upper zone, versus 1.50, 1.35, and 0.82 t/ha for the background alas, respectively. The productivity of these ecosystems considerably varies from year to year. According to the long-term observations, the average value varied in the following ranges: 0.1–0.42 t/ha in the upper zone, 0.5–0.75 t/ha in the middle one, and 0.75–1.63 t/ha in the lower zone for stage 3 degradation versus 0.5–1.0, 0.92–4.41, and 1.57–4.76 t/ha for stage 1 degradation, or background (Gavrilyeva, 2000).

A decrease in the influx of plant matter was accompanied by a natural decrease in the organic carbon (C_{org}) in soil. However, note that no decrease was observed in the mobile carbon content (the carbon of aqueous and salt extracts) (Table 1).

Microbial platings on standard nutrient media (meat peptone agar, starch ammonium agar, glucose agar, and Ashby medium) demonstrate medium and high enrichment of the 0–20 cm soil layer with microbial cells according to the scale of Zvyagintsev (1978), while the enrichment of the 20–40-cm layer is medium and low. Table 2 lists the microbial counts (CFUs) for a 30-fold diluted meat peptone agar medium. The counts obtained using this medium reflect the general patterns observed on the standard media. The counts for saprophytic microflora in the 0–20-cm soil layer from the middle and upper zones of the degraded alas do not yield to those for the background alas; however, an opposite pattern was observed in the 20–40-cm layer.

The metabolic activity of microbial complex was assessed according to MST using the sum of utilization intensity scores for all 23 used substrates.

The total activity in the 0–20-cm soil layer in the lower and upper zones did not significantly differ in the degraded and background alases. Moreover, the activity in the upper zone of degraded alas was somewhat higher as compared with the background one (Fig. 1). The main difference between these alases was observed in the 20–40-cm layer, where the soil micro-

Table 2. Microbial counts (CFU on diluted meat peptone agar) in alas soils

Alas name and degree of degradation	Hydrothermal zone	CFU in soil layer, million/g			
		0–10 cm	10–20 cm	20–30 cm	30–40 cm
Uolen, degraded	Lower	7.9	1.7	0.8	1.0
	Middle	13.9	3.1	1.6	1.3
	Upper	19.6	3.5	0.5	1.2
Toburuon, background	Lower	7.8	5.5	1.3	2.3
	Middle	6.4	3.2	2.8	1.5
	Upper	18.0	6.2	5.6	3.6
0.95 confidence interval		2		0.5	

Table 3. Changes in counts and activity of soil microbial complex during laboratory composting

Alas name and degree of degradation	Hydrothermal zone	Sum of MST scores		CFU, million/g		Specific activity	
		1*	2*	1*	2*	1*	2*
Uolen, degraded	Middle	62	19	10	1	6	17
	Upper	76	2	11	0.5	7	4.5
Toburuon, background	Middle	46	35	11	1.3	4	27
	Upper	72	50	19	1.8	4	28

1*, initial values and 2*, after composting.

bial activity was considerably lower in the degraded layer.

Thus, the microbial counts and activities in the 0–20-cm layer of the studied soils were almost independent of the degree of grass degradation. This conclusion is rather unexpected, since it would be logical to expect that soil biological activity will also decrease with the observed decrease in the plant matter that enters the soil. Presumably, this fact is associated with the content of the major nutrient source for microorganisms, the mobile organic fractions (carbon of aqueous and salt extracts), which was almost independent of the degree of alas degradation (Table 1).

Thus, the pasture degradation was accompanied by a decrease in the thickness of the biologically active layer in alas soils. Note that neither microbial counts nor microbial activity in the 0–20-cm layer depended on the degree of alas degradation. Our next task was to assess the functional stability of the system thus formed. For this purpose, we determined the degree of decrease in the characteristics of soil biological activity and the accumulation rate of nitrate nitrogen during soil composting in laboratory experiments. Soil samples were incubated for 3 weeks under optimal temperature and moisture conditions. The initial assumption was that, during composting, the soil would lose part of the readily accessible organic matter, such that the residual activity would allow us to assess the degree of stability of the living soil phase.

