Research Note

CARBON SEQUESTRATION IN SOILS OF THE RIO GRANDE DE ARECIBO WATERSHED, WEST-CENTRAL PUERTO RICO[1]

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The potential of soils to sequester atmospheric carbon and thus mitigate global warming has been a popular topic of research in recent years as documented, for example, in the book on *Soil Management and the Greenhouse Effect* (Lal et al., 1995). Relevant research in Puerto Rico includes two publications that determined the status of organic carbon in the soils of the island and evaluated the factors that control its accumulation (Beinroth, 1992; Beinroth et al., 1996). The data reported here further contribute to this effort. They were produced by a project on Carbon Sequestration in a Tropical Watershed, a component of the NASA-funded Tropical Center for Earth and Space Studies at the Mayagüez Campus of the University of Puerto Rico.

The objectives of the project are to 1) assess the amount of organic carbon sequestered in the soils of the Río Grande de Arecibo watershed, 2) determine the scope for additional sequestration of atmospheric carbon, and 3) develop soil management practices and techniques conducive to built-up of organic carbon in the soil. This research note presents the results of initial efforts to address the first objective.

The 44,240-ha Río Grande de Arecibo watershed is located in west-central Puerto Rico and is one of the largest of the island. (For the purpose of this study, only the area south of the dam of the Lago Dos Bocas reservoir was considered.) The watershed is bordered by latitudes 18°11' and 18°20' N and longitudes 66°32' and 66°46' W. Elevation in the watershed ranges from about 150 to 1,300 m. Annual precipitation averages 200 to 250 cm, and mean annual temperatures vary with altitude from 24 to about 18°C. Geologically, about two thirds of the watershed consists of volcaniclastic Cretaceous rocks of andesitic or basaltic composition, and one third of quartzdiorite and granodiorite of Late Cretaceous and Early Tertiary age. Tertiary limestone and Quaternary alluvial deposits occur in small areas. The terrain in the watershed is mountainous with a high degree of dissection, particularly in the area of the plutonic rocks. These rocks weather easily to produce a friable, sandy regolith that is very susceptible to erosion.

The soils of the watershed exhibit much diversity. There are 35 soil series that are subdivided into 82 map units on the basis of slope and degree of erosion. The variability is reflected in the taxonomic classification of the soil series according to Soil Taxonomy (Soil Survey Staff, 1999), which is presented in Table 1. The dominant soils of the watershed are three series of Ultisols (Humatas, Los Guineos) and three series of Inceptisols (Maragüez, Múcara, Pellejas), which together amount to 66 percent of the watershed area (Table 2). The Ultisol and Múcara series are developed on volcanic rocks, whereas the Pellejas series is derived from plutonic rocks. Nearly half of the 82 map units (37 or

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TABLE 1.—*Taxonomic classification of the soil series of the Río Grande de Arecibo watershed.*[1]

