DIVISION S-10—WETLAND SOILS

Predicting Carbon Storage in Tundra Soils of Arctic Alaska

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ABSTRACT

The distribution of soil organic carbon (SOC) was determined in 60 pedons from northern Alaska by horizon, within the seasonal thaw layer, and to a depth of 1 m. Concentration of SOC, bulk density, and SOC density were remarkably uniform for a given genetic horizon and had low standard errors. With increasing degree of decomposition, the bulk density increased, the concentration of SOC decreased, and the soil horizon C density increased in organic horizons. For mineral horizons, gleying is accompanied by an increase in C density, which is due to the effect of saturation on limiting decomposition of organic matter. Cryoturbation of organic or mineral minerals into the subsoil results in an increase in C density primarily from an increase in bulk density because of compaction from the overlying layers and more closely packed soil particles from frost churning. Estimated SOC storage for individual horizons and for the seasonal thaw layer were highly correlated ($p < 0.01$) with measured values from an independent data set for the same region published by other investigators. Equations relating C density to percentage of visible ice enable prediction of SOC in the near-surface permafrost. The equations generated by this study will be useful in preparing a detailed soil C map of the arctic regions.

There is considerable interest in SOC pools in arctic Alaska because of notable warming of the atmosphere in the past three decades, an increase in the thickness of the seasonal thaw layer (active layer), and warming of the near-surface permafrost (Serreze et al., 2000). These changes may have caused the arctic tundra to change from a net sink for atmospheric CO_2 in the early 1970s to a net source by the mid 1990s (Oechel et al., 1993). There is concern that release of CO_2 from arctic soils may exacerbate warming in the arctic.

Soil organic C storage in arctic Alaska is influenced by physiographic province with greater amounts in the Arctic Coastal Plain (average = 62 kg C m^{-3}) than in the Arctic Foothills (average = 44 kg C m^{-3}) (Michaelson et al., 1996). Land cover type also has an influence, with the greatest amounts in wet tundra (average = 68 kg C m^{-3}) and the least in dry tundra (average = 12 kg C m^{-3}) (Bockheim et al., 1997). Pedon C storage ranges from 2.5 kg C m^{-3} in modern beach sediments at Barrow, AK (Bockheim et al., 1999) to 98 kg C m^{-3} at a moist nonacidic tundra site in the Kuparuk watershed (Bockheim et al., 1997). Cryoturbation plays an important role in the distribution of SOC; as much as 62% of the SOC present in the upper 1 m exists in the near-surface permafrost (Michaelson et al., 1996; Bockheim et al., 1997).

The objectives of this study were to estimate SOC density (kg C m^{-2}) of genetic soil horizons and to test whether these values can be used to estimate C storage in individual soil horizons, the active layer, and the upper 1 m of arctic tundra soils. The latter includes both the active layer, typically 30 to 50 cm thick, and the near-surface permafrost.

MATERIALS AND METHODS

Sites

The study was conducted in two areas of arctic Alaska, the Barrow Environmental Observatory (71°N, 156°W) and the Kuparuk River watershed, which extends from Prudhoe Bay on the coast southward to Atigun Pass in the Brooks Range (about 68°30′–70°30′N lat., 148°30′–150°30′W long.). Twenty-five pedons were sampled and analyzed from the Barrow area and 35 from the Kuparuk watershed.

Sample Collection

Soil pits were dug by hand in major plant communities and soil taxa to the surface of the permafrost table in early August of 1995 through 1998 when the active layer was at its thickest (approximately 50 cm) and additionally excavated to a depth of 1 m with a gasoline-powered Pico impact drill[1] (Atlas, Copco, Kalmar, Sweden). Detailed soil descriptions were taken at all sites, and bulk samples were collected from each horizon within the active layer and placed in watertight bags.

In addition to the 60 soil pits, 30 cores were collected from the Barrow Environmental Observatory in April 2001 using a Big Beaver[1] drill (Little Beaver, Inc., Livingston, TX) with a 7.5-cm i.d. SIPRE coring barrel to an average depth of 124 cm. The cores were described according to soil horizon, the amount of segregation ice was estimated visually using a chart prepared by Yaalon (1966), and the cores were processed for moisture content and bulk density.

