SOIL PROCESSES AND THE CARBON CYCLE

Edited by

Rattan Lal
John M. Kimble
Ronald F. Follett
Bobby A. Stewart

CRC Press
Boca Raton Boston New York Washington London

Library of Congress Cataloging-in-Publication Data

Soil processes and the carbon cycle / edited by R. Lal . . . [et al.]
p. cm.
Papers from a symposium entitled, "Carbon Sequestration in Soils" held at Ohio State University, July 1996.
Includes bibliographical references and index.
ISBN 0-8493-7441-3 (alk. paper)
1. Soils- -Carbon content- -Congresses. 2. Carbon sequestration- -Congresses. 3. Carbon cycle (Biogeochemistry)- -Congresses.
I. Lal, R. II. Series: Advances in soil science (Boca Raton, Fla.)
S592.6.C35S65 1997
631.4′17—dc21 97-29442
CIP

International Standard Book Number 0-8493-7441-3
Library of Congress Card Number 97-29442
Printed in the United States of America 1 2 3 4 5 6 7 8 9 0
Printed on acid-free paper

CHAPTER 11

Soil Carbon Distribution in Nonacidic and Acidic Tundra of Arctic Alaska

J.G. Bockheim, D.A. Walker, and L.R. Everett

I. Introduction

Global climate models predict that greenhouse warming will be several times greater in the arctic regions than the projected global mean of 1.5 to 4.5°C (IPCC, 1992). Indeed, during the past several decades, climate warming has been greater in the arctic than in other regions. The warming has been particularly large over Siberia, northwestern Canada, and much of Alaska, where warming rates over the past 30 years have been approximately 1°C per decade (Oechel et al., 1993).

Most of the high-latitudes are underlain by permafrost, in which the summer thaw is limited to a thin (often <50 cm) active layer. The soil active layer (0 to 35 cm) in the circumarctic contains up to 455 Gt C which is approximately 60% of the ~750 Gt C currently in the atmosphere as CO_2 (Post et al., 1982; Billings, 1989; Oechel et al., 1993). However, the amount of carbon in arctic tundra soils may be even greater than previously believed as recent data show that the upper 30 to 40 cm of permafrost contains as much carbon as the active layer (Michaelson et al., 1996). If global warming induces thawing of permafrost, this carbon could be released to the atmosphere as CO_2, CH_4, and other trace gases, thereby amplifying the greenhouse effect. In fact, the warming of the 1970s and 1980s over the Alaskan North Slope appears to have changed the tundra from a net sink to a net source for the atmosphere (Oechel et al., 1993).

The only comprehensive survey of soil carbon stores in arctic Alaska was by Michaelson et al. (1996). Soil carbon values (to 1 m) commonly ranged from 16 to 94 kg C/m^2, about one-half of which was in the upper portion of the permafrost. Other soil carbon data are contained in reports of the Alaskan coastal plain (Everett and Parkinson, 1977; Parkinson, 1978; Walker et al., 1980) and the arctic foothills of Alaska (Walker et al., 1989; Walker and Barry, 1991).

A unique aspect of the physiography of arctic Alaska is a belt of calcareous loess between 5 and 70 km wide that extends across the arctic foothills and coastal plain provinces north of the Brooks Range (Carter, 1988). The loess exerts a strong effect on the distribution of plant communities and on soil development (Walker and Everett, 1991). Nonacidic landcover types may be more abundant than previously thought on the North Slope, occupying 50% or more of the Kuparuk basin (Auerbach et al., 1996). Nonacidic and acidic landcover types are readily distinguished by the normalized differences in vegetation index (NDVI) from SPOT multispectral digital data (Walker et al., 1995) and false color AVHRR images of northern Alaska (Walker and Everett, 1991).

Mollisols have been observed on south-facing slopes of pingos (Walker et al., 1991), on high-center polygons and rims of well developed low-center polygons (Everett and Parkinson, 1977; Parkinson, 1978), and on loess-affected floodplains of the arctic coastal plain (Walker and Everett,

ISBN 0-8493-7441-3

1991). However, Mollisols may be even more abundant than previously believed in the Kuparuk basin, also occurring in the northern Brooks Range and the arctic foothills.

The objectives of this study are (1) to determine the relative abundance of Mollisols and other nonacidic soils in the Kuparuk basin, the location of the Arctic Research Consortium of the U.S. CO_2 and methane flux study, (2) to compare key soil properties in moist nonacidic tundra and moist acidic tundra, and (3) to elucidate the mechanisms accounting for differences in the depth-distribution of carbon between these two landcover types.