Soil Series	Classification
Adjuntas*[2]	very-fine, kaolinitic isohyperthermic Inceptic Hapludox
Almirante*	very-fine, kaolinitic, isohyperthermic Plinthic Hapludox
Alonso*	very-fine, parasesquic, isohyperthermic Oxic Dystrudepts
Bayamón*	very-fine, kaolinitic, isohyperthermic Typic Hapludox
Caguabo	loamy, mixed, active, isohyperthermic, shallow Dystric Eutrudepts
Colinas*	coarse-loamy, carbonatic, isohyperthermic Typic Haprendolls
Coloso*	very-fine, kaolinitic, acid, isohyperthermic Vertic Endoaquepts
Consejo*	fine, kaolinitic, isohyperthermic Xanthic Hapludox
Consumo*	fine, mixed, semiactive, isohyperthermic Typic Haplohumults
Corozal*	very-fine, parasesquic, isohyperthermic Typic Hapludults
Cuchillas	loamy, mixed, active, isothermic, shallow Typic Dystrudepts
Dagüey*	very-fine, kaolinitic, isohyperthermic Typic Kandiudox
Espinosa*	fine, parasesquic, isohyperthermic Typic Kandiudults
Humatas*	very-fine, parasesquic, isohyperthermic Typic Haplohumults
Hydraquent	undifferentiated Hydraquents
Ingenio*	fine, kaolinitic, isohyperthermic Typic Hapludults
Juncal	fine, mixed, active, isohyperthermic Typic Hapludalfs
Lares*	very-fine, mixed, semiactive, isohyperthermic Aquic Hapludolls
Lirios	fine, mixed, subactive, isohyperthermic Typic Hapludults
Los Guineos*	very-fine, kaolinitic, isothermic Humic Hapludox
Maragüez	fine-loamy, mixed, superactive, isohyperthermic Dystric Eutrudepts
Maricao	fine, mixed, subactive, isohyperthermic Inceptic Hapludults
Moca*	very-fine, mixed, semiactive, isohyperthermic Vertic Paleudults
Morado*	fine, mixed, superactive, isohyperthermic Dystric Eutrudepts
Múcara*	fine-loamy, smectitic, isohyperthermic Dystric Eutrudepts
Pellejas	fine-loamy over sandy or sandy-skeletal, mixed, active, isohyperthermic Typic Dystrudepts
Perchas*	fine, smectitic, isohyperthermic Chromic Dystraquerts
Reilly	sandy-skeletal, mixed, subactive, isohyperthermic Mollic Endoaquents
San Germán	clayey-skeletal, carbonatic, isohyperthermic Typic Udorthents
San Sebastián	clayey-skeletal, carbonatic, isohyperthermic Typic Haprendolls
Soller	clayey, mixed, active, isohyperthermic, shallow Inceptic Haprendolls
Tanamá	clayey, mixed, active, isohyperthermic Lithic Hapludalfs
Toa*	fine, mixed, active, isohyperthermic Fluventic Hapludolls
Viví	coarse-loamy over sandy or sandy-skeletal, mixed, superactive, isohyperthermic Mollic Udifluvents
Voladora*	very-fine, mixed, active, isohyperthermic Typic Haplohumults

[1]According to Soil Taxonomy (Soil Survey Staff, 1999).
[2]Indicates availability of laboratory characterization data for one or more pedons of the series.

45%) are eroded, and 15 soil series occur as eroded phases only. The area of eroded soils amounts to about 16,500 ha or 39 percent of the soil area of the watershed, all of which relates to the fact that half of the map units (41) have slopes in excess of 20 percent, and in the recent past were intensively farmed.

TABLE 2.—*Organic carbon sequestered in the soils of the Río Grande de Arecibo watershed sorted by area of map units.*

Soil series	Map unit	Area (ha)	kg C/m²		Mg C in map unit	
			0-30 cm	0-100 cm	0-30 cm	0-100 cm
Pellejas	PeF	8680	4.71	5.38	408828	466984
Humatas	HmF	5510	10.82	16.01	596182	882151
Lirios	LcF2	4595	4.05	9.37	186098	430552
Humatas	HmF2	2747	7.57	12.76	207948	350517
Maragüez	MaF2	2367	5.55	8.39	131369	198591
Los Guineos	LgF	2089	12.78	22.67	266974	473576
Múcara	MuF	1867	6.39	8.34	119301	155708
Maricao	MkF2	834	3.95	9.17	32943	76478
Alonso	AoF2	828	7.35	16.32	60858	135130
Caguabo	CbF2	803	4.10	4.45	32923	35734
Los Guineos	LgE	765	12.78	22.67	97767	173426
Los Guineos	LuF	734	12.78	22.67	93805	166398
Los Guineos	LME	658	12.78	22.67	84092	149169
Humatas	HmE	607	10.82	16.01	65677	97181
Humatas	HmE2	581	7.57	12.76	43982	74136
Caguabo	CpF	550	5.68	6.21	31240	34155
Maricao	LME	458	5.64	10.86	25831	49739
Viví	Vm	456	6.66	11.74	30370	53534
Maragüez	MeF2	454	5.55	8.39	25197	38091
Adjuntas	AdF2	434	5.92	9.66	25693	41924
Morado	MpF2	398	3.29	4.89	13094	19462
Soller	SrF	397	7.79	9.08	30926	36048
Los Guineos	LyFX	375	12.78	22.67	47925	85013
Caguabo	CaF	339	5.86	6.21	19865	21052
Ingenio	InD	300	6.14	10.40	18420	31200
Consejo	CoF	294	9.96	14.77	29282	43424
Pellejas	PeF2	288	2.36	3.02	6797	8698
Reilly	Re	284	5.36	10.64	15222	30218
Alonso	AnF2	260	7.35	16.32	19110	42432
Maricao	LyFX	250	5.64	10.86	14100	27150
Lirios	LmF2	242	4.02	9.38	9728	22700
Lirios	LcE2	230	4.02	9.38	9246	21574
Múcara	MuF2	220	4.47	6.42	9834	14124
Caguabo	CdF	211	5.86	6.21	12365	13103
Voladora	VoE2	207	4.10	9.09	8487	18816
Los Guineos	LgD	175	12.78	22.67	22365	39673
Colinas	CmF2	175	4.20	6.09	7350	10658
Dagüey	DaD2	166	5.14	10.34	8532	17164
Ingenio	InE	155	6.14	10.40	9517	16120
Los Guineos	LuE	146	12.74	22.67	18600	33098
Adjuntas	AaF2	129	5.92	9.66	7637	12461
Toa	To	125	5.87	16.51	7338	20638
Cuchillas	CuF	111	9.50	14.79	10545	16417
Corozal	CrC	105	7.32	12.54	7686	13167

