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ESTIMATION OF CHANGES IN SOIL ORGANIC CARBON IN HILLSIDE SYSTEMS ON A REGIONAL SCALE

[ESTIMACIÓN DE CAMBIOS DE CARBONO ORGÁNICO DEL SUELO EN SISTEMAS DE LADERA A ESCALA REGIONAL]

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SUMMARY

Estimation of soil organic carbon (SOC) stocks at the regional scale, and of the changes that occur over time, is needed to conduct more realistic carbon (C) inventories. This study compares changes in estimated SOC in three regions of the Sierra Norte of Oaxaca (Mazateca, Cuicateca, and Mixe) with the method proposed by the Intergovernmental Panel on Climate Change (IPCC) and the RothC model fed with spatial information from the IPCC method. Changes were estimated for the periods 1980-2000 and 1990-2000. The SOC balance in the study regions resulting from the two methods indicates losses in the range of 342-1509 Gg in the first period and 29-1052 Gg in the second. Changes in SOC estimated with both methods, in general, exhibited the same trend for the two periods. The correlation coefficients varied between 0.86 and 0.99. This study shows that the RothC model used with partial information from the IPCC method is a useful tool for predicting changes in estimated SOC on a regional scale in the hillside systems studied.

Key words: Land use and vegetation; carbon modeling; IPCC categories.

RESUMEN

La estimación de los almacenes de carbono orgánico del suelo (COS) a escala regional y de los cambios que éstos experimentan con el tiempo, es necesaria para realizar inventarios de carbono (C) más apegados a la realidad. En el presente trabajo se compararon los cambios, en tres regiones de la Sierra Norte de Oaxaca (Mazateca, Cuicateca y Mixe), del COS estimados con el método propuesto por el Panel Intergubernamental sobre Cambio Climático (IPCC) y con el modelo RothC, alimentado con información espacial del método IPCC. Los cambios se estimaron para los periodos 1980-2000 y 1990-2000. El balance de COS en las regiones de estudio, realizado con ambos métodos, indica pérdidas en el rango de 342-1509 Gg para el primer periodo y de 29-1052 Gg en el segundo período. El COS estimado con ambos métodos presentó, en general, la misma tendencia en las regiones de estudio para los dos periodos analizados. Los coeficientes de correlación variaron entre 0.86 y 0.99. Este trabajo muestra que el modelo RothC usado con información parcial del método IPCC es una herramienta predictiva, adecuada para estimar los cambios de COS a escala regional en los sistemas de ladera estudiados.

Palabras clave: Uso de suelo y vegetación; modelación de carbono; categorías IPCC.

INTRODUCTION

The amount of SOC stored in the soil is an indicator of the environmental quality of mineral soils because of the effect it has on functional properties such as fertility, soil structure and water relationships (Ogle and Paustian, 2005). Janzen (2003) states that changes in SOC can help determine the influence of management on the ecosystem, the capacity of the ecosystems to tolerate or resist increasing global concentrations of atmospheric CO_2, and their soil's capacity to filter air, among other functions. The United Nations Framework Convention on Climate Change, among other institutions, recognizes the importance of estimating SOC stocks and changes under different scenarios and environments on the national and regional scales to broaden understanding of the global carbon cycle (Milne *et al.*, 2007).

Mexico must estimate SOC periodically to update national inventories of C, following the guidelines of the Intergovernmental Panel on Climatic Change (IPCC), or other C prediction models (Naciones Unidas, 1992). The ideal situation is that these inventories be taken at different geographic scales, considering different land uses and climatic scenarios.

The SOC Modeling System proposed by the Global Environmental Facility, or GEFSOC, measures SOC changes based on models of soil organic matter (SOM) incorporated into the Century and RothC models, as well as into the IPCC method (Milne *et al.*, 2007). The system, in general, comprises five stages: (1) evaluation of the Century and RothC models for the area of study; (2) information gathering on soil, climate, historical and current land use, and soil management to feed into the model; (3) development of the modeling system to join the dynamic SOM models and the IPCC method with spatial databases using a geographic information system (GIS); (4) estimation of current SOC stock with the information on historical and current land use and soil management; and (5) estimation of changes in SOC stock.

