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Microbial characteristics of soils depending on the human impact on archaeological sites in the Northern Caucasus

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ABSTRACT

Anthropogenic impact in prehistoric settlements results in a considerable alteration of soil microbial communities depending on intensity and the character of human activities. This paper present a case study from a Late Bronze Age settlement located in the high-mountain part of the North Caucasus (Russia). The site represents a community, which presumably specialized in intensive livestock herding. Samples from settlement soils anthropogenically affected in the past and unmodified background soils were taken and studied. Of particular interest were divergences in soil microbial communities, expected to indicate different activities and animal presence in the site. The total microbial biomass, their respiratory activity, the biomass of fungal mycelium and the proportion of dark-colored hyphae were determined, as well as the quantitative state of keratinophilic fungi.

The microbial characteristics vary considerably within the settlement locations, and contrast sharply with the reference soils exterior to the archaeological site. The cultural layer has higher percentage of active metabolizing microorganisms, whereas the total microbiological biomass is considerably lower than in the unmodified soils from the surroundings. A determining factor to transform the respiratory activity of microorganisms, in both qualitative and quantitative aspects, is the composition of the organic material which has been accumulated in the ground as a result of various human activities in the past. The cultural layers contain microorganisms, which can be reactivated when glucose is added. In the anthropogenically unmodified soils surrounding the prehistoric settlement, in contrast, 97% of the cells cannot be reactivated. Based on the mycological characteristics of the studied cultural layers and unmodified soils, in particular with regard to the total biomass of fungi mycelium, the dark pigmented fungal biomass, and the existence of keratin-decomposing soil fungi, detailed information about activity areas and their specific usage is given. The use of bio-indicators allows not only diagnosing anthropogenic impact in soils as such, but also significantly complements description of cultural layers of activity areas in the settlement, specifying their purpose. The paper presents the microbiological analyses applied and, moreover, discusses the potential of this approach as a non-destructive prospecting method on archaeological sites.

1. Introduction

Soil studies within archaeological sites have a long history, but most of them are concerned with general aspects of soil chemistry, in particular pH-variation, microelement studies, or micromorphology (e.g. Limbrey, 1975; Middleton and Price, 1996; Holliday and Gartner, 2007; Thiemeyer, 2009; Nicosia et al., 2011). In recent years, however, soil studies related to archaeological projects in Russia have introduced a microbiological perspective to the investigation of paleosols and sediments that had been anthropogenically influenced (Demkina et al., 2000; Kashirskaya, 2006; Demkin et al., 2008; Khomutova et al., 2011). Similar perspectives have also been adopted in the Americas (e.g. Brockman et al., 1992; Grossman et al., 2010; Kim et al., 2010). Research on microbial communities in soils was already used in investigations

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on Pleistocene and Holocene soils and sediments, as well as in studies to reconstruct environmental dynamics in a long-term perspective (Zvyagintsev et al., 1985; Colwell, 1989; Khlebnikova et al., 1990; Friedmann, 1993; Rivkina et al., 2004; Gilichinsky et al., 2005; Bai et al., 2006; Lacelle et al., 2011). Most of these studies were situated in permafrost soils of the tundra, Arctic, or Antarctic. Another study sampled drill cores through sediments to 100 m depth. The present case study is based on samples from a high-mountain site in the North Caucasus (Russia), where equally favorable conditions of a moist and cool environment hold out the prospect of good preservation of microbiological soil components.

Table 1
Physico-chemical properties of the cultural layer and background soils in the analyzed depth of the soil trenches.

Soil samples	C_{org} %	$CaCO_3$	P_2O_5 mg/ 100 g soil	pH ($CaCl_2$)	Particle-size distribution [%]	
					0.002 - < 0.063 mm	<0.002 mm
ST – 6	2.3	1.4	2.0	6.5	21	48
ST – 7	2.2	1.5	1.3	6.3	19	32
ST – 8	2.9	3.1	1.9	7.0	18	29
ST – 9	4.9	2.8	2.7	6.8	25	44
ST – 1	5.8	2.4	2.4	6.9	23	39
ST – 3	3.7	2.4	2.3	7.1	25	40
ST – 4	5.9	2.4	5.3	6.7	27	43
ST – 5	4.5	1.5	4.7	6.6	24	46
ST – 13	3.1	2.0	3.8	6.8	25	45
ST – 11	4.3	3.1	2.8	7.0	30	37
ST – 12	4.7	7.1	3.6	7.1	30	30
ST – 10	4.5	2.0	9.6	6.6	28	37
ST – 14	6.1	2.0	7.6	6.5	26	38
ST – 17 (0–20 cm)	5.0	1.5	6.6	5.5	28	40
ST – 17 (20–40 cm)	3.7	1.3	4.0	5.6	28	41
ST – 17 (40–60 cm)	3.7	1.1	4.0	5.7	28	40
ST – 17 (60–80 cm)	3.5	1.5	4.8	6.2	28	41

Table 2
Microbiological properties of the cultural layer and background soils in the analyzed depth of the soil trenches.

