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Spatial variability of soil properties in the floodplain of a river oasis in the Mongolian Altay Mountains

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ABSTRACT

In Mongolia, recent national policy pushed for the expansion and intensification of land use for crop and forage production, which may adversely affect soil quality of river oases. A better understanding of the small-scale variation of soil properties and the driving factors of soil quality are important for developing and refining site-specific agricultural management practices and for maintaining soil fertility. The current study hypothesized that spatial variability structure of ancient sedimentary processes override the actual variation of soil properties caused by land-use and environmental effects. The objectives were (i) to determine the small-scale variability of major topsoil properties within an exemplary river oasis in Western Mongolia, (ii) to assess the spatial structure of this variability (heterogeneity), and (iii) to identify factors driving the heterogeneity of soil biological properties. Within a four ha plot, 130 topsoil samples were collected in a constant 20 m grid and analyzed for major physico-chemical and microbial properties. The soil variability was assessed by descriptive statistics, the heterogeneity of properties by semivariogram model parameters, and heterogeneity driving factors by multiple linear regression analysis. Soil parameters showed a relatively high variability, particularly of $CaCO_3$-C and EC (86% and 163%, respectively). In contrast to that, both parameters showed a relatively low heterogeneity (nugget to sill ratio of ≥0.67) whereas most soil parameter were characterized by a moderate or strong spatial dependency (nugget to sill ratio down to 0.2 as for microbial biomass C) and by relatively low range values (down to 37 m as for ergosterol and microbial biomass C), respectively. This small-scale heterogeneity with relatively many small patches reflected inherent soil factors of the floodplain, which had a strong influence on soil properties as the extensive land use in the river oasis Bulgan Sum Center did not lead to a homogenization of the fluvial depositions. Besides the minor salinization, which had a positive effect on ergosterol and basal respiration, SOC determined biological soil properties. This underlines the significance of SOC to preserve the scarce and susceptible agro-ecological resources of the river oasis in Western Mongolia and likely many similar ones across Central Asia.

1. Introduction

Traditionally, land use in Mongolia was dominated by mobile animal husbandry while sedentary agriculture was of rather minor importance (Lkhagvadorj et al., 2013a, 2013b). However, recent national policies pushed for the expansion and intensification of land use for crop and forage production to foster food self-sufficiency and to alleviate livestock mortality, particularly during harsh winters (Priess et al., 2011, 2015). Given the easy access to water, the cultivation of crops and fodder in floodplains of river oases is of major importance to pursue this national campaign under the prevailing arid climate conditions. However, it leads to modifications in land cover and land use intensity.

In the Altay Mountains such regime shifts in the management of river oases were particularly large during the last five decades, reflecting changes in the economic structure (Dittrich et al., 2010; Goenster et al., 2017; Jordan et al., 2018) and likely stressing the scarce and susceptible agro-ecological resources of river oases (Hong et al., 2003; Liu and Chen, 2006). Indicated by soil microbial properties, Goenster et al. (2017) reported a possible negative impact of land modifications on soil quality in Bulgan Sum Center, a river oasis located in the foothills of the Mongolian Altay. In this context, Goenster et al. (2017) pointed to a high variability of soil microbial and physico-chemical properties and suggested their assessment at a high spatial resolution. This may allow a better understanding of the small-scale

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spatial variability of soil properties and the driving factors of soil quality. Such information is important for developing and refining site-specific agricultural management practices and for maintaining soil fertility in the river oases in the context of the national expansion and intensification strategy (Córdova et al., 2012; McGrath and Zhang, 2003; Zhang et al., 2014).

In the floodplain of Bulgan Sum Center, rangeland and irrigated agricultural land accounted for about two-third of the total land use and land cover in 2013 (Jordan et al., 2018). However, during the last two decades, both land use types were subjected to rapid fluctuations in spatial extension and land use intensification due to structural changes and natural disasters. During Mongolia's transition to market economy after the socialist period, the total livestock number and the total irrigated agricultural area rose by 90% and 240% from 1991 to 2008, while total yield ha^{-1} decreased by 38% (Goenster et al., 2017). After severe winter events (*dzud*) in 2009/2010, a decline in total livestock number and in total irrigated agricultural area by 36% and 54%, respectively, was observed until 2012. In contrast, crop production was intensified with a yield increase ha^{-1} by 20% (Goenster et al., 2017). Such changes in land use and management affect physico-chemical and biological soil properties. For instance, the soil carbon (C) to nitrogen (N) ratio (C/N ratio) and the soil organic carbon (SOC) concentrations were reported to decline with increasing management intensity, due to exposing previously inaccessible SOC to decomposition (Seeber and Seeber, 2005). Microbial biomass carbon (MBC) of meadow soils may increases with intensified grazing pressure (Banerjee et al., 2000; Wang et al., 2006) but declines after soil cultivation (Caldwell et al., 1999; Kandeler et al., 1999). Management intensification influences the soil microbial community, significantly reducing the biomass of saprotrophic fungi, measured as ergosterol in soil (Donnison et al., 2000). Irrigation alters salt and carbonate concentrations in soil, e.g. due to leaching effects.