The IPCC method uses the approach of stratified quantification of C in the soil and biomass at the regional scale (IPCC, 2003). SOC changes are obtained for the top 30 cm of the soil profile. Areas of the polygons are generated for recent and previous (20 years earlier) land use considering eight climatic regions and only six soil types. These types were proposed by the IPCC and include all of the soil classes recognized worldwide (IPCC, 2003). The amount of SOC existing on each of the two above mentioned dates is obtained by multiplying the value of C previously estimated or measured (Mg ha^{-1}) for specific land uses (or type of soil) by its respective area (ha); the difference in SOC is then calculated by subtraction. If the C value on the recent date of measurement is lower, the change is negative, meaning that C is discharged into the atmosphere; in the opposite case, atmospheric C is being accumulated.

The RothC model for predicting SOC is one of the most used, best-calibrated, and most validated in the world (Falloon *et al.*, 2002). The RothC model was generated from the classic experiments of Rothamsted in England established more than 100 years ago for non-flooding soils, and its use has extended to different types of soil and climate (Coleman and Jenkinson, 2005).

In the present study, the RothC model and the IPCC method are applied to hillside systems, a common type of landscape in Mexico, Central America, in the Andean countries, often under cultivation. The objectives this research were : (i) to estimate changes in SOC using the IPCC method, (ii) to predict changes in SOC with the RothC conversion model, and (iii) to establish trends in the changes identified by the two methods.

MATERIALS AND METHODS

Characteristics of the study region

The study was conducted in three experimental microbasins located in the Mazateca, Cuicateca, and Mixe regions of the Sierra Norte, Oaxaca, on hillsides with slopes steeper than 30% and slightly different climates. The Mazateca region (219 154 ha) is located at 18° 09’ N and 96° 54’ W; its altitude varies between 1380 and 1910 m, and mean annual precipitation is above 2000 mm, while the mean annual temperature ranges between 16 and 27^{o}C, depending on the altitude. The Cuicateca region (217 982 ha), located at 17° 51’ N and 96° 51’ W at altitudes between 1700 and 2200 m, has average precipitation between 500 and 700 mm and annual temperatures of 18 to 20^{o}C. The Mixe region (493 416 ha) is located at 17° 01’ N and 96° 53’ W at altitudes between 1280 and 1520 m and has average precipitation between 1500 and 2000 mm and mean annual temperatures ranging from 17 to 27^{o}C (Martínez-Menes *et al*., 2001). The dominant soils in the Mazateca, Cuicateca and Mixe regions are Humic Ferralic, Ortieutric Ferralic and Umbrichumic Ferralic, respectively (Estrada, 2007). The mean COS, total N and Olsen-P reported for the soils in these regions are 3.9, 1.9, and 4.2 %; 0.3, 0.2, and 0.3; and 5.8, 6.0, and 4.4 mg kg^{-1}, respectively (Vergara *et al*., 2005).

Cartographic material

Three series of digital maps of land use and vegetation obtained from INEGI (2001) were used. “Series I” was considered to be information corresponding to the year 1980. This series was based on the interpretation of aerial photographs taken between 1968 and 1986, scale 1:1 000 000 (CONABIO, 1999). “Series II”, reported on a scale of 1:250 000, was considered to be information from 1990. This is an INEGI (2001) update of Series I based on Landsat TM satellite images. Finally, as “Series III”, which was considered information on 2000, is an update of Series II based on the visual interpretation of color compositions of Landsat ETM images at a scale of 1:250 000 (INE-UNAM, 2002; INEGI, 2002). In addition, soil maps were used at scales of 1:250 000 and 1:1 000 000 (INIFAP and CONABIO, 1999).

IPCC method

The procedure used to estimate SOC changes with the IPCC method in all of the regions was the following:
(1) Aided by SIG ArcView 3.2 software, soil maps and land use and vegetation maps (1980, 1990, 2000) were reclassified according to the vegetation and soil categories defined by IPCC (2003) (Tables 1 and 2).

(2) The reclassified land use and vegetation layers of each series (I, II, III) were joined with the respective soil layers, thus obtaining 1980, 1990, and 2000 IPCC vegetation and soil layers.

(3) Areas (ha) of the combinations of IPCC vegetation and soil (polygons) generated by the above union were calculated, grouped by category, and added.