Laboratory Analyses

Samples from the 60 pedons were returned to the University of Wisconsin where bulk density was determined on an oven-dry (105°C) basis. 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, AK for SOC analysis by dry combustion on the Leco C determinator (Leco Corp., St. Joseph, MI). Carbonates reacting to a dilute acid solution were removed from samples in the Kuparuk watershed by treatment with 0.1 *M* HCl and analyzed on a Leco C determinator. Core samples from Barrow did not react with 1 *M* HCl; these samples were analyzed at the University of Wisconsin using a Dohrmann DC-190 total organic C analyzer (Tekmar-Dohrmann, Mason, OH).

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Published in Soil Sci. Soc. Am. J. 67:948–950 (2003).

[1] Mention of a trade names does not constitute endorsement by the University of Wisconsin.

Abbreviations: OC, organic C; SOC, soil organic C.

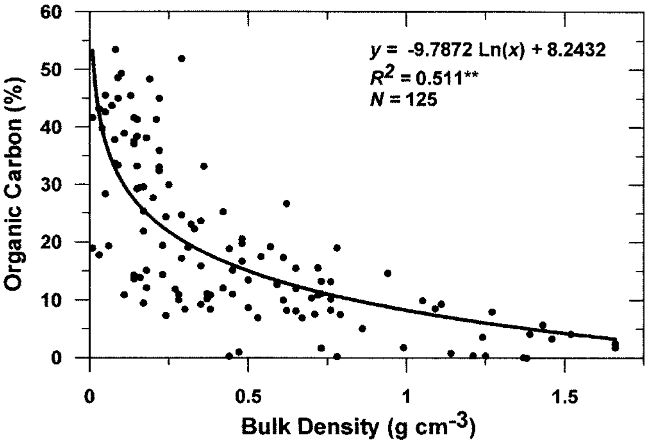

Fig. 1. Relation between organic C concentration and bulk density in tundra soils of arctic Alaska.

Computations and Statistical Analysis

Soil horizon C density was calculated using the equation:

$$\text{Horizon C density (kg C m}^{-2}\text{ cm}^{-1}) = D_{\text{bhor}}(\text{g cm}^{-3}) \times \%\text{C}_{\text{hor}}/10 \qquad [1]$$

where D_{bhor} is bulk density.

The estimated SOC densities for individual genetic horizons were used to compute SOC storage for soils sampled by Michaelson et al. (1996) in the Barrow area and the Kuparuk watershed. Soil organic C (OC) storage was investigated in (i) individual horizons, (ii) the active layer, and (iii) the upper 1 m of profile.

RESULTS AND DISCUSSION

There was a highly significant ($p < 0.01$) and moderately strong ($r^2 = 0.51$) correlation between the concentration of SOC and bulk density (Fig. 1). This empirically derived equation has utility for estimating bulk density from SOC concentration in studies where bulk density is needed for reporting soil nutrients on a volumetric basis.

Bulk density, SOC concentration, and soil horizon SOC density estimates are remarkably uniform for a specific horizon (Table 1). The concentration of SOC and soil horizon C density estimates are strikingly similar to values reported for the same soil taxa in arctic Alaska by Michaelson et al. (1996).

With increasing degree of decomposition, bulk density increases, the SOC concentration decreases, and soil horizon C density increases in organic horizons (Table 1). The increase in C density from the Oi to the Oe to the Oa horizon is likely because of comminution and the closer packing of organic particles during the decomposition process (Boelter, 1974).

For mineral horizons, gleying is accompanied by an increase in C density, which is likely because of the effects of saturation on limiting organic matter decomposition. Cryoturbation of organic or mineral materials into the subsoil results in an increase in C density, primarily from an increase in bulk density because of compaction from the overlying layers. In addition, displacement from alignment, rotation, sorting, and inclusions may cause the particles to become more closely packed (Fox, 1994).

Table 1. Bulk density, organic C concentration, and C density for major soil horizons in arctic Alaska (average + 1 standard error).