II. Methods and Materials

A. Sites

The study was conducted in the 9,200 km^2 Kuparuk watershed (Figure 1). Pedons were described and sampled in three physiographic provinces, the Brooks Range (4 sites), the arctic foothills (33 sites), and the coastal plain (18 sites) along a north-south gradient from ca. 70°17' to 68°30N. The area occurs within the zone of continuous permafrost (Péwé, 1975).

The climate of the area varies with distance from the Arctic Ocean and elevation. The mean annual temperature ranges from -12.8°C at Prudhoe Bay to -5.9°C in the Brooks Range (Haugen, 1982). Temperature extremes are greater in the Brooks Range and arctic foothills provinces than in the coastal plain. Precipitation declines from 300 to 450 mm/yr in the Brooks Range to 180 to 230 mm/yr in the coastal plain.

The major landcover classes in the Kuparuk watershed (including percentage of area) are moist nonacidic and dry tundra (38.9%), moist acidic tundra (30.8%), shrublands (16.8%), and wet tundra (7.0%), with water and shadows (5.1%) and barrens (1.4%) occupying the remaining areas (Auerbach et al., 1996). Moist nonacidic tundra contains predominantly non-tussock sedges (*Carex bigelowii* and *Eriophorum triste*), a few prostrate shrubs (*Dryas integrifolia*, *Salix reticulata*, and *S. arctica*), and brown mosses (*Tomenthypnum nitens* and *Hylocomium splendens*). In contrast, the moist acidic tundra contains cottongrass tussocks (*Eriophorum vaginatum*), dwarf-birch (*Betula nana*), and other acidophilous dwarf-shrub species, such as *Ledum palustre* spp. *decumbens*, *Vaccinium vitis-idaea*, *V. ulignosum*, *Salix planifolia* spp. *pulchra*, and *Sphagnum* moss (Walker et al., 1994).

Residual surfaces and dissected uplands dominate the Brooks Range and arctic foothills. Glacial deposits are limited to a region extending 65 km north of the Brook Range and vary from Holocene to early Pleistocene from south to north (Kreig and Reger, 1982). The coastal plain contains primarily drained or thaw lakes with isolated pingos of mid-Holocene age. Parent materials are dominantly loess and silty colluvium in the foothills and lacustrine silts and organics in the coastal plain. Alluvium occurs along the major river courses, including the Kuparuk, Toolik, and Sagavanirtok. Elevations range from 1150 m in the southern foothills to sea level at Prudhoe Bay.

B. Sample Collection

There were two sets of sampling localities. Thirty-two pedons were examined during a close-support helicopter reconnaissance to prepare landcover and soil maps of the watershed (designated as R95-1 through R95-32 on Figure 1). These pedons were located in major landcover types selected randomly from aerial photographs and located using a global positioning system. The pedons were excavated to the surface of the permafrost table in early August when the active layer was at its thickest. The upper 10 cm of the permafrost was sampled using a hammer and cold chisel.

An additional set of 23 detailed pedons (designated as A95-1 through A95-23 on Figure 1) were examined at 11 CO_2 and methane flux-tower measuring sites along a north-south gradient from Betty