(4) The SOC (Mg ha^{-1}) value for the IPCC polygons was the average of measurements taken of hillside agricultural and forest systems in the same region by Acosta (2003), González (2007), and Schott (2004), who used a procedure proposed by Monreal *et al*. (2005). Where there were no local values for the IPCC category, SOC values reported in "*Inventario Nacional de Emisiones de Gases de Efecto Invernadero 1990-2000*" (SEMARNAT and INE, 2006) were used.

(5) SOC values (Mg) for the IPCC vegetation and soil combinations for 1980, 1990, and 2000 were obtained by multiplying average SOC values (Mg ha^{-1}) (step 5) by estimated area (ha) (step 4).

(6) SOC changes over the 20 year period were estimated as the difference between the SOC values obtained (step 5) for the year 2000 and those obtained for the year 1980. The 10-year change was estimated in similar manner using IPCC vegetation and soil maps for 1990 and 1980.

Table 1. Reclassification of soil types from World Reference Base (WRB) for Soil Resources into equivalent IPCC categories in the study regions.

Soil types	
World Reference Base (WRB)	IPCC categories
Leptosols (Lithosol, Rendzinas), Luvisols, Phaeozems, Regosols, Cambisols, Fluvisols and Xerosols.	High clay activity (HCA) (Mazateca, Cuicateca and Mixe regions)
Acrisols, Planosols	Low clay activity (LCA) (Mazateca, and Mixe regions)

Table 2. Reclassification of land use and vegetation from map series I, II, and III into equivalent IPCC categories in the study regions.

Land use and vegetation			
Serie I (1980)	Serie II (1990)	Serie III (2000)	IPCC Categories
Agriculture, livestock and forestry management) (plantations)	Agriculture, livestock and forestry management	Agriculture, livestock and forestry management	Agriculture
Oak forest	Oak forest, Oak-pine forest	Oak forest, Oak-pine forest	Broadleaf forest forest
Pine forest, Pine forest diferents pines	Pine forest, Pine-oak forest, "Tascate" forest	Pine forest, Pine-oak forest, "Tascate" Forest	Pine forest
Tropical evergreen and sub-evergreen forests	Tropical evergreen forest	Tropical evergreen forest	Wet tropical forest
Tropical deciduous and sub-deciduous forest	Tropical deciduous forest	Tropical deciduous forest	Moist tropical forest
Mountain cloud forest	Mountain cloud forest	Mountain cloud forest	Moist montane
Bodies of water	Urban zone, Bodies of water	Urban zone, Bodies of water	No aplicable
-	Induced grassland	Induced grassland	Grassland
Crassicaule scrubland	Crassicaule scrubland	Crassicaule scrubland	Dry
Chaparral	-	-	Dry

RothC model

The RothC model considers the effects of soil type, moisture content, temperature, and vegetation cover on the processes of SOC conversion, dividing the process into five compartments, four of which are considered active and one passive because of their decomposition rates (Coleman and Jenkinson, 2005): (1) easily decomposed plant matter (DPM, 0.165 years), (2) resistant plant matter (RPM, 2.31 years), (3) microbial biomass (BIO, 1.69 years), (4) humus (HUM, 49.5 years), and (5) inert organic matter (IOM, 1980 years). Each compartment decomposes into atmospheric CO_2 and microbial biomass, while part accumulates in IOM, depending on clay content. IOM (Mg ha^{-1}) was obtained with the Falloon *et al.* equation (1998):

$$IOM = 0.049*SOC^{1.139} \quad \text{eqn 1}$$

Decomposition of the active compartment at the end of a month was given by the expression:

$$SOC=SOC_o\,(1 - e^{-abckt}) \quad \text{eqn 2}$$

Where SOC_o was initial SOC (Mg ha^{-1}); *a*, *b*, and *c* are factors of modification by temperature, moisture and soil cover, respectively; *k* is the rate of decomposition of the respective compartment; and *t* is 1/12, to convert *k* to a monthly scale.

Prediction of SOC changes for each region with the RothC model was done with the following data:
(1) Measured input data: (i) climate: average monthly data on precipitation (mm), temperature (°C) and evaporation (mm). These data correspond to the period 1951-2000 and were obtained from the database of the Extractor Rápido de Información Climática (ERIC) (IMTA, 2000). With the information on climate, isolines for average monthly precipitation, temperature and evaporation were projected to generate other points or stations with this climatic information (Table 3). (ii) initial SOC were the average values of IPCC vegetation categories; and (iii) clay content (%), considering the average in the Ap and A horizons. In the Mazateca region it was 34.5%, 17% in the Cuicateca region and 36.5% in the Mixe region (Estrada, 2007).