Horizon	No. of samples	Bulk density	Organic	C density
		g cm^{-3}	%	kg m^{-3} cm^{-1}
Oi	32	0.08 ± 0.01	43.1 ± 1.1	0.33 ± 0.03
Oe	28	0.23 ± 0.02	32.6 ± 2.0	0.69 ± 0.05
Oa	24	0.44 ± 0.04	25.4 ± 2.3	0.94 ± 0.06
A	10	0.64 ± 0.06	7.9 ± 1.0	0.47 ± 0.06
Bw	17	1.14 ± 0.05	4.4 ± 0.85	0.47 ± 0.07
Bg	19	1.10 ± 0.06	5.6 ± 0.82	0.56 ± 0.07
BC	3	1.40 ± 0.15	0.87 ± 0.47	0.13 ± 0.08
BCg	7	1.08 ± 0.06	5.1 ± 0.84	0.53 ± 0.05
C	7	1.23 ± 0.08	0.86 ± 0.38	0.11 ± 0.05
Cg	10	1.29 ± 0.10	4.6 ± 0.90	0.53 ± 0.08
Oijj	4	0.26 ± 0.04	19.2 ± 1.8	0.50 ± 0.09
Oejj	7	0.33 ± 0.06	26.5 ± 1.6	0.86 ± 0.15
Oajj	4	0.59 ± 0.05	17.4 ± 0.33	1.03 ± 0.11
Ajj	3	1.04 ± 0.15	7.7 ± 1.3	0.76 ± 0.02
Oajj/Cgf	3	0.34 ± 0.10	11.1 ± 1.2	0.40 ± 0.15

There was a highly significant ($p < 0.01$) and moderately strong ($r^2 = 0.51$) correlation between measured soil horizon C storage and C storage predicted on the basis of Eq. [1] (Fig. 2a). We are uncertain as to why the estimated soil horizon C values are less than the measured values. The relation between estimated and measured SOC storage in the seasonal thaw layer was highly significant ($p < 0.01$) and moderately strong ($r^2 = 0.52$; Fig. 2b). The equation relating estimated and measured soil C storage in the upper 1 m of the pedon was significant ($p < 0.01$) but had limited predictive power ($r^2 = 0.27$; Fig. 2c). Therefore, we are less confident in our ability to predict soil C storage in the upper 1 m of the pedon, which contains unpredictable quantities of segregation ice within permafrost comprising the lower part. For this reason estimates of soil C storage in permafrost should be corrected for ground ice content. We related C density to the percentage of visible ice for the Cgf and Oe/Cgf or Cg/Oef horizons (Fig. 3). These equations yielded highly significant ($p < 0.01$) results and enable prediction of C density for mineral or organic rich horizons in the near-surface permafrost.

The soils examined in this study contained negligible quantities of rock fragments >2 mm. For soils containing coarse fragments in excess of 15%, a correction should be made to allow for more precise estimates of soil C density. Most of the pedogenic horizons examined in this study were <15 cm thick. We observed the greatest source of error when predicting C storage in horizons greater than 25 cm thick.

Despite these limitations, soil horizon C density values reported here should be useful in preparing a detailed soil C map of arctic regions.

ACKNOWLEDGMENTS

This research was supported by NSF awards OPP-9912035 to J.G. Bockheim, OPP-9318528 to K.R. Everett and F.E. Nelson, OPP-9612647 to F.E. Nelson, and OPP-9529783 to K.M. Hinkel. L.R. Everett and J. Munroe assisted in the field. G.J. Michaelson and C.L. Ping kindly determined organic C on samples from the soil profiles and X.Y. Dai determined

