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^{14}C DATING AND SOIL ORGANIC MATTER DYNAMICS IN ARCTIC AND SUBARCTIC ECOSYSTEMS

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ABSTRACT. The carbon content, pH and ^{14}C concentration of humic acids were determined for three soil series of Arctic and Subarctic ecosystems. The measured ^{14}C ages were interpreted in the light of an equilibrium model of humus formation and of mineralization processes in recent soils, and the coefficient of renovation, K_r, was calculated for humic acids. The comparison of K_r for series formed under different climatic conditions suggested that global warming could accelerate decomposition of soil organic matter and possibly increase productivity of ecosystems of the Arctic region.

INTRODUCTION

The recent increased interest in the study of soil organic matter (SOM) dynamics in Arctic and Subarctic ecosystems is due mainly to environmental and global change issues. Radiocarbon analysis is the most important method used to investigate the rates of the exchange/cycling carbon processes. Yet these processes, in the soils of arctic regions, have received very little attention.

Thirteen tundra and north taiga soils, representing different climate conditions, vegetation types and geomorphic surfaces, were sampled according to their genetic horizons. This research was conducted as part of the Russian project, "Global Change of the Environment and Climate". I propose to define the renovation rate of organic carbon in the different fractions of the north ecosystem soils.

Determination of rates and coefficients of incorporation of fresh organic residue into humous substances is one of the principal tasks in research of soil biochemical processes. No less important an indicator of humus balance in soils is the coefficient of renovation of humus, K_r, which can be determined by measuring the natural concentration of ^{14}C in SOM and its fractions. This method is applied to SOM originally present in the soil and the resultant coefficient K_r reflects both biological mineralization and humus dissipation due to other processes such as erosional loss and leaching with solid solutions.

SITE DESCRIPTIONS

Arctic Soil, Svalbard Series, Norway (Sampled by A. E. Cherkinsky)

1. Peaty-gleyic arctic soil (gelic Gleysol) (77°35′N, 20°56′E), Edgeya Island, Ekralhamna Cape marine terrace, elevation *ca.* 10 m, permafrost table, 31 cm. The soil consists of a mixture of weakly decomposed peat, mor humus, almost unchangeable sandy loam and rock fragments. The surface has a full cover of mosses with polar willow, bog saxifrage and arctic bell heater also present.
2. Rendzina raw humic arctic (calcic Arenosol) (77°27′N, 21°01′E) Edgeya Island marine terrace, elevation *ca.* 30 m, permafrost table, 75 cm. The soil consists of sand and shell fragments with mor humus. There is only sparse vegetation on this surface (*e.g.*, lichens, saxifrages, arctic bell heater, polar poppy). Near this profile the fossil rib of a whale was found which permitted the dating of the terrace (see Table 1).
3. Peat arctic soil (gelic Histosol). Profile is 200 m westward of previous soil in microdepression. Permafrost table, 26 cm. The full 30 cm of the profile consists of weakly decomposed peat; it is covered by mosses with species of cotton grass and polar willow.

4. Rendzina humic arctic (Rendzina) (78°42′N, 16°30′E), West Spitsbergen, marine terrace, elevation *ca.* 25 m, permafrost table, 49 cm. The soil consists of sandy loam, shell fragments and humus of mor or moder types. The surface is completely covered by mosses with polar willow, saxifrages and polar poppy also present.
5. Dry peaty arctic soil (Arenosol) (79°32′N, 13°21′E), small volcanic cones and hot springs at Bockfjorden in northern Spitsbergen, elevation *ca.* 40 m, permafrost table, 65 cm.The soil consists of peat, mor humus and a mixture of basal till (sandy loam) with basaltic fragments.The surface is covered by a turf of mosses with mountain avens, rock sedge, saxifrages and polar poppy also present.
6. Arctic podbur (Arenosol) (78°20′N, 17°06′E) (sampled by V. O. Targulian and A. V. Kulikov). Coloradofjella plateau, elevation 400 m, Central Spitsbergen, permafrost table, 24 cm. The soil consists of loamy sand, rock fragments, mor humus and scarce vegetation (lichens, mosses and saxifrages).