(2) Data assumed by the RothC model 26.3: (i) ratio between easily decomposed plant matter and resistant plant matter (DPM/RPM). The values for this ratio depend on the system; a value of 0.25 is adopted for forest vegetation (for example, 20% of the plant remains are DPM and 80% is RPM), 0.67 is for non-grazed grasslands (including savanna) and scrub vegetation; (ii) soil cover is considered equal to one if the soil has plant cover or 0 if it does not; (iii) inert organic matter, whose value was obtained with Equation 1; and (iv) input and distribution of residues (C Mg ha^{-1}) is explained in point (3).

(3) Plant residue C input. C in plant residues (Mg ha^{-1}) for both periods was generated by running the model inversely using measured data (point 1) and described data (point 2).

With this information, climate-soil and soil management files were generated. Climate-soil files included monthly average precipitation (mm), temperature (°C) and evaporation (mm), and soil clay content (%) and sampling depth (m). The layer with the location of weather stations was overlaid onto the layers of IPCC vegetation and soil for the years 1980, 1990, and 2000, aided by a GIS to assign the closest weather station to each category of vegetation and soil. The soil management files were initialization and prediction. Both management files integrated monthly C information on plant residues (Mg ha^{-1}) and plant cover for each IPCC category.

Table 3. Weather stations existing and projected in the Mazateca, Cuicateca and Mixe regions.

	Weather stations	
Region	Existing	Projected
Mazateca	20112 (18º 09'N y 96º 41'O), 20182 (18º 02'N y 97º 10'O), 20029 (18º 15'N y 96º 49'O) y 2036 (º18 08'N y 96º 50'O)	MAZ1 (17º 55'N y 97º 13'O), MAZ2 (18º 04'N y 96º 59'O), MAZ3 (18º 06'N y 96º 59'O), y MAZ4 (18º 09'N y 97º10'O)
Cuicateca	20161 (18 º 00'N y 96º 45'O), 20158 (17º 48'N y 96º 51'O) y 20049 (17º47'N y 97º 04'O)	CUI6 (17º 43'N y 97º 04'O), CUI9 (17º 44'N y 96º 58'O) y CUI10 (17º 59'N y 96º 35'O)
Mixe	20007 (17º 01'N y 96º 06'O), 20045(17º 20'N y 95º 26'O), y 20017 (17º 27'N y 95º 26'O)	MIX1 (17º 17'N y 96º 02'O) y MIX2 (17º 14'N y95º 43'O)

Scenarios were constructed with the information in these files. However, because of the difference between the date of the field data collection and the date they were issued, it was necessary to make assumptions on changes in land use and vegetation. The scenario of the 20-year period (1980-2000) was constructed under the assumption that IPCC 1980 vegetation, with which the model initiated (Series I), began to change in 1980 into another type of IPCC vegetation use (Series III); for the 10-year scenario (1990-2000), the assumption was that 1980 IPCC vegetation (Series I) began transformation into another vegetation type (Series III) in 1995.

The first scenario, *initialization*, integrated the climate-soil files and soil management files, DPM/RPM ratio, and the IOM value of the corresponding land use and vegetation, while the second scenario, *prediction*, in the 1990-2000 period was done using the polygons generated from the union of 1990 IPCC vegetation and soil layers (Series II) and the 2000 IPCC (Series III) vegetation layer. For the period of 20 years, the 1980 IPCC vegetation and soil layer was overlaid onto the 2000 IPCC vegetation layer.

Changes in land use and vegetation were predicted for each polygon. For example, for the scenario of land use and vegetation change prediction from agriculture (1980) to grassland (2000), we used the climate-soil and soil management files, IOM and the DPM/RPM ratio of agricultural use and grassland. The summary of the information necessary for the SOC predictions in the case of the Cuicateca region is shown as an example in Table 4.