Indeed, composting resulted in a decrease in the microbial counts and activity. However, the specific activity of microbiota (ratio of the total activity scores to CFU counts) mainly increased. This parameter was higher in the background alas soils compared to the degraded alas, i.e., the functional range of the microbial complex in the degraded alas has turned out to be less stable compared to the background alas (Table 3).

The rate of autotrophic nitrification in soil under laboratory conditions (Fig. 2) was used as an additional criterion for assessing the stability of the examined objects. It is known that nitrification activity in an equilibrium system is usually inhibited, and the authors believe that its intensification suggests the impaired balance of matter in soil (Aristovskaya, 1988; Kurakov, 2004).

Our data suggest that the rate of nitrate nitrogen generation in the 0–20-cm layer in the degraded alas was considerably (up to threefold) higher compared to the background. Note that the absolute value of this parameter in the former reached the level of Western Siberian plowed chernozem. Taking into account that the organic matter content in the alas soils is considerably lower, the intensity of nitrification per unit organic carbon content in the alas soil considerably exceeded that in the chernozems. Thus, we may state that the rate of decomposition of organic matter in the degraded alas soil under optimal conditions can reach a considerable level that endangers the stability of the ecosystem.

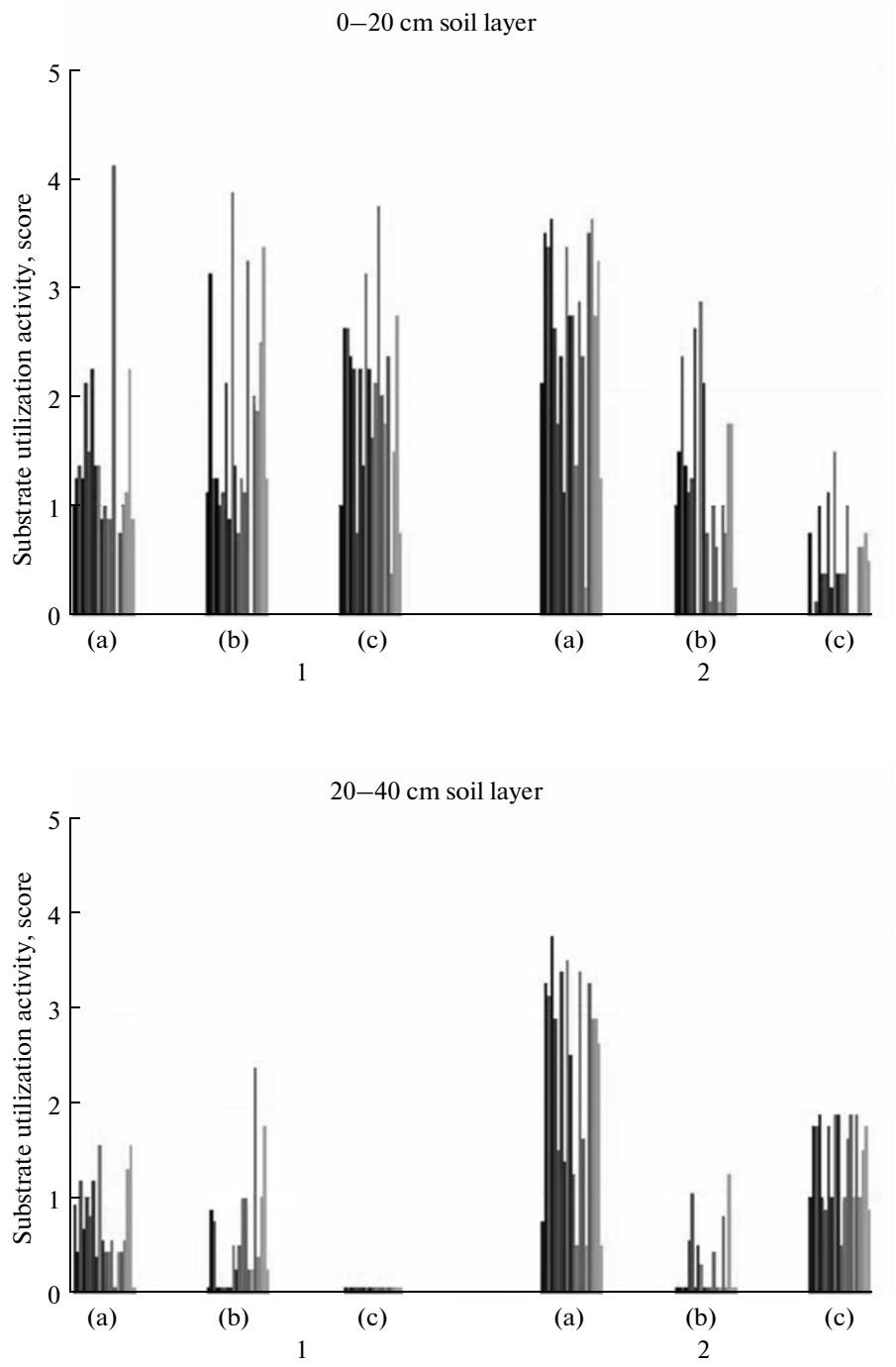

Fig. 1. Metabolic activity of soil microbial community in (a) lower, (b) middle, and (c) upper hydrothermal zones of degraded (Uolen) and intact (Toburuon) alases: (1) degraded and (2) background alases.

This inference made based on laboratory observations was confirmed by field studies. In particular, the decomposition rate of flax linen under field conditions observed for 1 year was threefold higher in the degraded alas soil compared with the background level (Table 4). Thus, a three- to fivefold decrease in the aboveground phytomass production in the examined alas ecosystems caused by excess pasturing and the consequent decrease in the plant matter entering the soil was not accompanied by a decrease in biogenicity of the 0–20-cm soil layer. When searching for the reason for this, we preliminary calculated the approximate amount of manure entering the soil. It has emerged that this value may reach 12 t fresh weight/ha or 2.0–2.5 t air-dry weight (average daily excrement production is 40 kg per livestock unit. On average,

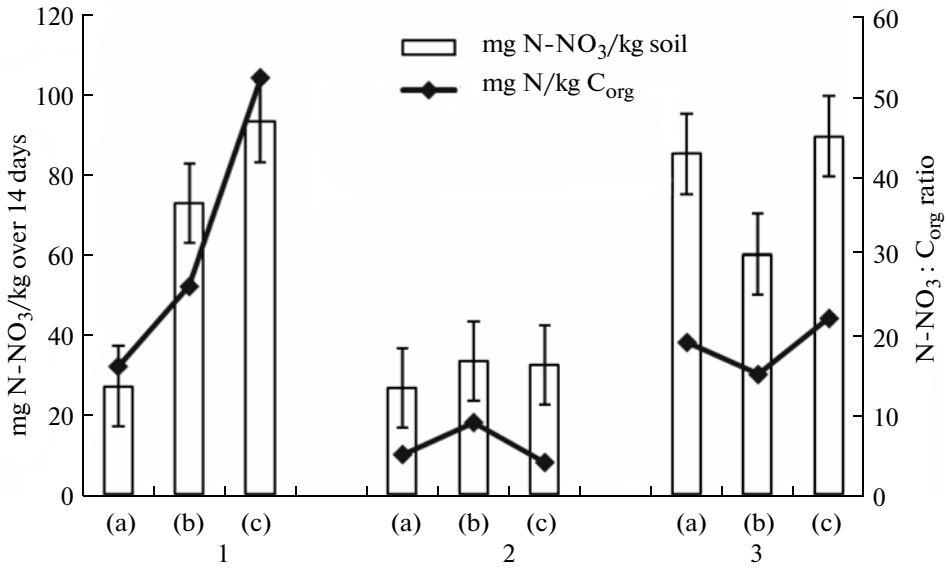

Fig. 2. Absolute and relative nitrification intensity in alas soils and Western Siberian chernozem (according to catena) in (a) lower, (b) middle, and (c) upper hydrothermal zones: (1) degraded alas; (2) background alas; and (3) chernozem (vertical bars denote 0.95 confidence interval).