South Tundra Soils, Mezen Series, Russia (66°25′N, 42°34′E) (Sampled by S. V. Goryachkin and A. E. Cherkinsky)

1. Fe-humic podzol (Haplic Podzol) is on the top of a small moraine hill. The soil consists of loamy sand, raw humus (in upper horizons) and illuvial humus (in deeper horizons). The surface has sparse vegetation, consisting of mosses, lichens and griminess plants.
2. Humic Podzol (Humic Podzol) it as the foot of the same hill. The soil is the same structure, and differs only by more humus content in the illuvial horizon. The surface has more mosses with no lichens; dwarf birch appears.
3. Peat gleyic soil (Dystric Gleysol) is at a depression 500 m north of Fe-humic Podzol. The top 39 cm is medium decomposed peat, and gleyic horizons with illuvial humus are deeper. The surface is densely covered with dwarf birch and mosses with sedges.

North Taiga Soils, Kuloy Series, Russia (Sampled by S. V. Goryachkin and A. E. Cherkinsky).

1. Podzolic gleyic soil (Gleyic Podzoluvisol) (64°36′N, 42°55′E) is on the slope of a moraine hill. Loamy soil with a humus-illuvial horizon.The surface has spruce with feather mosses and dwarf shrubs.
2. Sod-calcareous soil (Rendzina) (65°17′N, 43°11′E) is on the top of the residual hill. Loamy soil with calcareous fragments and mor-moder humus. The surface has larch and spruce forest with grasses and shrubs.
3. Sod-calcareous leaching soil (Cambisol) is on a gentle slope 200 m north of previous soil. Loamy soil with moder-mull humus. Vegetation is the same.
4. Burozem raw humus (Eutric Cambisol) (65°03′N, 45°34′E) is on the top part of a slope. Red loam soil with mor humus. The surface has larch and spruce forest with dwarf shrubs, shrubs and feather mosses.

Methods

With peat, litter and soil samples, all obvious fragments of roots and other unhumified organic material were discarded by handpicking. The peat and litters were then digested in 2.0 M HCl (at 96°C for 2 h), 0.5 M NaOH (at 96°C for 0.5 h) and 2.0 M HCL (at 96°C for 0.5 h). Samples were then washed reagent-free with distilled water after each digestion stage and dried.

Small roots and plant residues were discarded from the soil samples by flotation and were then washed calcium-ion-free in 0.1 M HCl. Humic acids were then separated with 0.1 M NaOH, repeatedly. Humic acid was precipitated from the separated solution by the addition of HCl or H_2SO_4 to give a pH = 1–2.The humic acid precipitate was washed acid-free with distilled water and dried. All reactions were carried out at room temperature. The samples were converted to benzene using the standard technique of Gupta and Polach (1985).

To define the renovation rate of organic carbon, Cherkinsky and Brovkin (1993) suggest using the coefficient of renovation K_r, which is the integral figure of organic carbon renovation resulting both from biochemical reactions of mineralization and from its migration within the soil profile

$$K_r = \lambda \frac{A_{sn}}{(A_{on} - A_{sn})\exp\lambda(y - 1950)} \times 100\% \ y^{-1} \tag{1}$$

where y = the year of measurement of the reference standard activity (A_{on}),
λ =1/8267 y^{-1}, and
A_{sn} = specific activity of the sample.

Percent of modern carbon (pMC) was calculated according to the definition of Stuiver and Polach (1977). All ^{14}C data are expressed at the 2-sigma (σ) interval for overall analytical confidence.

Total organic carbon contents (C_{tot}) in one soil mineral horizon were determined by wet oxidation with potassium dichromate and concentrated sulfur acid. In the organic horizons (*e.g.*, peat, litter) organic carbon contents were determined by dry combustion.Values are expressed as weight percent of the dry sample.

Sample depth increments are quoted (in cm) relative to the soil surface at the time of sampling including organic horizons; pH levels were determined in water suspensions.

All ^{14}C measurements that are identified with IGAN coding were determined by liquid scintillation counting as applied routinely at the Institute of Geography Radiocarbon Laboratory.

