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Soils response to the land use and soil climatic gradients at ecosystem scale: Mineralogical and geochemical data

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ABSTRACT

Ecosystem in responses to land use change create feedbacks in soils and ecological processes in Critical Zone (CZ). The identification and quantification of such changes is needed as a part of understanding the relationship between climate, CO_2 emission, humidity, biological activity, soil carbon, surface redox, and plant nutrient cycling and lithology, mineralogy, biogeochemistry of bedrocks. The CZ observation as complex investigation of three Luvic Phaezoem soils under secondary deciduous forest, grassland and cropland from Moscow region, Russia, was fulfilled with the main goal to study weathering processes in soils along global gradients of environmental change. Detailed study of mineralogy and chemistry (XRD, XRF), surface area, porosity, organic matter, carbon/microbial biomass, moisture content, monitoring of total soil respiration was performed. Ecosystem in responses to land use change the parameters of CZ (CO_2 emission, humidity, biological activity). Land use change result in climate parameter on a local scale (soil climatic gradients) and formed feedback in weathering intensity and basic soil properties-organic matter, acidity, bulk density, WHC, surface properties and porosity, mineralogy and geochemical changes. The decreasing of smectites in the upper parts of the profile and the increasing of illite and vermiculite content was observed. Montmorillonite into vermiculite transformation, which took place only under the forest, which caused the decreasing of pH, soil vermiculite may also derive from muscovite. The intensity of the given process increases as the following: forest soil < grassland < cropland. The given tendency was explained by both the mineral transformations and redistribution of mineral components within the soil profile. The redistribution of chemical elements between the different sub-fractions of silt and clay is in relationship to the land use. As a general trend, we can conclude that clay fractions in a comparison with bulk soil samples are enriched in both OC and N. Mineralogical and chemical changes influenced the surface properties and porosity. The 50–150 years of different land use resulted in these feedbacks with maximum in aboveground zone and soils as main point of surface of a given CZ.

1. Introduction

The beginning of 21th century outlined a new interdisciplinary study, a science of Earth's 'Critical Zone', as the integrated and life-supporting system of Earth's surficial terrestrial processes. "Critical Zone" (CZ) is defined as the, "heterogeneous, near-surface environment in which complex interactions involving rock, soil, water, air, and living organisms regulate the natural habitat and determine the availability of life-sustaining resources" (National Research Council (NRC, 2001)). The theoretical base of CZ is growing from the concept of the 'Biosphere' (Vernadsky, 1929, 1998). Biosphere includes the hydrosphere, troposphere, and the upper part of the Earth's crust and the constant exchange of matter and energy between the living and inorganic matter supports the existence of the biosphere. The CZ, in particular Earth's surface and soil, is a product of multiple environmental factors that have varied over time (Richter and Yaalon, 2012). CZ responds to climatic and anthropogenic forcings, and quantifying and modeling the paleo and modern CZ is a central challenge for achieving a sustainable environment (Brantley et al., 2007). Soil is at the central junction of the CZ, representing a geomembrane across which water, energy, gases, solids, and organisms are actively exchanged with the atmosphere, biosphere, hydrosphere, and lithosphere, thereby creating a life-sustaining environment (Amundson et al., 2007; Brantley et al., 2007; Chorover et al., 2007; Lin, 2010). In contrast to the other spheres of the Earth system, the pedosphere is a unique, relatively immobile sphere that is easily impacted by human activities. Each soil is relatively immovable and formed in situ as a natural body, which records environmental changes by transformations according to the interactions of

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climatic, biotic, and anthropogenic factors, as conditioned by geologic and topographic settings, over geological and biological time scales. We have taken in to account since the soils can be transformed or to be lost by the anthropogenic action, as land use and other. Because of the uncertainty in how soil ecosystems will change under altered climate scenarios, and the potential for large-scale disruption of important soil processes resulting from altered precipitation, temperature and elevated CO_2, research is needed to evaluate the potential for dramatic shifts. Climate change has the potential to alter soil ecosystem structure and function in non-linear ways, particularly in high-latitude ecosystems. Land use change can result in the emissions of greenhouse gases that may result in a positive feedback loop to climate change by increasing flux of CO_2 to the atmosphere. Climate change also affects the productivity of land, which in turn leads to further land-use change. Soil can also influence climate on a smaller scale (soil climatic gradients), soils that are wetter or denser hold heat and stabilize the surroundings from temperature changes more so than drier, looser soils. This makes the monitoring of soil change an excellent environmental assessment, because every block of soil is a timed “memory” of the past and present biosphere-geosphere dynamics (Arnold et al., 1990). A growing world-wide international network of CZ Observatories (CZOs) enables experiments across global, regional, and local environmental gradients, providing the scientific base for the understanding of the CZ processes with response to the land use and climate change (Banwart et al., 2011).

In this paper, we emphasize the importance of CZ at ecosystem scale, as local environmental gradients, and focus on their effect on mineralogical and geochemical changes in soils profiles. The complex investigation of three Luvic Phaezoem soils under secondary deciduous forest, grassland and cropland from Moscow region, Russia, were fulfilled with the main goal to study the state of solid phases of soils along global gradients of environmental change: land use and climate. This study was a part of the ISTC Project No. 4028 “Quantification of carbon stocks and pollution loads in northern latitude soils: assessment of potential release resulting from climate change” (2010–2012).

