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Factors controlling mineralization of soil organic matter in the Eurasian steppe

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Abstract

To understand the dynamics of soil organic matter (SOM) in the Eurasian steppe, several soil and meteorological properties were tested in order to estimate the amounts of potentially mineralizable organic carbon (PMC) and nitrogen (PMN). Total 41 surface soil samples were collected in Ukraine and Kazakhstan from cropland, forest, grassland, and desert ecosystems. The fresh soils were incubated for 133 days under constant temperature and moisture conditions, and the CO_2 emissions and the mineral N from the soils were monitored. PMC and PMN were determined by fitting models to the cumulative curves of the CO_2 and the mineral N. Tested soil properties included soil pH, sand, silt and clay contents, carbon and nitrogen contents of light fraction (LF, $<1.6\,g\,cm^{-3}$) and heavy fraction (HF), and C/N ratio of LF and HF. The meteorological properties considered were mean annual temperature and precipitation. Using multiple regression analysis with the stepwise method, PMC was well estimated by carbon content of LF (LFC) and clay content, compared to the simple correlation with organic carbon (OC). Similarly, PMN was better determined by nitrogen content of LF (LFN) and clay content. These results suggest the partially labile nature of clay-associating OM and of LFC and LFN. The higher PMC and PMN in the forest and grassland sites would be attributed to the higher LFC and LFN, while the lower LFC and LFN in cropland sites would suggest the relatively higher contribution of clay-associating OM to PMC and PMN.

Keywords: Potentially mineralizable carbon; Potentially mineralizable nitrogen; Light fraction; Heavy fraction; Clay; Principal component analysis; Multiple regression analysis

1. Introduction

The dynamics of soil organic matter (SOM) have been widely studied in global terrestrial ecosystems because of the vast SOM stock in soil, which is almost double the atmospheric carbon stock and triple the terrestrial plant carbon stock. Smith et al. (1997) tested several models for simulating the long-term dynamics of SOM and discussed the advantages and disadvantages for each model. Some of the models (e.g. the CENTURY and RothC models) showed good performance in simulating the SOM dynamics under various conditions. Since SOM is conceptually separated into several pools by different turnover rates in most of the models, one of the limitations of this approach is the lack of experimental determination of the pools (Christensen, 1996; Elliott et al., 1996).

Among the SOM fractions with a wide range of turnover rates, potentially mineralizable organic matter (OM) has been studied extensively, because it varies widely depending on land use or agricultural management (e.g. Bonde et al., 1988). Potentially mineralizable organic carbon (PMC) indicates the total metabolic activity of heterotrophic microbes releasing labile organic carbon (OC) as CO_2, while potentially mineralizable nitrogen (PMN) has been used for many years as an indicator of the N fertility of soils and their ability to supply N for crop growth (Haynes, 2005). In terms of methodology, Stanford and Smith (1972) measured inorganic N mineralized during a 24-week incubation period and introduced first order kinetics to

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estimate the amount of PMN. Since the long-term incubation method is time consuming and labor intensive (Qafoku et al., 2001), the content of potentially mineralizable OM in soils has, to date, been related to many other soil properties including total SOM (Zak et al., 1993), water-soluble OM (Stanford and Smith, 1972; Curtin and Wen, 1999), light fraction (LF) of OM (Sollins et al., 1984; Curtin and Wen, 1999; Funakawa et al., 2006), microbial biomass (van Veen et al., 1984; Bonde et al., 1988), pH and CEC (van Veen and Kuikman,1990; Schrawat, 1983). However, because of the complex interactions amongst these factors, regional and macroclimatic influences on potentially mineralizable OM are not yet well understood (Franzluebbers et al., 2001).

The ultimate goals of the present study were (i) to determine the factors controlling potentially mineralizable OM, and (ii) to offer a simple process-based model with measurable SOM pools that describe SOM dynamics. In this work, we tested soil samples from the Eurasian steppe, which is one of the most important areas for food production and environmental security in the world, in efforts to reveal the relationship between potentially mineralizable OM, soil and meteorological properties.

