Soil organic matter in relation to altitude in equatorial Colombia[*]

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COMPENDIO

La influencia del dióxido de carbono atmosférico en el clima del mundo y su incremento debido a la quema de combustibles fósiles ha estimulado un interés mundial en el ciclo del carbono. Los suelos son importantes en este ciclo, porque mucho carbón orgánico es almacenado en ellos. En una región de Colombia con clima tropical húmedo, el carbón (método Walkley-Black) almacenado a un metro de profundidad en estos suelos (excluyendo el lecho superficial) fue del orden de 6,9 kg/m² a 600 m de altitud hasta 33,8 kg/m² a 3.700 m de altitud.

Una ecuación exponencial predice valores de 5,7 a 59,0 kg/m² entre el nivel del mar y 4.000 m de altitud (r = 0,78 para 16 muestras). A 25 cm de profundidad, los valores correspondientes son de 1,8 a 32,9 kg/m² (r = 0,84 para 31 muestras).

En los suelos, la relación carbono orgánico, a nitrógeno total se aumenta con el incremento de la altitud, pero con una aparente discontinuidad desde menor a 10 aproximadamente por debajo de 2.000 m hasta mayor de 12 por encima de los 2.000 metros de altitud. Esto implica discontinuidad en la relación entre carbono o nitrógeno o ambos y la altitud.

Introduction

THE global carbon cycle has attracted special interest due to the possible climatic implications of burning fossil fuels (3, 14). Large quantities of organic carbon are stored in soils. These quantities are not low in tropical soils (9), contrary to much popular opinion, and they increase considerably with altitude (10). Since previous studies have generally been confined to surface soils, we have compiled organic carbon contents to one meter depths in pedons sampled for soil characterization in an inventory of the soils of eastern Cundinamarca, Colombia. The resulting soil organic carbon-altitude relationships will allow more accurate estimals of carbon storage in the humid tropics.

Organic carbon data are compiled from soils in eastern Cundinamarca (Figure 1) because it is an area of considerable relief lacking noticeable influence from volcanic ash. The soil organic carbon-altitude relationship is obscured in areas of abundant recent volcanic ash deposits (11).

Environmental Setting

In Colombia, the Andes Mountains are split into three distinct ranges separated by the Cauca and Magdalena Rivers (Figure 1). The Department of Cundinamarca straddles the eastern range, or Cordillera Oriental. Data from 31 freely drained pedons in the Medina-Rio Guavio area of eastern Cundinamarca (Rio Negro area excluded) were used to establish soil organic carbon-altitude relationships. This area is between 4° and 5° N latitude and altitudes range from approximately 300 meters on the Llanos Orientales, a very large plain east of the mountains, to 4000 meters on the crest of the Cordillera Oriental.

Geology. In eastern Cundinamarca, the Cordillera Oriental consists predominantly of Mesozoic and older sedimentary and metamorphic rocks with lesser amounts of plutonic rocks and Tertiary sedimentary rocks

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Fig 1.—*A map of Colombia showing the location of eastern Cundinamarca (solid black) east of Bogotá*

The Llanos Orientales are surfaced with Quaternary sediments. These are dissected adjacent to the Cordillera Oriental exposing Tertiary sedimentary rocks. Data used are from pedons over Cretaceous sandstones and shales and similar but softer Tertiary clastic sedimentary rocks, except for the highest and lowest pedons. The highest pedon is on till from clastic sedimentary rocks and some of the lowest pedons are in Quaternary alluvial fan deposits.

Climate Mean annual temperatures in Cundinamarca are related to altitude by the formula $T = 30 - 6 \cdot A/1000$, where T is temperature in degrees Celsius and A is altitude in meters. However, temperatures in the Medina area average 1 degree higher than predicted by this formula (4). Therefore, mean annual temperatures range between 29°C on the Llanos Orientales, adjacent to the Cordillera Oriental, and 6° C on the crest of the Cordillera Oriental. Monthly means do not vary more than 1 or 2 degrees from the annual means.

Eidt (4) has compiled an isohyetal map showing annual precipitation decreasing with altitude from 170 cm in the Medina area to approximately 100 cm along the crest of the Cordillera Oriental. The annual distribution is bimodal, with maxima in April to May and in October to November. Evapotranspiration decreases more than precipitation decreases with elevation; therefore, the drier localities are in isolated valleys rather than high in the mountains. Soil water deficits reflected in plant growth are appreciable only in the Rio Negro area of eastern Cundinamarca.