Evaluation of SOC changes

To evaluate the SOC changes obtained with the two methods, the following statistics were calculated: coefficient of correlation (r), parameters (slope and ordinate) of the linear regression model, root mean square error (RMSE) (Mg ha^{-1}year^{-1}), and mean relative error (MRE) (%):

$$MRE = \left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{SOC - SOC_{RothC}}{SOC_{IPCC}}\right)\right]*100$$

eqn 3

$$RMSE = \sqrt{\sum_{i=1}^{n}\frac{\left(SOC_{IPCC} - SOC_{RothC}\right)^2}{n}}$$

eqn 4

RESULTS AND DISCUSSION

Changes in SOC estimated with the IPCC method

The SOC balance for the Mazateca region for the periods 1980-2000 and 1990-2000 (Figure 1) indicates that the soil sequestered 1962 Gg and 1689 Gg (1 Gg=1x10^{9}g) SOC, respectively, when land use was agriculture and scrubland. Carbon sequestered by the soil is explained by a 31 and 25% increase in agricultural area between the beginning and end of each period, respectively. Loss of C, or CO_2 emissions into the atmosphere, in the two periods was 3423 and 2608 Gg, 50-51%, or 1733 Gg C, of which corresponds to moist montane.

Table 4. Synthesis of information for construction of SOC predictions with the RothC model in the Cuicateca region.

IPCC categories				C in plant residues		
Vegetation	Soil†	SOC (Mg ha^{-1})	IOM‡ (Mg ha^{-1})	Total (Mg ha^{-1})	Monthly (Mg ha^{-1})	W.S.
Broadleaf forest	HCA	131.5	12.7	13.4	1.1	2161
Pine forest	HCA	186.0	18.8	7.2	0.6	2158
Wet tropical forest	HCA	140.6	13.7	17.0	1.4	CU10
Moist tropical forest	HCA	98.0	9.1	2.7	0.2	CUI9
Moist montane	HCA	165.8	16.5	16.8	1.4	2161
Agriculture	HCA	83.7	7.6	2.0	0.1	2049
Grassland	HCA	52.6	4.5	1.6	0.1	CUI6

†Soil IPCC; HCA= High clay activity; ‡IOM= Inert organic matter; ¶W.S.= Weather stations
SOC changes for prediction scenarios were estimated by multiplying the area of the land use and vegetation change polygon (ha) by the SOC (Mg ha^{-1}) obtained from the corresponding prediction scenario.

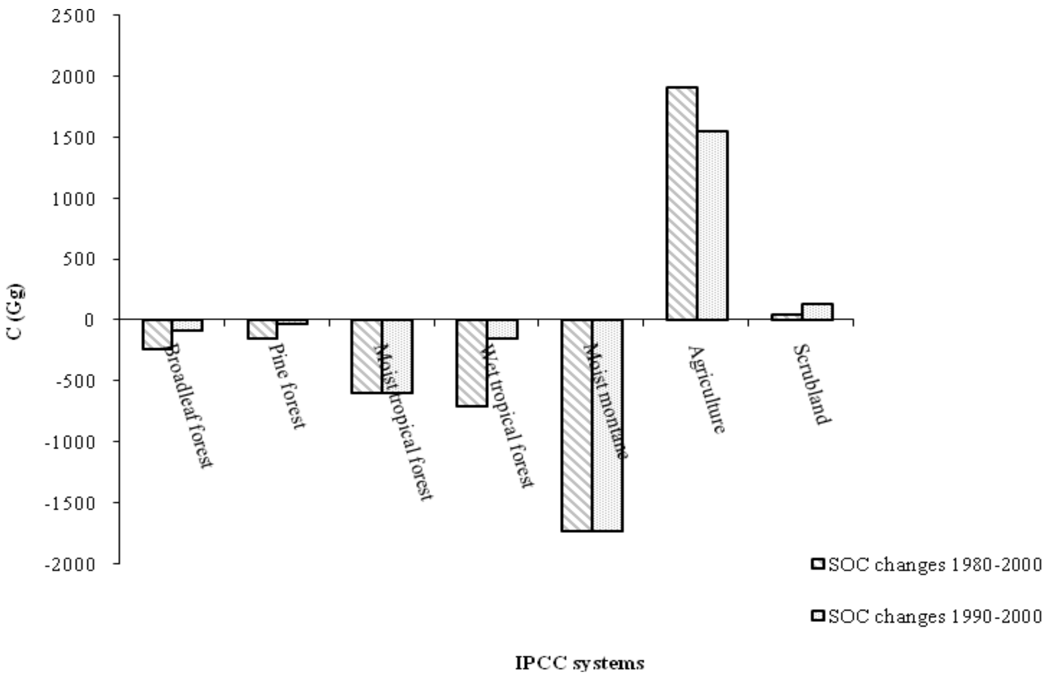

Figure 1. SOC changes in IPCC categories of land use and vegetation in the Mazateca region, 1980-2000 and 1990-2000.

