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GEOGRAPHY

Carbon and Nitrogen Stable Isotopes in Forest Soils of Siberia

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The labeled atoms of carbon and nitrogen are widely used in biology, biochemistry, and soil science. Both radioactive (^{14}C) and stable (^{12}C, ^{13}C, ^{15}N) isotopes are used as such labels. Recently, an increase in mass spectrometry sensitivity made it possible to study natural ratios of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) stable isotopes in various biological objects. Since most biological processes discriminate isotopes, i.e., use lighter isotopes for fermentative reactions [10] and leave heavier isotopes in substrate, the study of isotopic compositions of various habitats of organisms yields information on intensity and direction of biological processes. However, the interpretation of carbon and nitrogen isotopic compositions in complex objects, such as soil, meets difficulties because of the far too great number of factors that control isotope fractionation [2, 6, 11, 13]. The forest soils of the Yenisei meridian significantly vary in terms of environmental factors, and this variability opens up possibilities to reveal the most important factors that determine carbon and nitrogen isotopic compositions of soils. In this work, the distribution of carbon and nitrogen isotopes in the forest soils of the Yenisei region of Siberia was investigated for the first time. It has been shown that these isotopes are good indicators of (a) the intensity of organic matter (OM) mineralization, (b) the contribution of nitrogen fixation to the nitrogen status of ecosystems, and (c) the provision of ecosystems with moisture.

The soil samples were taken in August 2003 from test sites of the Siberian IGBP transect set up by the Sukachev Institute of Forestry, Siberian Division, Russian Academy of Sciences within the framework of the International Geosphere–Biosphere Program (IGBP) [7]. The sections were set up in the northern taiga forests (lower reaches of the Nizhnyaya Tunguska River) and at the boundary between the southern taiga and the forest–steppe zone (Pogorel'sky Bor Station). Thixotropic cryosol (*kriozem*) and brown taiga soil (*podbur*) were studied in the northern taiga. Two sections of gray forest soil in the birch and larch types of forest were studied at the boundary between the southern taiga and forest–steppe zones. The soil types chosen for the investigation are the most typical of the northern taiga and forest–steppe zones. The ecological and genetic characteristics of these soils are given in [9, 10]. Some chemical properties of the soils are presented in the table. Three soil samples were taken from each soil horizon, followed by an average composite sample. The samples were dried outdoors and screened through a sieve of 1 mm. Carbon and nitrogen concentrations and isotope ratios ($^{13}C/^{12}C$ and $^{15}N/^{14}N$) were measured by burning the samples on a Carlo Erba NC 2500 element analyzer connected with a Delta Plus (Thermo Finnigan) mass spectrometer (Bremen, Germany). The carbon (nitrogen) isotope ratios expressed as $\delta^{13}C$ ($\delta^{15}N$) were calculated from formula

$$\delta = 1000\ \% \cdot (R_{\text{sample}}/R_{\text{standard}} - 1),$$

where R is the molar ratio $^{13}C/^{12}C$ ($^{15}N/^{14}N$). The isotope ratio is presented in pro mille (‰). High values of this parameter indicate the enrichment of carbon (nitrogen) in heavy isotopes, while the low values mark the depletion in heavy isotopes relative to the standard. The Pee Dee Belemnite (PDB) limestone ($\delta^{13}C = 0$) and atmospheric nitrogen ($\delta^{15}N_{\text{air}} = 0$) serve as international standards for carbon and nitrogen, respectively.

In all samples, the concentrations of heavy carbon and nitrogen isotopes increased (i.e., $\delta^{13}C$ and $\delta^{15}N$ became positive) with increasing depth of the soil sampling (Fig. 1). Although the concentration of C and N in deeper zones of the soil profile was pointed out in [5], causes of this phenomenon remains unclear. It was suggested that the heterotrophic microorganism weakly (but appreciably) discriminates isotopes in the course

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Some chemical properties of soil samples used for the determination of carbon and nitrogen isotopic compositions. Symbols of genetic soil horizons are explained in [8, 9]