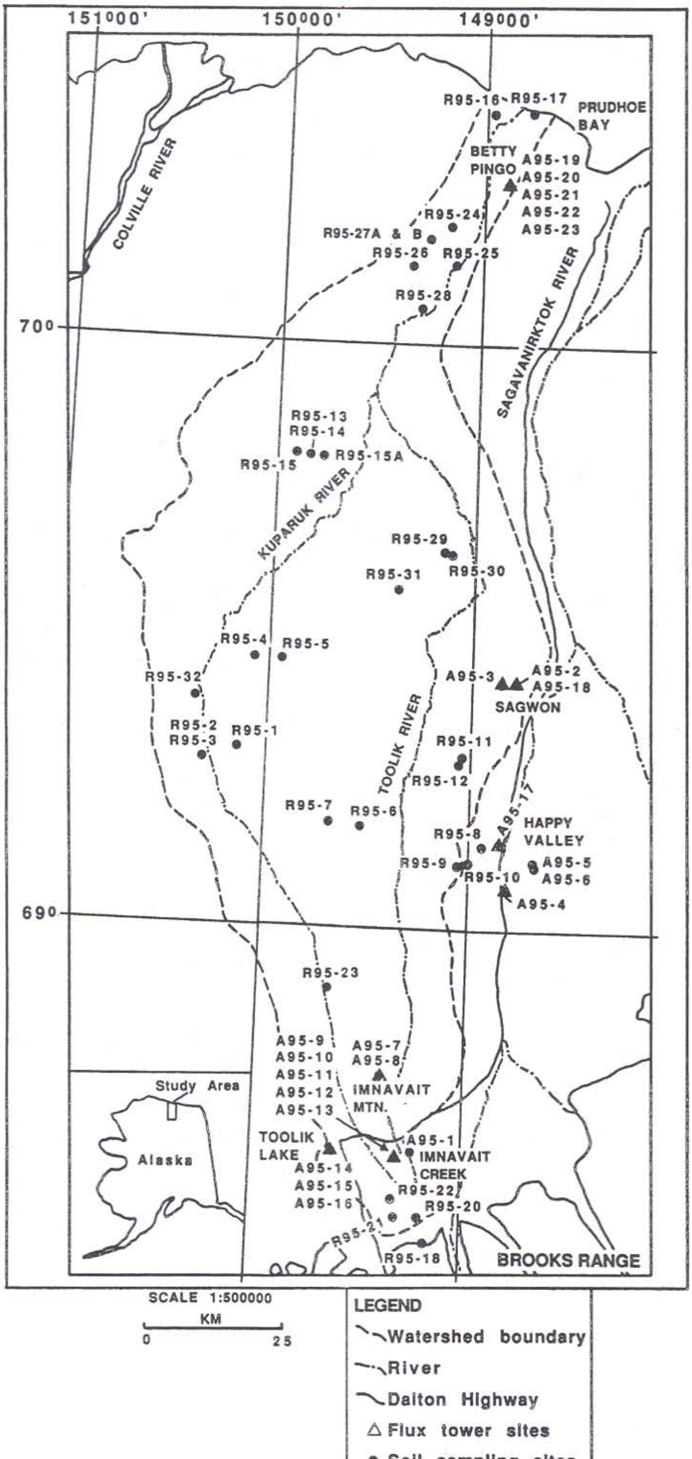

Figure 1. The Kuparuk drainage showing detailed and reconnaissance description and sampling sites.

Pingo near Prudhoe Bay to Imnavait Creek (Figure 1). These pits were dug by hand to the permafrost table (average depth = 51 cm) and additionally excavated to 1 m with a gasoline-powered Pico impact drill. Detailed soil descriptions were taken at all sites, and bulk samples were collected from each horizon and placed in water-tight bags. The soils were classified according to *Soil Taxonomy* (Soil Survey Staff, 1994) and the recently proposed Gelisol order (ICOMPAS, 1996).

Bulk density cores were taken from each horizon of the detailed pedons within the active layer. Bulk density of reconnaissance pedons and permafrost horizons were estimated from the equation, $y = 1.374*10^{-0.026x}$, where y = bulk density (g/cm^3) and x = organic carbon (%). The equation was derived from 82 measurements and had an r^2 of 0.823 ($p = 0.0001$). Soil pH was measured on a saturated paste within 8 hours of sample collection using a portable pH meter.

C. Laboratory Analyses

The samples were returned to the University of Wisconsin where bulk density (reported on samples dried at 105°C) and gravimetric and volumetric field moisture contents were determined. Air-dried samples were ground to pass a 0.5-mm screen and subsamples were sent to the University of Alaska-Fairbanks Agriculture and Forestry Experiment Station at Palmer for carbon analysis. Total carbon and nitrogen were determined by dry combustion on a Leco C and N determinator (LECO Corp., St. Joseph, MI). No adjustments were made for $CaCO_3$ so that the carbon values represent organic and inorganic forms. The carbon and nitrogen contents of the profiles were determined to a depth of 1 m by taking the product of carbon or nitrogen concentration, bulk density, and horizon thickness. The percentage of coarse fragments was very low so that no corrections were necessary for skeletal material. The carbon and nitrogen data are reported for the active layer, the upper part of the permafrost, and to a depth of 1 m.

Comparisons in soil properties between nonacidic and acidic landcover types were done by one-way analysis of variance.