In the Cuicateca, there was a gain in SOC of 1040 Gg (1980-2000) in moist montane, wet and moist (with dry season) tropical forest and broadleaf forest systems, and a loss of SOC of 1941 Gg (54%), mainly because of agricultural land use (Figure 2). For the period 1990-2000, a gain in total SOC of 659 Gg was estimated for the moist montane, agriculture, and grassland systems, and a loss of 1201 Gg by broadleaf, pine, and wet and moist tropical forests (Figure 2).

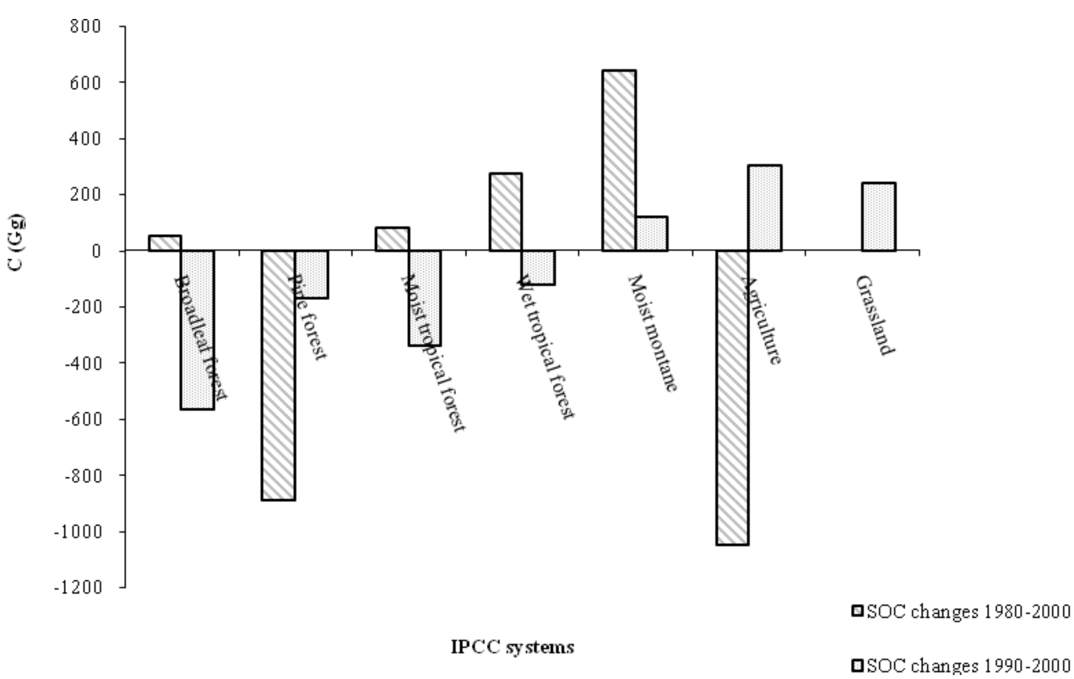

Figure 2. SOC changes in IPCC land use and vegetation categories in the Cuicateca region, 1980-2000 and 1990-2000.

In the Mixe region, captured SOC was estimated at 3404 Gg (1980-2000) and 1833 Gg (1990-2000). In both periods C gains were due to moist montane and agricultural systems. The C losses in these periods were estimated at 3746 and 1881 Gg, mainly due to a decrease in the surface of broadleaf, pine, and wet and moist tropical forests (Figure 3).

The regional balance of SOC showed cases of loss due to a decrease in area of native vegetation and gain through an increase in agricultural use. This can be explained because the IPCC method bases its estimation of changes in SOC on changes in areas of land use. However, some results were affected by cartographic (the only available data for performing this type of studies in Mexico) errors, both thematic and spatial. These occur, according to Mas and Fernández (2003), when maps of different scales are compared. A thematic error was found in the Cuicateca region because of discrepancies in agricultural area; in 1980, 1990, and 2000; agricultural area was calculated at 45 573, 29 361, and 33 000 ha, respectively. In 1980 part of the area covered by moist montane, broadleaf forest, moist tropical forest, and grasslands was mistaken for agricultural area. This error was clearly seen by overlaying the 1980, 1990 and 2000 land use and vegetation maps. On the 1980 map of the Mazateca region a 789 ha body of water does not appear but it does on the 1990 and 2000 maps, resulting in an inconsistency. Errors in area also occurred when maps at different scales or different input dates were compared, as was the case of the Series I (1:1 000 000) land use and vegetation map, which was compared with the Series II and III (1:250 000) maps.