Vegetation zone and forest type	Soil type	Genetic horizon and its depth, cm		Chemical indices of soil				
				N (%)	C (%)	C/N	pH (H_2O)	pH ($CaCl_2$)
Northern taiga, larch forest	Thixotropic cryosol (*kriozem*)	O	0–5	1.00	37.29	37	4.78	4.16
		At	5–14	0.93	29.79	32	4.09	3.35
		$B_{h, tx}$	14–27	0.15	2.92	20	5.18	4.51
		mBC	41–54	0.07	1.51	20	6.2	5.63
	Brown taiga forest (*podbur*)	O	0–5	1.25	42.71	34	4.52	4.03
		O_{at}	5–14	1.08	45.75	42	4.21	3.47
		$B_{h, fe}$	14–20	0.14	2.70	20	5.08	4.58
		B_h	20–30	0.02	0.50	22	5.99	5.46
		C	35–40	0.02	0.42	21	6.72	6.25
Southern taiga/forest–steppe zone, birch forest	Gray medium-loam forest soil	O	0–5	0.57	11.70	21	5.62	5.09
		A	5–25	0.17	2.36	14	5.9	5.19
		B	25–40	0.04	0.74	18	6.42	5.81
Southern taiga/forest–steppe zone, larch forest		O	0–5	0.32	5.78	18	6.21	5.7
		A	5–15	0.09	1.47	16	6.11	5.54
		B	15–35	0.03	0.37	14	5.81	5.08

of OM mineralization in soil [12, 14]. The potential activities of OM mineralization in the studied soils were reported previously [9, 10]. In this work, we established a significant positive correlation between the activities of OM mineralization and isotopic compositions of both carbon ($r = 0.88$, $P < 0.001$, $N = 16$) and nitrogen ($r = 0.81$, $P < 0.001$, $N = 16$). This implies that the vertical distribution of stable isotopes across the forest soil profile in the Yenisei region of Siberia is controlled by activity of heterotrophic microorganisms.

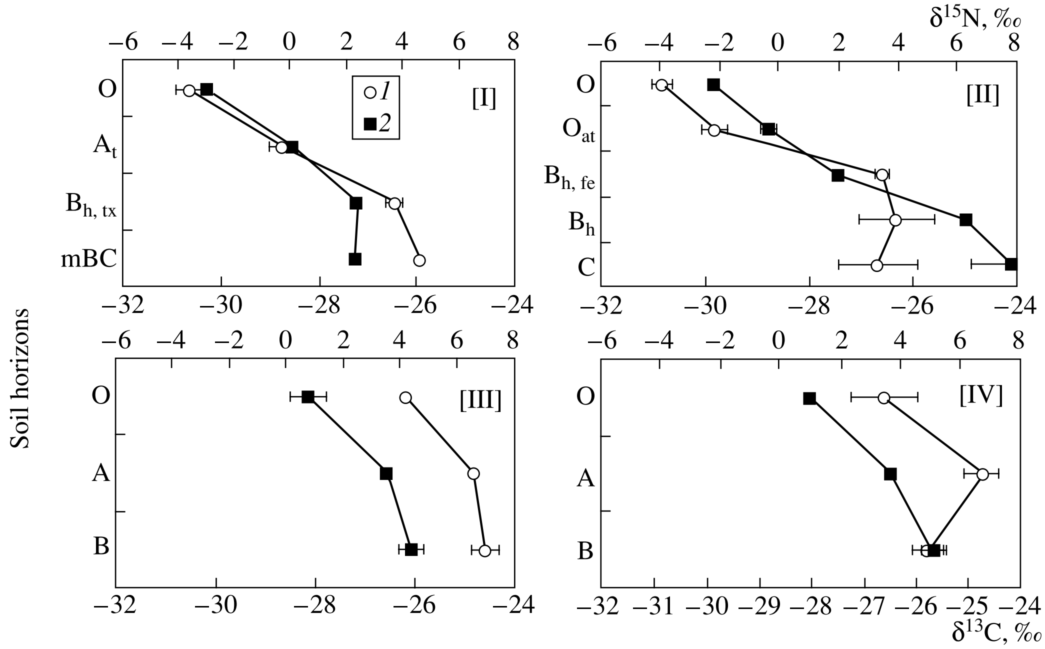

Fig. 1. Isotopic compositions of (*1*) nitrogen ($\delta^{15}N$) and (*2*) carbon ($\delta^{13}C$) in various genetic horizons of soil. (I) Thixotropic medium-loam cryosol (northern taiga); (II) dry-peat light-loam brown taiga soil (northern taiga); (III) gray medium-loam forest soil (forest–steppe zone, birch forest); (IV) gray medium-loam forest soil (forest–steppe zone, larch forest).

Nitrogen isotopic compositions of soils of the northern and southern taiga forests show distinct differences (Fig. 1, $\delta^{15}N$). The $\delta^{15}N$ values are negative in the upper organic horizons of the northern soil (A and A1); i.e., the ^{15}N concentration is lower than in atmospheric air. Such a distribution was not established in organic soil horizons of the southern taiga. The most logical explanation for this difference is the character of plant composition (mainly, moss and lichen in the northern soils) at the lower stage [9, 10]. As is known, the moss and lichen are a symbiosis of fungi and blue-green algae, many species of which can fix atmospheric nitrogen [1]. It was deemed previously that nitrogenase, the main ferment of nitrogen fixation, does not discriminate nitrogen isotopes [3, 8]. Subsequently, it was revealed that the tubercles and leafs of legumes have negative $\delta^{15}N$ values that indicate weak discrimination of nitrogen isotopes in the course of nitrogen fixation [15]. The northern forest ecosystems are depleted in mineral forms of soil nitrogen, and biological fixation of atmospheric nitrogen by lichens is probably important in the nitrogen status of these ecosystems [1]. The negative $\delta^{15}N$ values in the upper horizons of the northern soils are related to the nitrogen fixation. Such values confirm the crucial role of this process in the nitrogen balance of the northern forests.