Espinal and Montenegro (5) mapped climatic (life) zones in Colombia. These are based on vegetation related to climate (6) and, since there are few weather recording stations in eastern Cundinamarca, may be better indicators of climate than the maps of Eidt (4). The life zones mapped in eastern Cundinamarca indicate a much wider range of precipitation (less than 100 to more than 400 cm/year) than does the isohyetal map of Eidt (4).

Vegetation. Broadleaf evergreen forest is the natural cover in most of the Medina-Rio Guavio area. Subalpine grasslands, called páramo, predominate above 3200 meters in drier areas and above 3300 meters in wetter areas. Most of the pristine forest has been cut, except in the rugged Farallones de Medina, and nearly all pedons sampled are in unimproved pastures or secondary woodlands.

At approximately 1800 to 2000 meters there are dramatic changes in surface soil horizons related to altitude, and possibly a change in the temperature lapse rate (4), but no obvious changes in vegetative cover. This last observations applies only to physiognomy, since we did not determine plant species compositions.

Table 1.—Upland soils representative of the Medina-Rio Guavio area of eastern Cundinamarca. Shallow soils, which are generally on slopes greater than 65%, are not included

Altitude m	Soil Temperature Regime	Soil Classes (13)
3200-4000	Isomesic[1]	Humitropepts, and Histic Tropaquepts and Tropaquods
2600-3300	Isomesic	Andic Humitropepts, sparse Troporthods
1800-2700	Isothermic	Typic and Andic Humitropepts
900-2000	Isothermic and Isohyperthermic	Typic Dystropepts and Typic Tropudults
300-1000	Isohyperthermic	Orthoxic Tropudults, Plinthic Tropudults on convave slopes, and Oxic Dystropepts

1/ Isofrigid at 4000 meters

Table 2.—Some properties of soils in eastern Cundinamarca. Each of these soils is representative of one of the altitude zones in Table 1.

Horizon	Depth	Moist Color	Soil Texture	Volume Weight	Organic Carbon	C/N Ratio	pH
	cm			g/cm³	%		
Fine-loamy, mixed, isomesic Andic Humitropept (3250 m).							
A11	0—5	10YR 2/1	loam		19.8	15	3.9
A12	5—30	10YR 2/1	loam	0.68	13.0	15	4.3
A13	30—60	10YR 2/1	cl	0.86	4.4	15	4.9
Cr1	60—80	N 9/0	weakly consolidated sandstone and shale				
Cr2	80 +	2.5YR 6/4[1/]	weakly consolidated sandstone and shale				
Fine, mixed, isomesic Andic Humitropept (2750 m).							
A11	0—24	10YR 3/2	sic		8.2	15	5.1
A12	24—52	10YR 2/1	clay	0.8	3.4	13	5.0
B21	52—75	10YR 5/5	sicl	0.9	1.66	10	5.3
B22	75—90	10YR 6/6	clay	1.12	0.32	5	5.2
BC	90—115	10YR 6/6	cl		0.18	6	5.2
Cr	115—150+	N 9/0	weakly consolidated fine sandstone				
Coarse-loamy, mixed, isothermic Andic Humitropept (2250 m)							
A11	0—15	10YR 2/1	scl		12.4		4.9
A12	15—35	10YR 2/1	sl		8.4		4.7
A13	35—45	10YR 2/2	sl		4.8		5.6
B2	45—115	7.5YR 5/8	sl		1.76		5.3
C	115—130		ls				5.5
Fine, kaolinitic, isothermic Typic Tropudult (1875 m).							
A1	0—26	10YR 3/3	sicl		1.63		4.5
B1	26—37	10YR 5/6	cl		1.27		4.5
B2t	37—75	10YR 6/8	clay		0.62		4.9
B3	75—135		clay		0.35		5.2
R	135 +						
Fine, kaolinitic, isohyperthermic Orthoxic Tropudult (500 m).							
A1	0—3	10YR 4/3	scl		2.45	10	4.7
A3	3—8	2.5Y 5/4	cl		1.31	9	4.8
B1t	8—35	5YR 5/4	cl		0.86	9	4.9
B2t	35—80	5YR 5/6	cl		0.40	7	5.0
B3	80—120	2.5YR 5/6[2/]	cl				
C	120—150+	variegated[3/]					

1/ Many, medium, irregular 7.5YR 5/6 mottles.