Results and Conclusion

Tables 1–3 show measured ^{14}C concentrations and related data. As the Tables show, K_r decreases with depth in the soil profile and from south to north as a consequence of the reduction in biochemical activity. The renovation rate of the surface horizons of Svalbard soils is 0.02–0.03%C yr^{-1} in Arenosols and Gelic Histosols; this rate is 0.18%C yr^{-1} in Calcic Arenosols. The maximum renovation rate is 0.27%C yr^{-1} measured in Gelic Gleysols.

In the Russian European North (Mezen series, Arkhangelsk region), south tundra soils have much faster renovation rates than arctic soils: the minimum rate is 0.3%C yr^{-1} in Haplic Podzols and the maximum is 1.7 in Humic Podzols for surface horizons.

North taiga soils (Kuloy series, Arkhangelsk region) have K_r of 3.7%C yr^{-1} for Gleyic Podzoluvisols and 1.9%C yr^{-1} for Rendzina surface horizons–litters. These bioclimate-induced differences among soil carbon renovation rates suggest that warming could accelerate decomposition of SOM, but, at the same time, it could increase productivity of ecosystems of the Arctic region, and consequently increase the store of soil carbon.

TABLE 1. Arctic Tundra Soil Profiles (Svalbard Series, Norway)

Lab code (IGAN-)	Soil order and type		Year sampled	Depth (cm)	OM type	^{14}C results			C_{tot}	Soil
	FAO*	Local				pMC	Conv. age†	K_r, % yr^{-1}	WT%	pH_{H_2O}
988	Gelic	Peaty-	1988	0–4	HA	98.9 ± 1.5	85 ± 50	0.265	19.3	5.28
989	Gleysols	gleyic		4–11	HA	92.6 ± 1.3	640 ± 90	0.124	14.3	5.62
987		arctic		11–21	HA	89.0 ± 1.0	960 ± 80	0.090	11.7	5.62
986		soil		21–31	HA	70.9 ± 0.6	2840 ± 60	0.030	11.9	5.94
994	Calcic	Rendzina	1988	0–2	Bone	54.6 ± 0.9	5000 ± 250	--	--	--
996	Arenosols	raw humic		0–2	HA	95.9 ± 1.0	350 ± 70	0.180	2.3	7.38
995		arctic		2–11	HA	84.7 ± 0.9	1370 ± 80	0.065	0.9	7.51
993	Gelic	Peat	1988	0–6	Peat	87.7 ± 1.4	1090 ± 100	0.080	43.8	4.05
992	Histosols	arctic		6–15	Peat	75.4 ± 0.8	2330 ± 70	0.037	42.1	4.64
991		soil		15–26	Peat	65.1 ± 0.7	3550 ± 60	0.023	44.2	5.27
990				26–30	Peat	64.0 ± 0.7	3690 ± 60	0.022	43.5	5.80
1175	Rendzic	Rendzina	1988	0–3	HA	105.3 ± 0.9	--	0.604	4.8	7.23
1174	Leptosols	humic		3–8	HA	95.7 ± 1.2	360 ± 70	0.177	2.6	7.47
1173		arctic		8–16	HA	87.2 ± 0.7	1130 ± 80	0.077	1.4	7.42
1250	Arenosols	Dry-	1989	0–5	HA	99.5 ± 1.2	--	0.282	20.4	5.80
1249		peaty		5–15	HA	83.4 ± 0.6	1500 ± 65	0.059	10.0	6.22
1248		arctic		18–28	HA	71.4 ± 0.6	2780 ± 80	0.030	7.5	7.20
1247		soil		28–32	HA	66.3 ± 0.7	3400 ± 120	0.024	4.5	7.08
157	Arenosols	Podbur	1975	1–3	HA	63.9 ± 0.4	3700 ± 40	0.022	3.2	5.65

*Relates to soil type locations and descriptions as provided in Site Descriptions section
†Conventional ^{14}C ages reported in yr BP ± 1 σ

TABLE 2. South Tundra Soil Profiles (Mezen Series, Russia)