III. Results

A. Soil Classification

Nonacidic soils comprise 54% of the Kuparuk basin, including nonacidic Pergelic and Histic Pergelic Cryaquepts (26.6%), Pergelic Cryoborolls (16.9%), and lesser amounts of Cryaquolls and nonacidic Cryorthents (Table 1). These soils occupy primarily moist nonacidic tundra and, to a lesser extent, shrublands, wet tundra, and barrens. Moist acidic tundra contains almost exclusively Pergelic and Histic Pergelic Cryaquepts. Histosols comprise only 3.9% of the watershed.

In the recently proposed Gelisol order (ICOMPAS, 1996), about 38% of the soils in the Kuparuk drainage are classified as Turbels, primarily Aquaturbels; 58% are Haplels, primarily Aquahaplels and Histohaplels; and about 3.9% are Histels (Table 2).

B. Morphological and Chemical Soil Properties

Although data are shown for soils of all of the landcover types, the results for the moist nonacidic tundra and moist acidic tundra will be emphasized. The active layer thickness was significantly greater for the moist nonacidic tundra than for the moist acidic tundra (Table 3). The organic layer was thicker for the moist acidic tundra than the moist nonacidic tundra, but the differences were not significant. There was a highly significant ($p = 0.0004$) correlation between active layer thickness and

Table 1. Distribution of soils in the Kuparuk drainage according to Soil Taxonomy (1994)

Soil taxonomy	Landcover type	% of Kuparuk[a]
Perglic, Histic Perglic Cryaquepts	Moist acidic tundra	40.8
Perglic, Histic Perglic Cryaquepts, nonacidic	Moist nonacidic tundra, shrublands	26.6
Perglic Cryoborolls	Barrens, moist nonacidic tundra	16.9
Perglic, Histic Perglic Cryaquolls	Moist nonacidic tundra, wet tundra	8.1
Perglic Cryofibrists	Wet tundra	2.7
Perglic Cryorthents, nonacidic	Shrublands	2.3
Perglic Cryochrepts	Barrens	1.0
Perglic Cryohemists	Wet tundra	0.6
Perglic Cryosaprists	Wet tundra	0.6
Perglic Cryumbrepts	Barrens	0.2

[a]Reported for land area only.

Table 2. Distribution of soils in the Kuparuk drainage according to the recently proposed Gelisol order

Soil taxonomy	Landcover type	% of Kuparuk[a]
Aquaturbels	Moist nonacidic tundra, moist acidic tundra	25.4
Aquahaplels	Moist nonacidic tundra, moist acidic tundra, shrublands	22.0
Histohaplels	Moist nonacidic tundra, moist acidic tundra, shrublands, wet tundra	20.4
Mollihaplels	Barrens, moist nonacidic tundra, shrublands	9.5
Molliturbels	Moist nonacidic tundra	8.2
Orthohaplels	Barrens, moist nonacidic tundra	4.9
Fibristels	Wet tundra	2.6
Haploturbels	Barrens, moist nonacidic tundra	2.2
Umbrihaplels	Barrens	0.2
Histoturbels	Moist nonacidic tundra	2.0
Hemistels	Wet tundra	0.6
Sapristels	Wet tundra	0.6

[a]Reported for land area only.

organic layer thickness for soils in the moist nonacidic tundra and moist acidic tundra. The A horizon averaged 19 cm thick for moist nonacidic tundra soils; an A horizon was not present in soils of the moist acidic tundra. The organic layers in the moist acidic tundra commonly overlaid a mottled, dilatant-prone Bg horizon. There were no significant differences in thickness of the B horizon or the solum between the two landcover types.

The pH values of the surface organic layer and the uppermost B horizon averaged 7.2 and 7.0, respectively, for the moist nonacidic tundra soils and were significantly greater than the average values of 4.5 and 5.3 for the moist acidic tundra soils (Table 3).

There were no significant differences in the amount of soil carbon in the upper 1 m between the two landcover types; however, there were significantly greater amounts and proportion of carbon in the active layer of soils in the moist nonacidic tundra than in soils of the moist acidic tundra (Table 3). Similarly, the amounts of nitrogen in the active layer and in the upper 1 m were significantly greater in soils of the moist nonacidic tundra than in soils of the moist acidic tundra. Whereas the