2/ Common, medium, soft to slightly hard 10R 3/4 to 4/6 mottles.

3/ Red mottles harder than in B3 horizon.

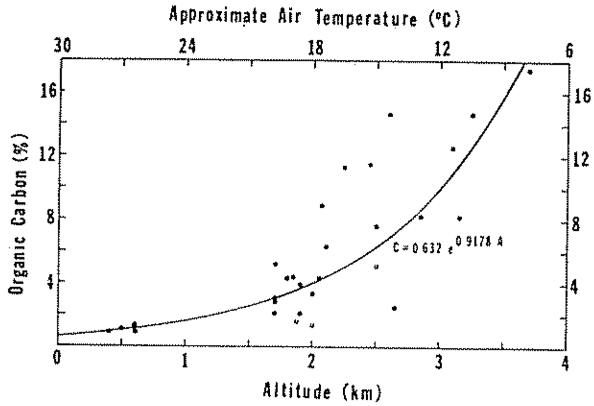

Fig. 2.—*Percentages of organic carbon in surface soils (0-20 cm) of the Medina-Rio Guavio area in eastern Cundinamarca*

Soils. The most representative soils of the Medina-Rio Guavio area are listed in Table 1. Other than the somewhat poorly drained Tropaquepts and Tropaquods, which appear to be major components of the subalpine grasslands, all of the more extensive soils are well drained. Histosols are common above 2000 meters altitude, but inextensive. Soils in Lithic subgroups of Dystropepts and Humitropepts are common on very steep slopes.

Soils with argillic horizons predominate at lower altitudes but are less prevalent with increasing altitude and absent above 2700 meters in humid areas. There is an abrupt change in epipedon characters at approximately 1800 to 2000 meters, which is common at the same altitude in other parts of Colombia where ever-volcanic ash is not too great an influence. Below 1800 meters ochric epipedons predominate and above 2000 meters umbric epipedons predominate. The high altitude umbric epipedons are very friable with low bulk densities regardless of the influence of volcanic ash, although soils with appreciable deposits of recent volcanic ash have epipedons with similar properties at considerably lower altitudes.

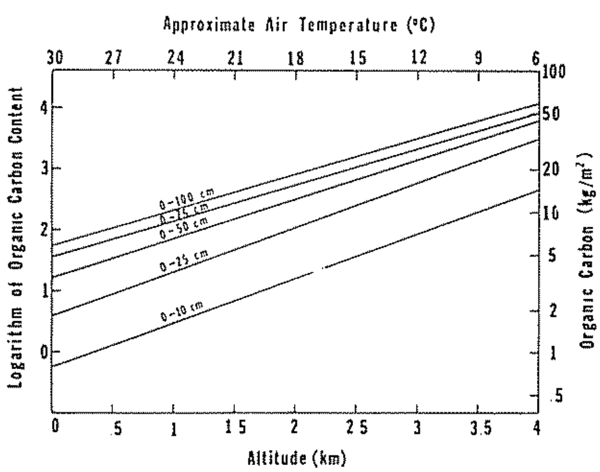

Fig. 3.—*Weights of organic carbon (C) in meter squares to 0-10, 0-25, 0-50, 0-75, and 0-100 cm depths based on least squares estimates by equations of the form ln (C) = ln (a) + b . A, where ln in the symbol for Napierian logarithm and A is altitude. Soil volumes in cubic meters corespond to depths in meters; therefore 0.1, 0.25, 0.5, 0.75, and 1.0 cubic meters, where soil depths are measured perpendicular to slopes (1)*

Table 3.—Organic carbon in soils of eastern Cundinamarca.