TABLE 2.—*(Continued) Organic carbon sequestered in the soils of the Río Grande de Arecibo watershed sorted by area of map units.*

Soil series	Map unit	Area (ha)	kg C/m²		Mg C in map unit	
			0-30 cm	0-100 cm	0-30 cm	0-100 cm
Alonso	AnE2	100	7.35	16.32	7350	16320
Cuchillas	CuF2	78	7.35	11.94	5733	9313
Soller	SoD	69	7.79	9.08	5375	6265
Dagüey	DaD	68	7.34	12.54	4991	8527
Consumo	CpE	60	3.67	6.22	2202	3732
Tanamá	RtF	52	7.46	8.37	3879	4352
Soller	SpF	51	7.79	9.08	3973	4631
Alonso	AoE2	50	7.35	16.32	3675	8160
Maricao	McF	50	5.64	10.86	2820	5430
Voladora	VoC2	49	4.10	9.09	2009	4454
Caguabo	CbF2	47	5.86	6.21	2754	2919
Tanamá	TaD2	36	5.22	6.13	1879	2207
Morado	MtF2	35	3.29	4.89	1152	1712
Soller	SpD	34	7.79	9.08	2649	3087
Perchas	PhD2	33	4.75	6.22	1568	2053
Cuchillas	CvF	31	9.50	14.79	2945	4585
Lares	LeC	31	6.14	10.15	1903	3147
Colinas	ClD2	29	4.20	4.29	1218	1244
Moca	MoC2	25	4.86	10.59	1215	2648
Consejo	CoE	23	9.96	14.77	2291	3397
Múcara	MuE	20	6.39	8.34	1278	1668
Hydraquents	HD	19	5.87	16.51	1115	3137
Alonso	AoD2	18	7.35	16.32	1323	2938
Espinosa	EcC	18	2.29	5.35	412	963
Moca	MoD2	12	4.86	10.59	583	1271
Soller	SoF	8	7.79	9.08	623	726
Coloso	Cn	7	6.63	14.15	464	991
Colinas	ClF2	7	4.20	4.29	294	300
Múcara	MuE2	6	4.47	6.42	268	385
Juncal	JuD2	5	4.70	9.90	235	495
Almirante	AnC	5	8.29	13.55	415	678
Voladora	VoD2	4	4.10	9.09	164	364
San Sebastián	SmF	4	13.35	15.45	534	618
Los Guineos	LsF	4	12.78	22.67	511	907
Múcara	MuD2	2	4.47	9.90	89	198
Perchas	PhD2	2	4.57	6.22	91	124
Bayamón	ByC	1	7.04	9.18	70	92
San Germán	SgF	1	3.22	3.22	32	32
Almirante	AnB	1	8.29	13.55	83	136
	Total	42694			3001217	4811782

The study is based on spatial information contained in the soil surveys on a scale of 1:20,000 for the Arecibo area (Acevedo et al., 1982) and the Ponce area (Gierbolini et al., 1979) produced by the USDA Natural Resources Conservation Service (NRCS), and on characterization data provided by the National Soil Survey Laboratory of the NRCS. This laboratory uses the modified Walkley-Black method (Walkley and Black, 1934) for determining organic carbon.