Table 3. Properties of soils in the Kuparuk drainage, northern Alaska

Profile number	Active layer (cm)	Organic layer (cm)	A hor. (cm)	B hor. (cm)	pH O hor.	pH B hor.	N (g/m^2) Active	N (g/m^2) Perm.	N (g/m^2) 100 cm.	N (g/m^2) % Active	C (kg/m^2) Active	C (kg/m^2) Perm.	C (kg/m^2) 100 cm	C (kg/m^2) % Active
Barrens														
A95-1	>100	2	4	35		4.3	943	0	943	100	14.2	0.0	14.2	100
A95-7	>85	0	4	16		5.3	913	0	913	100	7.5	0.0	7.5	100
A95-8	>100	0	8	14		4.6	865	0	865	100	12.7	0.0	12.7	100
A95-18	>80	5	9	17	4.7	5.8								
R95-23	>60	1	5	26		5.6								
R95-21	>70	3	15	5	6.3	6.4								
Avg.	>60	2	8	19	5.5	5.3	907	0	907	100	11.5	0.0	11.5	100
SE		1	2	4.2	0.5	0.3	23	0	23	0	2.0	0.0	2.0	0
Moist nonacidic tundra and dry tundra														
A95-2	72	24	0	45	7.4	7.3	2464	1261	3725	66	35.5	18.6	54.1	66
A95-18	71	3	0	32	8.0	7.9	2697	1194	3890	69	41.1	20.1	61.2	67
A95-19	43	0	21	0	7.3	7.4	2136	260	2396	89	32.5	4.1	36.6	89
A95-20	41	25	0	0	7.0		1575	2497	4072	39	27.6	40.8	68.5	40
A95-21	49	17	41	>41	7.7	7.3	3452	2681	6133	56	55.0	42.9	97.8	56
R95-4	83	1	17	16	7.0	6.9	2344	1132	3476	67	35.4	13.4	48.8	73
R95-8	30	23	10	0	6.6		523	3352	3874.1	13	11.5	52.8	64.3	18
R95-11	50	26	8	16	7.1	6.3	1980	1485	3464.9	57	30.5	21.7	52.2	58
R95-12	60	14	6	30	7.3	6.3	1528	1991	3519	43	22.2	29.1	51.3	43
R95-13	64	8	43	13	7.1	7.4	2909	3133	6042.8	48	43.6	32.6	76.2	57
R95-15	46	7	9	16	7.0	6.8	1917	3594	5511.2	35	29.7	42.5	72.2	41
R95-15A	53	2	5	26		7.8								
R95-17	41	5	8	28		6.0								
R95-24	>92	3	20	0	7.0		933	0	933.4	100	14.0	0.0	14.0	100
R95-26	43	13	42	0	7.0		1549	266.8	1815.5	85	24.5	18.3	42.8	57
R95-27A,B	61	1	41	0	7.0		1981	185.6	2166.5	91	34.6	11.0	45.6	76
R95-28	78	1	10	0										
R95-29	52	9	32	27	7.1	7.1	1942	1733	3674.1	53	28.1	19.5	47.6	59
R95-30	>70	0	13	0										
R95-32	70	5	55	0		6.7	2464	1261	3725.1	66	30.7	21.9	52.6	58
Avg.	56	9	19	13	7.2	7.0	2025	1627	3651	61	31.0	24.3	55.4	60
SE	3.6	2	3.8	3.5	0.086	0.16	18[illegible]	291	355	5.8	2.7	3.7	4.7	4.9