Soil samples	V_{bas}	V_{sir}	C_{act}	C_{mic}	C_{act}/C_{mic}	C_{mik}/C_{org}
	µg C*g-1 soil *h-1		µg*g-1 soil		%	
ST – 6	0.18	1.03	83.53	8356.47	1.00	36.33
ST – 7	0.34	2.01	163.39	5730.20	2.85	26.05
ST – 8	0.37	1.58	128.62	6200.17	2.07	21.38
ST – 9	0.33	2.82	229.03	3957.86	5.79	8.08
ST – 1	0.16	5.84	473.34	2330.66	20.31	4.02
ST – 3	0.32	2.99	242.81	3347.71	7.25	9.05
ST – 4	0.81	4.96	268.26	3177.26	8.44	5.39
ST – 5	0.37	4.29	347.73	3719.08	9.35	8.26
ST – 13	0.41	7.91	640.65	2886.77	22.19	9.31
ST – 11	0.11	3.27	264.86	3808.62	6.95	8.86
ST – 12	0.05	3.43	277.96	2520.82	11.03	5.36
ST – 10	0.53	6.43	520.86	3728.83	13.97	8.29
ST – 14	0.29	7.43	601.89	3097.61	19.43	5.08
ST – 17 (0–20 cm)	0.87	10.54	853.98	6224.19	13.72	12.45
ST – 17 (20–40 cm)	0.67	4.92	398.43	5785.60	6.89	15.64
ST – 17 (40–60 cm)	0.52	1.75	141.72	5628.18	2.52	15.21
ST – 17 (60–80 cm)	0.68	3.40	275.36	3671.43	7.50	10.49

Table 3
Microbiological parameters and organic carbon content of background soils in comparison to settlement soils and soils near settlement.

Soil samples	Corg [%]	C_{mic}/Corg [%]	C_{act}/C_{mic} [%]
Reference soils	2.4	27.2	1.8
Soil near settlement	4.9	8.1	5.8
Settlement soils	4.5	7.1	11.5

During the last decade, the study of microbial communities in paleosols was transferred by Russian soil scientists to research on archaeological monuments. Especially, soils buried under burial mounds have been investigated (Demkina et al., 2000, 2004, 2007, 2010a, 2010b; Khomutova et al., 2004, 2011; Kashirskaya et al., 2009, 2010). Demkin (1997) has pointed out that paleosols retain some of their characteristics after being buried. They depend on the degree of conservation, which is, among other factors, reflected by the microbial characteristics (Demkina et al., 2007).

Most of the cited studies focus on chronological and spatial variability of microbial soil characteristics, and discuss them within the framework of paleoclimate studies. As a dynamic integrated soil component, microbial communities are highly sensitive to changes of the environment. Concurrently, soil microorganisms manage to survive under adverse environmental conditions such as lack of nutrition or other unfavorable settings. They retreat into a dormant state and thus survive indefinitely long periods of time (Xu et al., 1982; Roszak and Colwell, 1987; Demkina et al., 2000, 2008; Khomutova et al., 2007). It is this factor which allows the use of microbiological methods in archaeopedological investigations. The characteristics of microbial soil communities do not only reflect the conditions of soil formation, i.e. the paleoecological perspective. They are also precise indicators of anthropogenic impact during soil formation in an ancient settlement. Based on the fact that microbial communities react specifically to the input of nutrients in the form of organic substances into soil, variations of quantitative and qualitative aspects can be expected depending on the intensity and mode of human activities in the past. It is most likely that the anthropogenic factor is the crucial one in soil formation within a settlement during its formation and use. It will therefore have a considerable impact on soil microbiological properties. When superimposed by layers of non-anthropogenic soil formation, we suggest that the characteristics of microbial communities in prehistoric cultural layers are preserved. They form a kind of archive both of environmental and anthropogenic conditions during the period of their formation. Their variation in layers of a similar age can be taken as a spatial indicator for activity areas, adding very precise statements about the nature of activities in the past.

Bioindication as a new aspect in archaeopedology, however, opens a wide-ranging perspective to study human activities in the past. To date, mycological features have been shown as most promising sources of information (Marfenina et al., 2003). Fungi are highly sensitive to environmental variations, and in specific conditions form physiologically and structurally characteristic communities (Ivanova et al., 2006).

Marfenina et al. (2001) presented a study of mycological characteristics of cultural layers from settlements. Spatial variation in the presence of keratin-decomposing fungi in sediments of streets, living-floors in and outside houses, or from wall-fillings revealed differences in the activities and the intensity of anthropogenic impact (Ivanova et al., 2006). These fungi utilize keratin, a very resistant protein in human and animal fibers (epidermis, hoof and horn material, fur, hair and feathers) as the sole source of C, N, S, and energy (Korniłłowicz-Kowalska and Bohacz, 2011). Keratinolytic fungi intensively degrade native keratin, and are represented