A digital version of the soil maps was obtained from the U.S. Geological Survey and analyzed by using the ARCView v.3.2a geographic information system (GIS). Laboratory data are available for 21 of the 35 soil series. In cases where no series-specific data exist the parameters used in computing carbon contents were estimated from taxonomically identical or similar soils that have been analyzed.

Because of the intricacy of the soil pattern, soil associations and soil complexes rather than single soil series were mapped on about 3,000 ha (7%) of the watershed; e. g., the Los Guineos-Maricao-Rock Outcrop Association (LME) and the Soller-Rock Outcrop Complex (SrF). For these areas we considered the proportion of the area with a soil cover, as indicated in the soil survey reports. About 1,500 ha in the watershed has no soil. Among these areas, rock outcrop (630 ha), surface water (550 ha) and urban land (250 ha) are the most extensive. These areas were excluded from the assessment.

The organic carbon contained in one square meter of soil to a depth of 100 cm was calculated by multiplying gravimetric organic carbon content, bulk density and thickness for the different soil layers to a depth of 100 cm or to a lithic or paralithic contact if it was shallower. For eroded soils, we assumed that erosion has removed about 30 percent of the original carbon content and reduced the carbon amount accordingly. The GIS was used to determine the area of all map units and to aggregate the carbon content over the watershed. Carbon data are reported for the customary 0- to 30-cm and the 0- to 100-cm depth, and are expressed as Mg (1 Mg = 1 metric ton).

The soils of the watershed sequester approximately 4.8 million tons (4,811,782 Mg) of organic carbon. Most of this amount (62%) is contained in the 0- to 30-cm layer. The data are summarized in Table 2 for each map unit.

The average carbon content per hectare is about 109 Mg, which is nearly identical to the island-wide average of 107 Mg/ha (Beinroth, 1992). There is, however, considerable variability in the watershed, ranging from 2.29 to 13.35 kg C/m^2 in the 0- to 30-cm layer and from 3.02 to 22.67 kg C/m^2 in the 0- to100-cm layer. This variability reflects the geology of the parent material and the degree of erosion. The extensive Pellejas, which is derived from plutonic rocks, and the Los Guineos series, which is developed in volcanic rocks, represent the two extremes of carbon content (Table 2).

Figure 1 illustrates the spatial distribution of organic carbon in the watershed for the 0- to 30-cm and 0- to 100-cm layers and three levels of organic matter (high, medium and low). Again, the geologic control of the amount of carbon stocks is clearly evident.

Eroded soils amount to 16,500 ha or 39 percent of the watershed. These soils are identified by the numeral 2 in the map unit code in Table 2. If all of these eroded soils could be restored to their original level of organic matter, an additional amount of about 379,500 Mg of carbon could be sequestered in the watershed. This addition would represent a relatively small increase of 7.9 percent above the current level.

The carbon data reported here were calculated by using soil series-generic and estimated parameters. The map unit-specific sampling and analysis of the soils of the watershed that is currently in progress may well necessitate a revision of our estimates. Particularly relevant will be the comparison of the carbon values for the eroded vs. noneroded soils generated by site-specific and our generic data. This difference in the amount of carbon between eroded and noneroded soils would indicate the potential for further carbon sequestration. It is assumed that this potential can be realized by land use practices conducive to the accumulation of organic matter, such as conversion to pasture or forest, or planting environmental cane *(Saccharum spontaneum)* or vetiver grass *(Vetiveria zizaniodes)*. However, given the adverse terrain characteristic of the watershed, it may be difficult to fully rehabilitate the eroded soils.