2. Materials and methods

The experimental plots are located in the territory of the Experimental station of the Institute of Physico-chemical and Biological Problems in Soil Science, Russian Academy of Sciences (54°50′N, 37o34′E, ~100 km to the south of Moscow) on a clay grey forest soil, Luvic Phaezoem (loamy). Some physico-chemical characteristics of the surface A1 horizon of the three soils are given in Table 1.

The catchment area is 0.5 km^2, on a watershed with a mean elevation of 230 m above sea level (Fig.1). The climate is humid continental; average annual temperature varies from +3.5 to +5.5 °C and average annual rainfall is within 450–650 mm. The investigations were conducted in situ over three years (2010–2012) in soils under secondary mixed forest (age 150–200 years), grassland (last 45 years; cereal herbs) and cropland (~50 last years, cereal-fallow rotation). The weekly monitoring of CO_2 emission, soil and air temperatures, soil moisture was carried out in all three ecosystems. The total soil respiration (root respiration + heterotrophic soil respiration) without the above ground plant respiration was determined by a close chamber method (Kurganova et al., 2011). The data for total soil respiration were taken between 9 and 11 a.m. because soil respiration at this time of the day corresponds to an average daily rate. On average, 5–10 replicates were taken during the growing season and 3 in winter. The measurements of soil moisture and temperature in the upper 0–5 cm soil layer as well as meteorological data (air temperature and humidity, wind speed, precipitation, etc.) were registered each time.

The soil samples were taken from each profile in 3 replicates in 10 cm increments (layer 0–50 cm) and in 25 cm increments (layer 50–100 cm) and from the genetic horizons of soils for mineralogical and geochemical investigations. The most part of analysis were made for

Table 1
General characteristic of Luvic Phaeozems soils, (mean values from three replication).

Land use/ Ecosystem Depth, cm	Forest (DF1)	Grassland (DF2)	Cropland (DF3)
Bulk density of soils, g/cm^3			
0–5	1.01	1.24	1.34
5–10	1.06	1.48	1.36
15–20	1.29	1.46	1.31
35–40	1.34	1.44	1.50
55–60	1.46	1.54	1.55
75–80	1.54	1.48	1.53
95–100	1.53	1.56	1.49
Water content in air dried soil samples %			
0–5	2.38	1.01	0.45
5–10	2.40	0.34	0.38
15–20	2.85	0.19	0.19
35–40	3.32	0.11	0.18
55–60	3.78	0.10	0.20
75–80	4.01	0.14	0.50
95–100	4.02	1.77	4.99
Water holding capacity of soil samples, % (gravimetric)			
0–5	57.5	47.1	41.0
5–10	43.1	39.9	41.5
15–20	41.7	39.4	39.8
35–40	39.3	39.9	37.7
55–60	40.2	40.0	38.5
75–80	38.8	39.5	40.2
95–100	39.4	38.8	40.9
Content of total carbon in soil samples, g C/kg of soil			
0–10	30.03	20.92	10.51
10–20	11.54	10.82	11.03
20–30	6.11	7.32	7.42
30–40	4.68	3.98	4.67
40–50	4.49	3.33	3.37
50–75	1.36	1.19	2.33
75–100	1.42	0.72	1.26
Content of total nitrogen in soil samples, g N/kg of soil			
0–10	2.35	2.03	1.10
10–20	1.08	1.25	1.11
20–30	0.60	0.85	0.80
30–40	0.50	0.55	0.55
40–50	0.48	0.49	0.46
50–75	0.00	0.00	0.00
75–100	0.00	0.00	0.00

soil samples taken at the soil depth, particle size analysis was done for samples taken in each genetic horizon for comparison with mineralogical and geochemical data including analysis of fractions content. The laboratory study of soils included basic soil properties (particle size, bulk density, water holding capacity (WHC) and pH-values in KCl extracts was determined using the standard procedures for soil analysis (Van Reeuwijk, 2002).

Organic carbon and nitrogen were determined by means of CHNS analyzer Elementar (Vario EL III). In fresh samples of Phaeozems the respiratory activity and biomass of soil microorganisms (substrate induced respiration method) were determined.

Autopore IV 9500 (Micrometrics INC, USA) mercury porosimeter was used to determine the pore size distribution. The undisturbed soil samples were oven-dried at 105 °C and degassed in a vacuum under pressure of 6.67 Pa at the temperature of 20 °C before intruding mercury in step-wise pressure increments in the range from 0.0036 to 400 MPa. The measurements were done in three replicates

The mineralogical composition was determined by X-ray diffractometry using CuKα radiation and a Bruker–D2 Phaser diffractometer (0.02° step scan and a count time of 1 s per step) was used to identify bulk and clay (< 2 μm) mineralogy. Bulk mineralogy was studied using the randomly oriented specimens. Specimens were prepared on the glass slides from the ethanol suspension with 10% of ZnO addition as the inner standard. The clay fraction was separated by