Lab code (IGAN-)	Soil order and type		Year sampled	Depth (cm)	OM type	^{14}C results			C_{tot}	Soil
	FAO*	Local				pMC	Conv. age†	K_r, % yr^{-1}	WT%	pH_{H_2O}
781	Haplic	Fe-Humic	1986	0–3	HA	99.6 ± 1.6	--	0.299	28.3	4.03
779	Podzol	Podzol		3–6	HA	93.7 ± 0.4	540 ± 30	0.142	6.5	4.21
778				15–22	HA	72.5 ± 0.4	2660 ± 30	0.032	1.8	4.70
782				15–22	FA	80.8 ± 1.1	1760 ± 130	0.050	--	--
795				22–27	HA	71.3 ± 0.6	2800 ± 50	0.030	1.6	4.72
777				22–27	FA	78.8 ± 0.7	1970 ± 70	0.045	--	--
752	Humic	Humic	1986	0–4	HA	115.7 ± 0.7	--	1.665	9.4	4.15
788	Podzol	Podzol		4–19	HA	78.3 ± 0.5	2020 ± 40	0.043	11.1	4.24
796				19–38	HA	72.9 ± 0.4	2610 ± 40	0.033	3.4	4.50
789				38–72	HA	69.6 ± 0.5	3000 ± 70	0.028	1.2	4.56
753	Dystric	Peat-	1986	0–9	Peat	109.0 ± 0.5	--	0.941	40.7	4.05
751	Gleysol	gleyic		33–39	Peat	53.4 ± 0.5	5190 ± 60	0.014	38.6	4.72
755		soil		39–42	HA	56.2 ± 0.5	4770 ± 50	0.016	3.8	5.12
787				39–42	FA	54.8 ± 0.5	4980 ± 60	0.015	--	--
754				42–47	HA	56.3 ± 0.5	4750 ± 60	0.016	2.6	5.35
786				42–47	FA	71.1 ± 1.0	2820 ± 90	0.030	--	--
783				47–55	HA	61.9 ± 0.8	3960 ± 100	0.020	2.3	5.27
784				47–55	FA	63.8 ± 1.0	3710 ± 170	0.022	--	--

*Relates to soil type locations and descriptions as provided in Site Descriptions section
†Conventional ^{14}Cages reported in yr BP ± 1 σ

TABLE 3. North Taiga Soil Profiles (Kuloy Series, Russia)

Lab code (IGAN-)	Soil order and type: FAO*	Soil order and type: Local	Year sampled	Depth (cm)	OM type	^{14}C results: pMC	^{14}C results: Conv. age†	^{14}C results: K_r, % yr^{-1}	C_{tot} WT%	Soil pH_{H_2O}
665	Gleyic Podzo-luvisol	Podzolic gleyic soil	1984	0–6	Litter	126.9 ± 0.6	--	3.716	41.4	4.91
664				6–12	Litter	98.3 ± 0.4	140 ± 30	0.256	34.7	4.62
663				12–25	HA	79.7 ± 0.4	1880 ± 50	0.047	4.4	4.49
662				33–42	HA	57.6 ± 0.7	4760 ± 110	0.017	3.2	5.35
806	Rendzina	Sod-calcareous soil	1985	0–1	Litter	117.2 ± 0.8	--	1.896	28.9	6.33
805				1–5	HA	107.0 ± 0.4	--	0.779	7.5	5.88
804				5–10	HA	99.1 ± 0.4	--	0.283	2.4	5.71
803				10–17	HA	91.9 ± 0.4	650 ± 30	0.118	0.9	6.23
809	Cambisol	Sod-calcareous leached soil	1985	1–8	HA	106.8 ± 0.7	--	0.762	2.7	4.43
808				8–16	HA	93.2 ± 0.5	580 ± 50	0.135	1.4	4.95
807				16–31	HA	87.0 ± 0.7	1150 ± 100	0.077	0.8	4.79
1054	Eutric Cambisol	Burozem raw humic	1986	--	Grass	126.1 ± 0.5	--	--	--	--
1053				0–2	HA	115.6 ± 1.6	--	1.645	17.1	4.98
1052				2–8	HA	112.4 ± 0.8	--	1.274	3.0	4.78

*Relates to soil type locations and descriptions as provided in Site Descriptions section
†Conventional ^{14}C ages reported in yr BP ± 1 σ

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