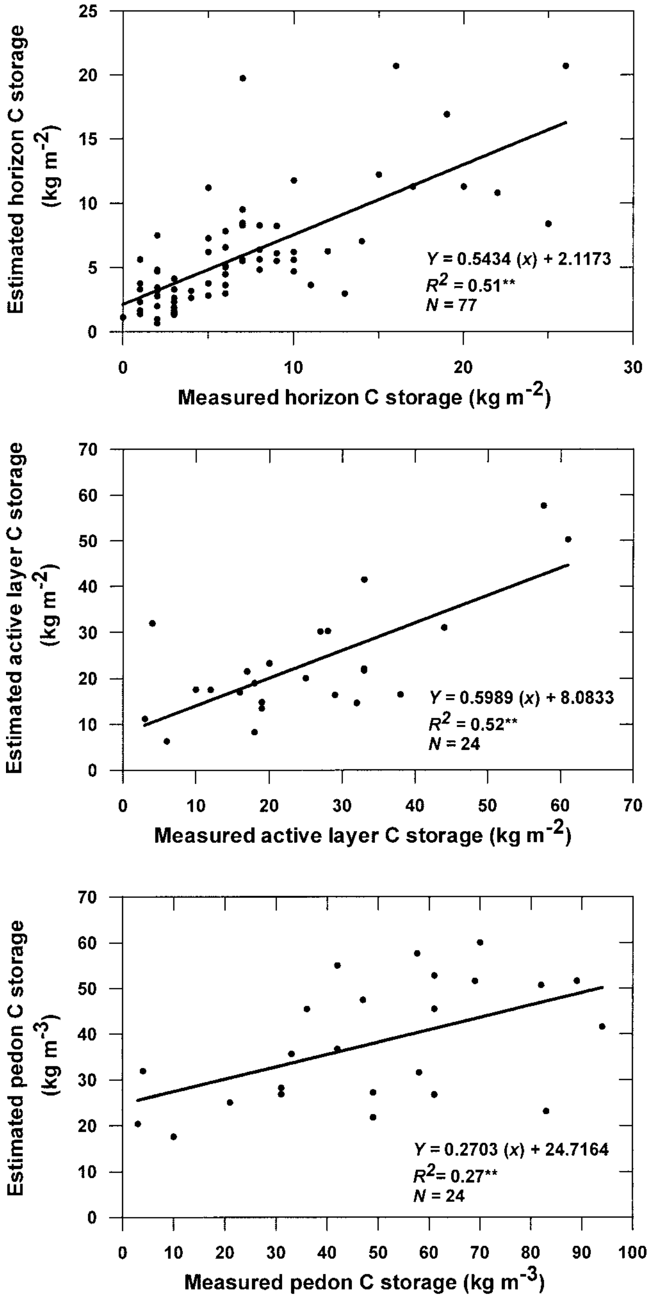

Fig. 2. Relation between estimated (equations generated herein) and predicted (from data by Michaelson et al., 1996) C storage in arctic soils on the basis of (A) horizon, (B) seasonal thaw layer, and (C) upper 1 m of profile.

organic C on core samples from Barrow. We appreciate the cooperation from the Barrow Arctic Science Consortium and the Ukpeagvig Inupiat Corporation.

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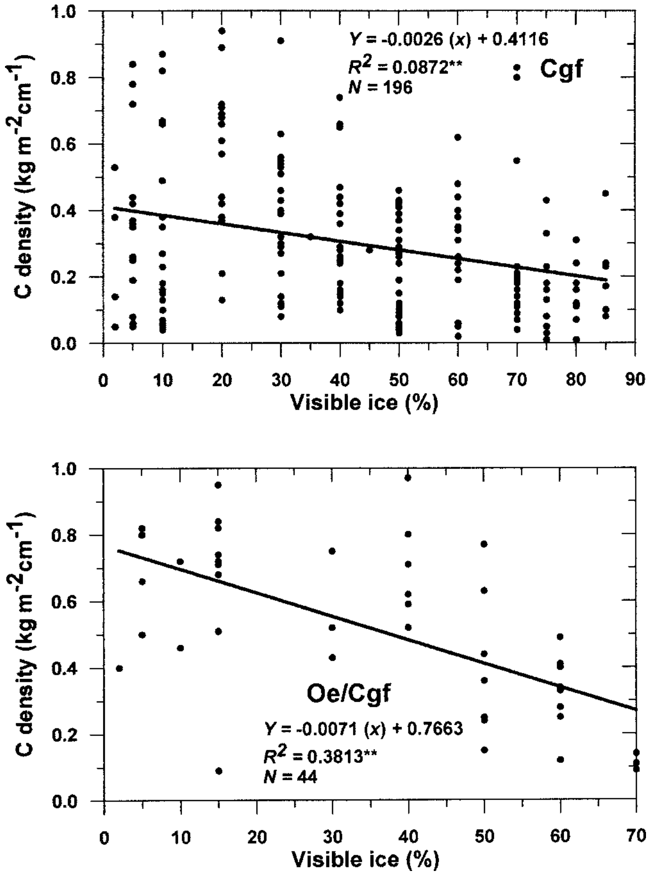

Fig. 3. Relation between C density and estimated visible ice in near-surface permafrost for the (A) Cgf and (B) Oe/Cgf or Cg/Oef horizons.