Soil physico-chemical and biological properties are well known to vary at different scales (Bruland et al., 2006; Cambardella et al., 1994). For the characterization of soil property variations, a distinction can be made between variability, the value changes of a given soil property across space, and heterogeneity, the spatial distribution of variability with its pattern and scales (Ettema and Wardle, 2002). For the assessment of heterogeneity, geostatistical analyses based on semivariograms became popular as this method allows a reliable quantitative assessment of the spatial structure by considering autocorrelation (Ferreira et al., 2015; Reza et al., 2017; Rosemary et al., 2017). Semivariogram parameters such as nugget, sill, range and the nugget to sill ratio are helpful indicators for the characterization of spatial structures (Bruland et al., 2006; Kiliç et al., 2004; Wang et al., 2009).

The current study is based on the hypothesis that the spatial variability structure of sedimentary processes overrides the actual variation of soil properties caused by land-use and environmental effects. The specific objectives of this study were (i) to determine the small-scale variability of major physico-chemical and microbial topsoil properties within the floodplain of Bulgan Sum Center, (ii) to assess the spatial structure of this variability (i.e. heterogeneity), and (iii) to identify factors, which drive the heterogeneity of soil biological properties.

2. Material and methods

2.1. Study site and sampling design

Soil samples were taken in the river oasis of Bulgan Sum Center located in the western foothills of the Altay Mountains, Khovd Province, western Mongolia (Fig. 1ab). The river oasis is subjected to a harsh continental climate characterized by an air temperature amplitude of 41.6 K (average monthly air temperature ranged from −20.6 °C in January to 21.0 °C in July) and a rainfall maximum during the summer period from May to September (two-third of the annual rainfall

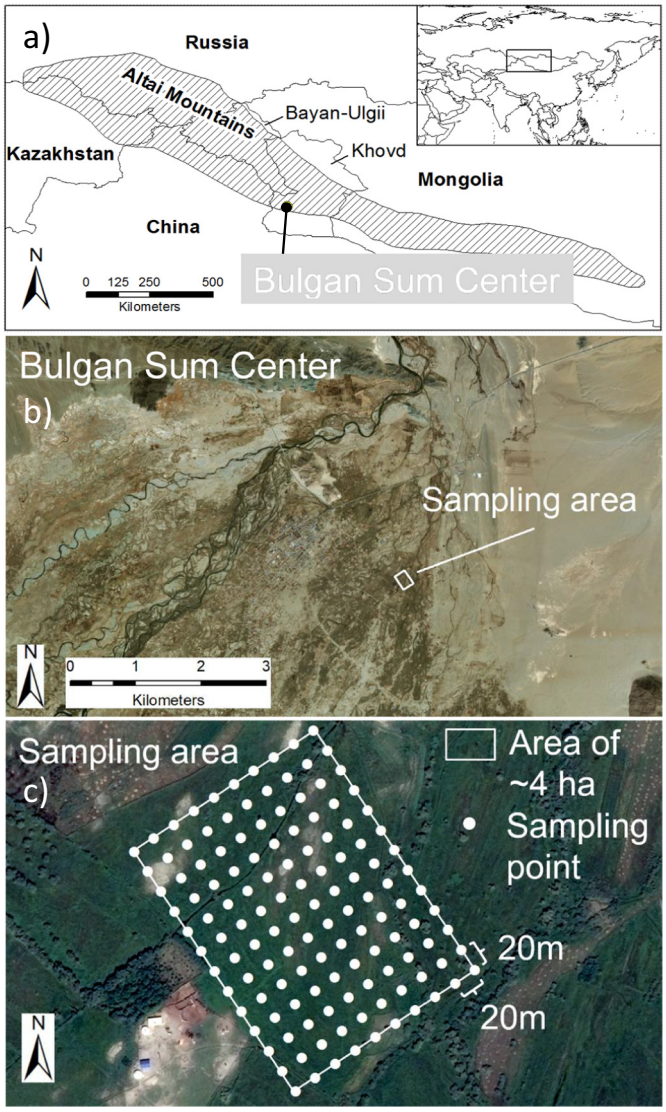

Fig. 1. Location of the sampling area in Bulgan Sum Center, Western Mongolia, at a regional (a) to local scale (b and c).

amount). During the year of study (2013), average air temperature (4.2 °C) was higher and average annual rainfall amount (47.9 mm) was lower than the long-term average (2.5 °C and 75.4 mm, respectively; 1963–2014, Baitag weather station, WMO code 44265, 46.094 N, 91.552 E, 1186 m.a.s.l.). Given the climatic conditions, land use in the floodplain and the hinterland of Bulgan Sum Center is dominated by mountain transhumance systems with seasonally migrating herds (Jordan et al., 2016). Additionally, land use in the floodplain of the river oasis is characterized by small-scale cultivation of crops and particularly hay, which depends largely on water drawn from the Bulgan River and groundwater wells (Goenster et al., 2017; Jordan et al., 2016; Jordan et al., 2018). According to the FAO World Reference Base for Soil Resources, soils of the floodplain are predominantly classified as Fluvisols (IUSS Working Group WRB, 2015). The topsoil (0 to 10 cm) texture of the Fluvisols was dominated by sand and silt, whereas values varied considerably within the floodplain (sand = 45%, CV = 37%; silt = 43, CV = 32%; clay = 12%, CV = 38%; n = 210). SOC concentration varied around a mean of 1.5% with a CV of 45% (n = 210).

The sampling design was dense (= low distance between sampling points), systematic and non-randomized that is 130 topsoil samples were taken in a constant 20 m grid within an area of about 4 ha located