150 livestock units are pastured, pasturing season is 100 days, pasturing time is 12 h/day, and pasturing area is 24 ha). Taking into account that, on average, the phytomass stock in the background alas is close to 1.5–2 t fresh weight/ha, the calculated value of dry manure biomass that enters soil of the pasture is comparable to the aboveground biomass production on the undamaged alas. Consequently, this amount of manure may be able to compensate for a significant loss in the plant waste caused by a decrease in productivity of the degraded alas. This suggests that a considerable amount of fresh manure entering the soils of degraded Uolen alas is a particular factor that allows the biological properties of the soil to be maintained at a level that is not inferior to that of the background Toburuon alas. However, the functioning stability of the formed system has turned out to be considerably lower compared to the control.

Thus, the degradation of the grass cover of the alas due to excess pasturing and the replacement of plant waste carbon that enters the ecosystem via manure carbon under the specific cryoarid conditions of Central Yakutia enhance the establishment of a special fraction of organic matter that maintains the population and activity of soil microbiota at a level equal to that of the background alases. When the soil humidity and temperature were experimentally adjusted to optimal values, this fraction rapidly degraded and all studied characteristics of the potential biological activity of the soil decreased at least tenfold as compared with the initial levels, which suggests a high potential sensitivity of degraded alas ecosystems to changes in climatic parameters.

According to our data, this instability was associated with excess intensification of organic matter decomposition in the degraded alas soils, as is demonstrated by a threefold increase in the nitrification and decomposition rates of cellulose-containing material under field conditions compared with the background variant.

Table 4. Intensity of decomposition of cellulose-containing material in alas soils during 1 year, August 2010–July 2011 (loss in linen weight, % of initial value)

Alas hydrothermal zone	Uolen alas, degraded	Toburuon alas, background
Lower	27	18
Middle	39	14
Upper	33	11
0.95 confidence interval, $n = 5$	8	

Our experimental data once again confirm and supplement the known concept of integrity of plant and animal components of pastures. According to these views, under arid conditions unfavorable for common saprophages (microorganisms and invertebrates), grazing animals take on the role of the latter, in particular by mobilizing the nitrogen fixed in plant biomass (Abaturov and Kulakova, 2010). Under cryoarid conditions (dry and cold), this phenomenon is likely to be even more significant. Our studies rather distinctly demonstrate the role of animals in intensifying the mineralization processes in the ecosystem. The manure added to ecosystem decomposes extremely slowly, forming the stock of a special mobile fraction in the soil organic matter. The role of this fraction should be considered from at least two points of view. On one hand, being an accessible nutrient source, it is a kind of the buffer that prevents a drastic decrease in the biological activity of the soil with a considerable reduction in the plant matter entering the soil. On the other hand, lability determines its extreme instability towards the changes in environmental conditions. This is fraught with danger of a rapid degradation of the alas soils at late stages of pasture degradation against a background of the known trend of warming and increase in the humidity in high latitudes.

Note that the probability of our prediction coming true is rather high, since the current field observations already record a higher rate of organic matter decomposition in degraded alas compared with the background.

CONCLUSIONS

The counts (CFUs) and metabolic activity of the microbial community in the upper (0–20 cm) layer of alas soils do not depend on the degree of degradation of the grass cover at a pasturing load of six livestock units per hectare, which is associated with the fact that manure enters the degraded alas ecosystem in amounts comparable to the productivity of background alas (about 2 t fresh weight/ha).

Soil composting under optimal temperature and humidity conditions is accompanied by a decrease in the studied characteristics in the background alas by up to 30% and, in a degraded soil, by up to 90% relative to the initial values, thereby demonstrating the low ecological stability of the soil microbial complex in the degraded alas soils compared with the background alas.

Pasture degradation is accompanied by the approximately threefold intensification of organic matter decomposition (nitrification and decomposition of flax linen) in alas soils compared with undamaged alas.

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