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Table 3. continued--

Profile number	Active layer (cm)	Organic layer (cm)	A hor. (cm)	B hor. (cm)	pH O hor.	pH B hor.	N (g/m²) Active	N (g/m²) Perm.	N (g/m²) 100 cm.	N (g/m²) % Active	C (kg/m²) Active	C (kg/m²) Perm.	C (kg/m²) 100 cm	C (kg/m²) % Active
Moist acidic tundra														
A95-3	45	16	0	24	4.0	5.5	1151	1763	2915	40	19.2	34.4	53.6	36
A95-9	35	18	0	12	4.6	4.9	1052	1263	2315	45	21.7	25.5	47.2	46
A95-10	48	23	0	17	4.5	5.2	831	1057	1888	44	20.5	23.6	44.1	46
A95-15	44	11	0	24	4.5	5.2	1058	705	1763	60	21.9	14.6	36.5	60
A95-17	39	10	0	18	4.4	5.2	451	1146	1597	28	10.2	23.9	34.1	30
R95-1	34	32	0	0	4.1	5.3	496	2540	3036	16	15.3	43.4	58.7	26
R95-6	41	9	0	6	4.3	5.4	1062	2402	3464	31	19.4	47.2	66.6	29
R95-7	46	22	0	0	4.7	6.4								
R95-22	61	11	0	28	5.1	5.2								
R95-31	47	4	0	32		5.0								
Avg.	44	16	0	16	4.5	5.3	872	1554	2425	38	18.3	30.4	48.7	39
SE	2.4	2.6	0	3.6	0.11	0.13	109	265	272	5.3	1.6	4.4	4.4	4.6
Prob. level[a]	0.013	0.08	0.002	0.77	0.000	0.000	0.001	0.88	0.044	0.022	0.005	0.35	0.40	0.017
Shrublands (acidic)														
A95-6	40	21	0	19	4.4	4.4	934	0	934	100	17.0	0.0	17.0	100
A95-14	30	14	0	14	5.0	5.0	803	1559	2362	34	15.7	27.9	43.6	36
A95-16	72	18	0	0	6.7		1571	554	2125	74	26.6	12.1	38.8	69
R95-2	>50	0	8	8		5.6								
Avg.	47	13	2	10	5.4	5.0	1103	704	1807	69	19.8	13.3	33.1	68
SE	11	5	2	4	0.7	0.3	237	456	442	19	3.4	8.1	8.2	18
Shrublands (nonacidic)														
A95-5	59	26	0	33	5.5	6.6	1844	631	2475	74	31.2	17.8	49.0	64
A95-4	>192	0	1	0		7.1	573	0	573	100	27.9	0.0	27.9	100
R95-10	82	12	0	0	5.9	6.4								
R95-26	85	0	35	25			1774	33	1807	98	27.1	6.5	33.6	81
Avg.	75	10	9	15	5.7	6.7	1397	221	1618	91	28.7	8.1	36.8	81
SE	7.1	6.2	9	8.5	0.2	0.2	412	205	557	8.2	1.3	5.2	6.3	10

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Table 3. continued--

Profile number	Active layer (cm)	Organic layer (cm)	A hor. (cm)	B hor. (cm)	pH O hor.	pH B hor.	N (g/m^2) Active	N (g/m^2) Perm.	N (g/m^2) 100 cm.	N (g/m^2) % Active	C (kg/m^2) Active	C (kg/m^2) Perm.	C (kg/m^2) 100 cm	C (kg/m^2) % Active
Wet tundra (mineral soils only)														
A95-23	39	21	18	0	7.5		2287	3131	5418	42	34.8	50.4	85.2	41
R95-9	33	25	>20	0	5.8									
R95-14	49	20	29	0	6.9									
R95-16	46	32	0	0	6.7									
R95-20	29	33	0	0	5.5	6.5	955	6780	7735	12	19.1	29.0	48.1	40
Avg.	39	26	12	0	6.5	6.5	1621	4956	6577	27	27.0	39.7	66.7	41
SE	3.8	2.7	6.4	0	0.4		666	1825	1159	15	7.9	10.7	18.6	0.5
Wet tundra (organic soils)														
R95-3	54	54+	0	0	5.5									
R95-5	36	42+	0	10	5.5	5.3	625	2931	3556	18	12.8	57.0	69.8	18
A95-11	65	65+	0	0	4.6		1740	1482	3221	54	33.1	50.4	85.2	39
A95-12	62	62+	0	0	4.5		2433	2432	4865	50	46.3	29.9	76.2	61
A95-13	36	40+	0	0	4.1		2458	678	3137	78	45.4	11.6	57.0	80
A95-22	35	35	0	0	7.3		1684	0	1684	100	26.7	0.0	26.7	100
Avg.	48	35+	0	2	5.3	5.3	1788	1505	3293	60	32.9	29.8	63.0	60
SE	4.7		0	2	0.5		334	540	508	14	6.2	10.9	10.2	14

SE = standard error of the mean.

[a]Based on single-factor analysis of variance between moist nonacidic tundra and moist acidic tundra.

amount and proportion of field moisture in the active layer were significantly greater in moist nonacidic tundra soils, the amounts of field moisture in the upper permafrost and in the entire profile were significantly greater in moist acidic tundra soils.

There also were comparable differences in morphological and chemical properties in nonacidic and acidic shrublands (Table 3); however, there were an insufficient number of sites to do meaningful statistical comparisons.