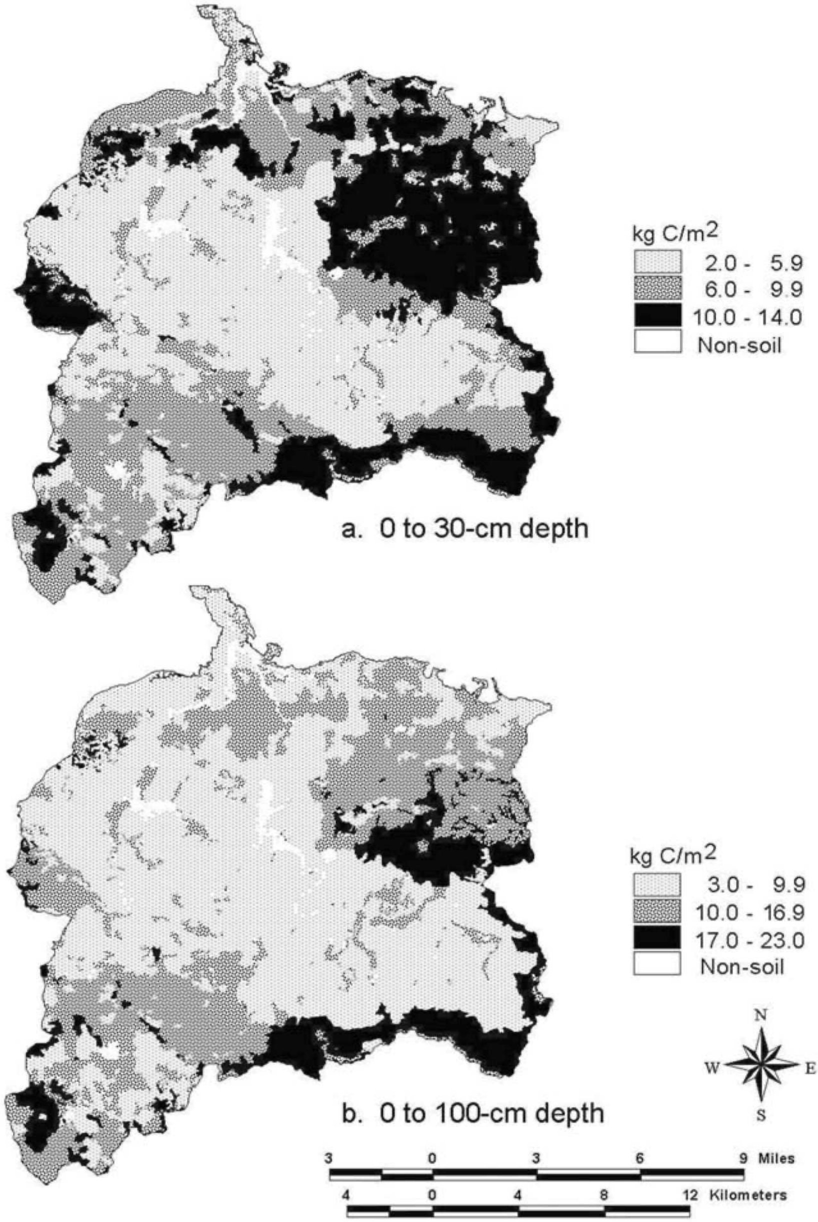

FIGURE 1. Organic carbon content of the soils of the Río Grande de Arecibo watershed (kg C/m² for two depths).

Our study and the subsequent sampling indicate the status quo of soil carbon in the watershed. It does not indicate the dynamics of soil carbon over time and thus fails to show the rate of change in carbon content, i.e., whether the watershed is a sink or source for atmospheric carbon. Further research is needed, therefore, to monitor the dynamics of carbon over time. A comprehensive study should also evaluate and measure the biological characteristics related to the three organic matter pools in soils – fast, intermediate and slow pools. In addition to traditional analyses, this research would include analysis of microbial biomass and activity, labile carbon fractions of organic carbon, mineralizable nitrogen, root biomass and particulate organic matter, and clay associated amorphous organic matter (Franks, 2002). A research program addressing these issues is now being initiated by the National Soil Survey Center of the USDA Natural Resources Conservation Service. We are exploring the possibility of having the Río Grande de Arecibo watershed included in this program.

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