Pedon Altitude m	Soil Organic Carbon Content 1/ kg/m²				
	0-10 cm	0-25 cm	0-50 cm	0-75 cm	0-100 cm
3700	12.7	25.1	28.4	30.2	33.8
3250	9.8	21.5	32.4		
3150	6.0	14.3	23.1	26.0	28.8
3100	7.8	18.6	32.2	35.7	36.0
2750	5.7	14.0	20.8	24.7	25.5
2650	2.3	5.7	9.4		
2600	8.8	19.3	25.3	28.1	30.6
2500	4.1	9.0	13.5	17.5	
2500	6.5	12.4	16.1		
2450	8.0	20.1	40.2	57.2	61.1
2250	7.4	17.0	27.6	31.6	35.5
2100	4.4	11.0	18.0	23.6	23.1
2075	6.5	15.3	21.8	20.6	
2050	3.4	8.5	15.5		
2000	2.7	6.7	13.5	20.3	27.1
2000	1.3	3.0	5.1	9.4	9.6
1900	2.7	4.4	5.3	7.4	11.0
1900	3.7	7.2	9.4	10.7	12.0
1900	1.9	4.6	7.1	8.3	9.3
1875	1.5	3.7	6.2	8.0	
1850	3.6	7.8	11.4	14.4	
1800	3.4	8.5	15.5		
1700	2.5	6.2	8.5		
1700	4.1	9.1	12.0	13.8	
1700	1.9	4.7	7.8	10.5	13.3
1700	2.5	6.2	12.4	18.5	20.4
600	1.3	2.9	5.5	7.9	
600	1.4	2.9	4.9	6.5	8.0
600	1.2	2.6	5.2	6.7	6.9
500	1.5	3.1	5.0	6.5	
400	0.9	2.3	4.6	6.8	

1/ Organic carbon by Walkley-Black method (2, 8)

Table 4.—The relation of soil organic carbon (C) to altitude (A) in eastern Cundinamarca as determined by regression analyses, assuming an exponential relationship, C = a ebA. All of these regressions are highly significant (p = 0.01).

Depth	Organic Carbon	Number of Pedons	Constants		Coefficient of Determination	Doubling Altitude	Halving Temperature
			a	b			
cm	units	N			r^2	m	°C
0–10	kg/m^2	31	0.782	0.729	0.703	951	5.7
0–20	%	31	0.6321	0.9178	0.714	755	4.5
0–25	kg/m^2	31	1.780	0.729	0.714	951	5.7
0–50	kg/m^2	31	3.352	0.646	0.638	1073	6.4
0–75	kg/m^2	25	4.773	0.590	0.631	1175	7.0
0–100	kg/m^2	16	5.705	0.584	0.610	1187	7.1

Methods

Field. Soils were described and sampled by horizons. All data used are from freely drained soils on slopes less than 65% (33 degrees). Soil properties most pertinent to soil organic matter-altitude relationships are listed in Table 2.

Laboratory. All quantitative analyses of soil samples were done in the Soils Laboratory of the Departamento Agrológico, Instituto Geográfico "Agustín Codazzi". Organic carbon was determined by the Walkley-Black method and total nitrogen by the Kjeldahl method (12). A few samples were taken in cyinlders to determine representative bulk densities.

Calculation. Organic carbon was compiled as percent in the upper 20 cm of soil and as kg/m^2 to depth of 10, 25, 50, 75, and 100 cm. Although volume samples were not taken from each pedon sampled, enough were taken from several pedons in the Medina-Rio Guavio area and other parts of Cundinamarca to confidently relate bulk density to soil organic matter content (percent by weight). Bulk densities of 0.6, 0.7, 0.8, 0.9, 1.0, 1.2, and 1.5 g/cm^3 corresponding to organic carbon contents of greater than 12, 6 to 12, 3 to 6, 1.5 to 3, 0.9 to 1.5, 0.6 to 0.9, and less than 0.6% were used in all calculations. No corrections were made for coarse fragments, but few of the soils sampled had many.

Results and discussion

Organic carbon contents of soils in eastern Cundinamarca increase with increasing altitude and decreasing temperature, just as has been reported for other areas by Jenny (9). The results for the Medina-Rio Guavio area of eastern Cundinamarca are summarized in Table 3 and shown graphically in Figures 2 and 3. Organic carbon contents are essentially exponential functions of altitude in the Rio Guavio-Medina area ($C = a\ e^{bA}$), just as in other areas (7).