IV. Discussion

A. Cryoturbation and Active Layer Dynamics

A greater proportion (60%) of soils in the moist nonacidic tundra were cryoturbated than in the moist acidic tundra (40%). This is also reflected by a greater percentage of frost scars on the surface of the moist nonacidic tundra. For example, at Sagwon, frost scars comprised 36% of the moist nonacidic tundra (pedons A95-2 and A95-18) and <1% (pedon A95-3) of the moist acidic tundra. Cryoturbation may be inhibited in the moist acidic tundra by the thicker organic mat. This mat also insulates the soil and results in higher volumetric moisture contents and a thinner active layer. The organic mat, which is often dominated by *Sphagnum*, produces strongly acidic conditions (Sjors, 1963).

In contrast, cryoturbation causes mixing of the organic matter throughout the active layer and exposes the dark-colored mineral soil, enabling greater thermal diffusivity in the moist nonacidic tundra than in the moist acidic tundra. The incorporation of organic matter causes the development of an A horizon, which often qualifies as mollic in most soils of the moist nonacidic tundra; an A horizon is lacking in the moist acidic tundra soils. The amounts of carbon and nitrogen are significantly greater in the active layer of the moist nonacidic tundra than in the moist acidic tundra (Table 3). Whereas 60% of the carbon and nitrogen present in the upper 1 m exists in the active layer of the moist nonacidic tundra, only 40% is in the active layer of the moist acidic tundra. A preliminary model of the influence of cryoturbation on carbon dynamics and soil development in the moist tundra of northern Alaska is given in Figure 2.

B. Origin of Alkalinity

According to Walker and Everett (1991), the distribution of moist nonacidic tundra closely parallels the zone of calcareous loess deposition. The silt originates from limestone deposits of the Lisburne Group in the Brooks Range and is transported by Sagavanirktok River and its tributaries to the coastal plain. The calcareous silt is then transported as loess by strong, predominantly east-northeasterly winds. Moist acidic tundra exists in areas receiving lesser amounts of snowfall and calcareous loess, or on older surfaces where a *Sphagnum* layer has developed during plant succession (Walker et al., 1989; 1995).

C. Implications

This study suggests that nonacidic soils may comprise 54% of the Kuparuk drainage, which is greater than previous reports. The Kuparuk basin may represent a modern analogue of steppe tundra that existed across Alaska and Siberia during Pleistocene glaciations (Hopkins, 1982; Guthrie, 1990; Walker et al., 1991). Cryoturbation is an important soil-forming process that causes deep mixing of carbon and results in dark-colored, organic-enriched mineral soils. Our estimates suggest that soils