The organic soil horizons in the northern and southern taiga forests also drastically differ in carbon isotopic composition. The $\delta^{13}C$ values in the upper organic horizons of the northern soils are 3‰ lower than those in soils of the forest–steppe zone. Carbon of the forest litter is mainly formed by leaf debris. Therefore, the high C content and low C/N ratio testify to the relative freshness (weak mineralization) of the litter (table). In our case, $\delta^{13}C$ of the litter is approximately equal to that of leaf debris related to the lower stage. As is known, the $\delta^{13}C$ values of C3 plants correlate with the moisture content: lower $\delta^{13}C$ values correspond to the greater discrimination of isotopes by the main ferment of photosynthesis (RuBisCo) [4]. The correlation between discrimination of isotopes and moisture content is related to stomatal conductance that is governed by the moisture content: the water stress decreases the size of stomas [4]. In the northern ecosystems, both the increase in the amount of precipitation and the thawing of permafrost in the summer raise the moisture content in soil, eventually leading to the higher moisture content in plants. The high moisture content in the northern ecosystems results in different styles of carbon isotope discrimination by plants. This difference is reflected in the $\delta^{13}C$ values of organic soil horizons. Since the carbon isotopic composition ($\delta^{13}C$) of organic horizons of forest soils reflect the perennial moisture content in forest ecosystems, this parameter may be used for prediction of the response of Siberian forests to variations in the water regime of soils induced by global climatic changes.

Thus, the carbon and nitrogen stable isotopes in forest soils of the Yenisei region of Siberia reveal a distinct vertical differentiation in the soil profile, which reflects perennial activity of OM mineralization in soils of this region. Furthermore, the zonal variation in nitrogen isotopes controlled by differences in the plant composition of the lower stage indicates that nitrogen isotopes can be used as an indicator of the contribution of nitrogen fixation to the nitrogen status of ecosystems. Organic soil horizons also show zonal variability of carbon isotopic composition related to the water stress of plants. Therefore, the ^{13}C value in the organic horizon may serve as an indicator of the moisture content in ecosystems.

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REFERENCES

1. C. J. Ellis, P. D. Crittenden, C. M. Scrimgeour, and C. Ashcroft, Oecologia **136**, 115 (2003).
2. T. E. Dawson, S. Mambelli, A. H. Plamboeck, et al., Ann. Rev. Ecol. Systematics **33**, 507 (2002).
3. P. Dijkstra, C. Williamson, O. Menyailo, et al., Isotopes Environ. Health Stud. **39**, 29 (2003).
4. G. D. Farquhar, J. R. Ehleringer, and K. T. Hubick, Ann. Rev. Plant Physiol. Plant Mol. Biol. **40**, 507 (1989).
5. B Heil, B. Ludwig, H. Flessa, and F. Beese, Isotopes Environ. Health Stud. **36**, 35 (2000).
6. P. Högberg, New Phytologist **137**, 179 (1997).
7. *Forest Ecosystems of the Yenisei Meridian*, Ed. by F. I. Pleshikov (Sib. Otd., Ross. Akad. Nauk, Novosibirsk, 2002) [in Russian].
8. A. Mariotti, F. Mariotti, M.-L. Chanpigny, et al., Plant Physiol. **69**, 880 (1982).
9. O. V. Menyailo and Yu. N. Krasnoshchekov, Pochvovedenie **4**, 469 (2001).
10. O. V. Menyailo and Yu. N. Krasnoshchekov, Izv. Ross. Akad. Nauk, Ser. Biol. **3**, 365 (2003).
11. O. V. Menyailo, B. A. Hungate, J. Kehmann, et al., Isotopes Environ. Health Stud. **39**, 41 (2003).
12. K. J. Nadelhoffer and B. Fry, Soil Sci. Soc. Am. J. **52**, 1633 (1988).
13. D. Robinson, Trends Ecol. Evolut. **16**, 153 (2001).
14. G. Shearer and D. H. Kohl, Austral. J. Plant Physiol. **16**, 305 (1989).
15. T. Yoneyama, N. Yamada, H. Kojima, et al., Plant Cell Physiol. **25**, 1561 (1984).