Comparisons between data sets are facilitated by doubling altitudes and halving temperatures. The halving temperatures listed in Table 4 compare closely to values of 4.9 to 5.3 determined previously for surface soils in Colombia (9). Doubling altitudes are least for surface soils (0-25 cm), indicating that organic carbon differences are greater in surface than in subsoils. Also, doubling altitudes are less for results compiled in percent than for results compiled as weight in a unit volume (kg m^{-2} $depth^{-1}$), because soil bulk densities (or volume weights) decrease with increasing altitude and organic carbon contents.

The slope of the exponential curve increases at a constant rate as altitude, and hence soil organic carbon, increases. Since soil organic carbon might not be expected to increase at the same rate indefinitely, we tried an equation of the form $C = a\ e^{bA}\ A^c$. The slope of this curve would decrease at high altitudes if the constant b were negative, but it was positive for all of

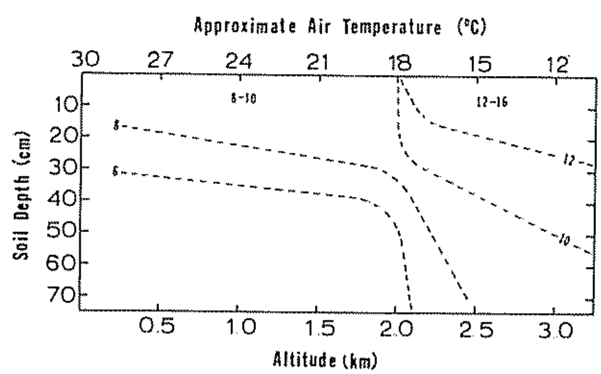

Fig. 4.—*Organic carbon to total nitrogen ratios in relation to soil depth and altitude in eastern Cundinamarca, based on analyses of 72 horizont samples from 26 pedons. The diagram is truncated at 75 cm, due to low ratios (some less than 2) in the subsoil which are presumedly due to substantial quantities of inorganic nitrogen as determined elsewhere (15).*

the regression equations developed for the data of eastern Cundinamarca and the curves were practically coincident with the simple exponential curves

The exponential curves should not be extrapolated beyond 4000 m altitude, and they certainly will not be valid above the climatic snowline which is at approximately 5000 m altitudes in equatorial Colombia.

The organic carbon to total nitrogen ratios in soils of eastern Cundinamarca increase with altitude (Figure 4). There appears to be a discontinuity at about 2000 meters, although the data are not sufficient for anything more than a schematic representation of this concept. Either the soil organic carbon or the soil nitrogen contents, or both, may be discontinuously related to altitude. No definite discontinuity was detected for organic carbon, but one might be substantiated with more data.

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Notas y Comentarios

No hay daño en las vacas extrafértiles

El tratamiento para provocar la producción de óvulos extra no les hace ningún daño a las vacas, según un informe de la Animal Research Station, en Cambridge, Inglaterra. Los ganaderos estarán satisfechos de saber que esta nueva forma de obtener mayor número de genes superiores, que consiste en estimular a las vacas que tienen un útil acervo genético a producir múltiples óvulos y trasplantar los resultantes embriones en desarrollo a madres putativas, no causará daños a la fertilidad de las vacas posteriormente (*Veterinary Record*, vol. 104, p. 281).

Los biólogos ejecutan esta notable hazaña inyectando a una vaca con una hormona aislada de un equino (suero gonadotropina de yegua preñada), la que estimula el desarrollo de los folículos del ovario. Inyectan entonces una sustancia química, cloprostenol, que hace que se rompan todos los folículos recién estimulados y que liberen todos sus óvulos juntos.

Dos días después se insemina a la vaca, y después de dejar que los óvulos se desarrollen por una semana, los colectan con un delicado lavado del útero. Estos embriones pueden entonces ser trasplantados a otras vacas, o ser congelados y almacenados en bancos de embriones, antes de su trasplante final al útero de su nueva madre adoptiva.

W. B Christie, R Newcomb, y L E A. Rowson superovularon 14 vaquillas hasta 10 veces en rápida sucesión, y las vacas respondieron con cosechas de hasta 19 óvulos en una sola ovulación. Al final del experimento las vacas fueron inseminadas después de su retorno a ciclos estrales normales. Más del 90 por ciento concibieron, la mayoría en dos inseminaciones

Los ganaderos pueden tener ahora más confianza de que los centros de transferencia comercial de embriones que funcionen en el futuro serán eficaces y seguros.