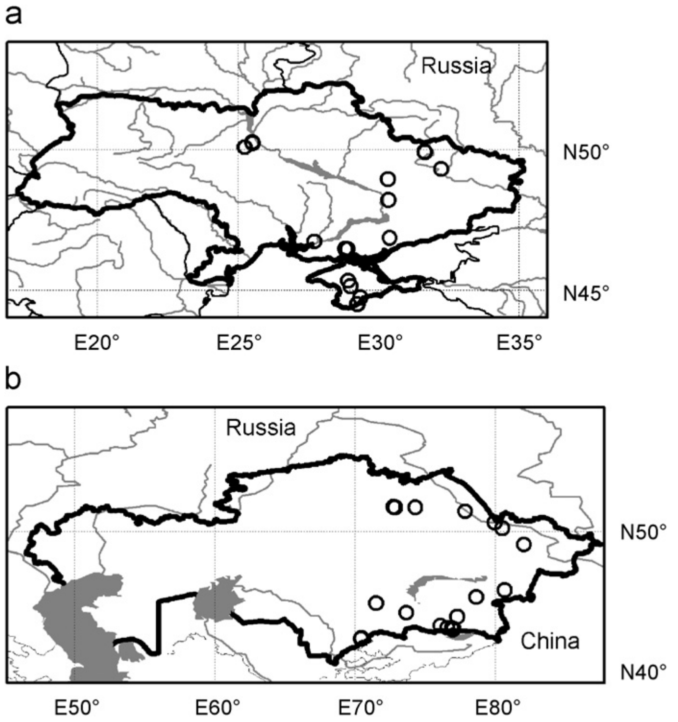

Fig. 1. Locations of sampling sites (◦) in Ukraine (a) and in Kazakhstan (b).

2. Materials and methods

2.1. Sample description

A total of 41 mineral surface soil samples were collected from Ukraine in May 2000 and from Kazakhstan in September–October 2000, covering a range of climatic conditions and land use (Fig. 1). Each soil sample was collected as a composite of five 0–10 cm sub-samples.

Mean annual precipitation (MAP) and temperature (MAT) for each sampling site were estimated from their adjacent meteorological stations (Peterson and Vose, 1997). According to the US Soil Taxonomy (Soil Survey Staff, 1998), soil temperature regime (STR) and soil moisture regime (SMR) were determined from the meteorological station data. The sites in Ukraine were classified as having a mesic temperature regime and ustic or xeric moisture regime. In Kazakhstan, most of the sites in northern region had a frigid STR while the other regions were mostly mesic. Though several xeric and udic sites were included in the southern mountain area, most parts of our sites had an aridic SMR.

The sampling sites were categorized into four ecosystems: cropland ($N = 12$), forest ($N = 6$), grassland ($N = 21$) and desert ($N = 2$). In the cropland sites, the vegetation included wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), sugar beat (*Beta vulgaris*), sunflower (*Helianthus annus*), maize (*Zea mays*), oat (*Avena sativa*), alfalfa (*Medicago sativa*) and sweet cherry (*Prunus avium*). For the forest ecosystem, natural forest included mixtures of oak (*Quercus robur*), maple (*Acer platanoides*) and elm (*Ulmus laevis*) trees and of oak, pine (*Pinus sylvestris*) and juniper (*Juniperus communis*) trees, while secondary forest included locust (*Robinia pseudoacacia*), spruce (*Picea abies*) and pine trees. The grassland ecosystem included natural steppe and pasture. The natural steppe vegetation mainly consisted of fescue grasses (*Festuca sulcata, F. valesiaca*), feather grasses (*Stipa lessingiana*, *S. ucrainica* and *S. capillata*), couch grass (*Agropyron repens*) and *Artemisia* spp. The desert ecosystem had sparse vegetation, with only a few species such as *Ephedra* spp.

Each soil sample was sieved to 2 mm. A portion was stored in a refrigerator for analysis of PMC and PMN, and the remainder was air-dried for chemical analysis.

2.2. Potentially mineralizable OC

An amount of 20 g aliquots of fresh soil, adjusted to a moisture content of 60% water holding capacity (Tanaka et al., 1998), were incubated at 30 °C in sealed plastic bottles with 1 M NaOH (Anderson, 1982) in duplicate. The amount of CO_2 trapped in the alkali solution was measured by titration after 7, 35, 63, and 133 days. PMC was calculated by fitting the amounts of CO_2 released to the best of the following two equations:

$$Ct = \mathrm{PMC}^{*}(1 - \exp(-k_{\mathrm{C}}t)),$$

$$Ct = \mathrm{PMC}^{*}\exp(-\exp(-k_{\mathrm{C}}(t - t_0))),$$

where Ct (mg C kg^{-1}) is cumulative CO_2 released in time t (day), PMC (mg C kg^{-1}) is potentially mineralizable organic C, k_{C} (day^{-1}) is the rate constant, and t_0 (day) is the time when C equals $1/e$ of the PMC. The former equation is a simple first-order kinetics model, while the