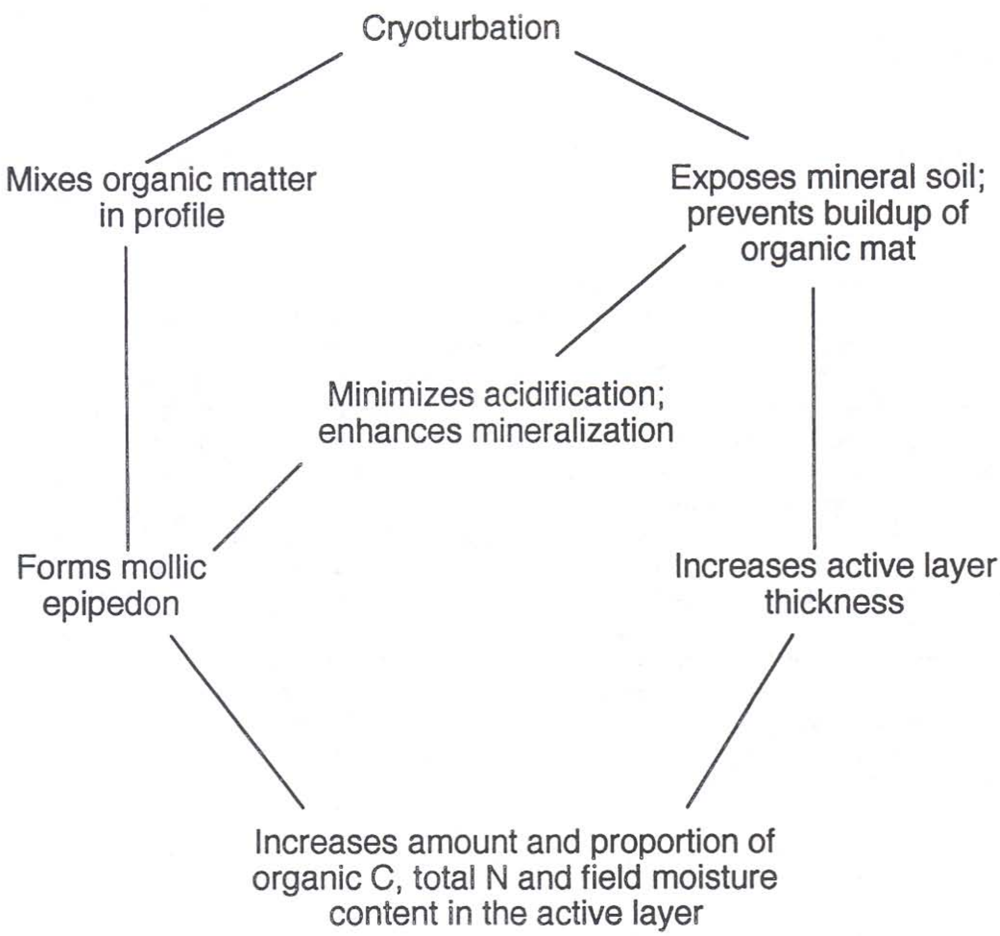

Figure 2. Conceptual model of the influence of cryoturbation on carbon distribution and soil development in moist nonacidic tundra in arctic Alaska.

of the Kuparuk basin may contain 435 Tg of carbon in the upper 1 m (Table 4) which is slightly greater than the 381 Tg estimate of Michaelson et al. (1996).

We propose that in the event of global warming there will be a greater release of CO_2 from soils of the moist nonacidic tundra than from soils of the moist acidic tundra because of the greater carbon and field moisture contents in the active layer. Soils in the moist acidic tundra are protected by a thick organic mat (average thickness = 16 cm) that will buffer against sudden changes in soil moisture and temperature. However, the moist acidic tundra may be more susceptible to thermokarst because of a greater proportion of ice wedges and other forms of massive ice than in moist nonacidic tundra. Additional studies are needed to monitor CO_2 and CH_4 dynamics in moist acidic and moist nonacidic tundra.

Table 4. Distribution of soil carbon to 1 m by landcover type in the Kuparuk basin

	Area		Soil C (kg m^{-2})			
Landcover type	%	ha	Active	Permafrost	Total	Soil C (Tg)
Barrens	1.4	129	11.5	0	11.5	1.5
Moist nonacidic	38.9	3579	31.0	24.3	55.4	198.3
Moist acidic	30.8	2834	18.3	30.4	48.7	138.0
Shrublands (nonacidic)	9.0	828	28.7	8.1	36.8	30.5
Shrublands (acidic)	7.8	718	19.8	13.3	33.1	23.8
Wet tundra (organic)			33.2	33.2	66.4	
	7.0	644				43.0
Wet tundra (mineral)			19.1	29.0	48.1	
Water and shadows	5.1	469				
Clouds and ice	0.1	9				
Total	100.1	9210				435.1

V. Summary and Conclusions

Nonacidic soils comprise 54% of the Kuparuk basin primarily in association with moist nonacidic tundra, shrublands along rivers, and wet tundra landcover types. Based on analysis of variance, the following soil properties were significantly greater in soils of moist nonacidic tundra than in soils of moist acidic tundra: active layer thickness, the thickness of the A horizon, pH of the surface organic and the uppermost B horizon, and the amount and proportion of carbon, nitrogen, and field moisture content in the active layer.

The depth-distribution of carbon in soils of arctic Alaska is controlled largely by the presence or absence of an organic mat and its effect on the degree of cryoturbation (frost churning). Cryoturbation in moist nonacidic tundra exposes the mineral soil, prevents the buildup of the thick organic mat that is characteristic of moist acidic tundra, and slows down the rate of soil acidification. Cryoturbation also mixes organic matter into the soil, contributes to the formation of a mollic epipedon, and results in a deeper active layer in soils of the moist nonacidic tundra than in soils of moist acidic tundra. Additional studies are needed to determine whether soils of moist nonacidic tundra and moist acidic tundra will act as a source or a sink of CO_2 in a climate-warming scenario.

Acknowledgments

Funds for this project were provided by the National Science Foundation Arctic System Science Land-Atmosphere-Ice Interactions Program. G. Michaelson and C.L. Ping kindly analyzed N and C on the samples. J. Munroe assisted in the field work. This chapter is Byrd Polar Research Center contribution 1058.

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