Changes in SOC estimated with the RothC model

Changes in SOC due to transitions from different land use systems (1980) to agricultural use (2000) in the Mazateca region are presented as an example of application of the RothC model (Table 5). The conversion from broadleaf forest to agricultural use accounts for a 19% loss in SOC; in the change from pine forest to agriculture 25% is lost, while 19% is lost in the transition from wet tropical forest to agriculture. When the change is from moist tropical forest to agriculture, 8% is lost, and a transformation from moist montane to agriculture means a 19% loss. These estimations of SOC loss predictec by the model RothC were consistent with those found by Guo and Gifford (2002), who analyzed 74 publications that report a 42% loss of SOC in the conversion from forest to cropland, and Heath *et al.* (2002), who revealed losses of 30% for the same case of conversion.

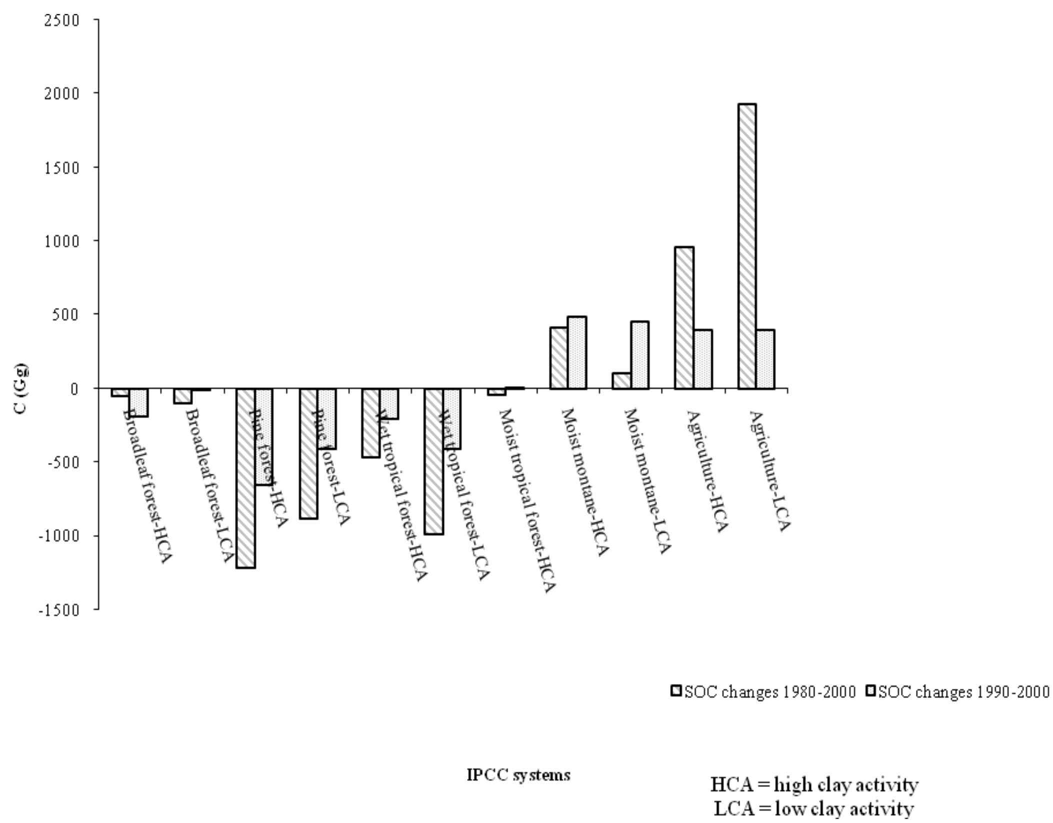

Figure 3. SOC changes in IPCC land use and vegetation categories in the Mixe region, 1980-2000 and 1990-2000).

Table 5. SOC changes in the Mazateca region, model RothC, 1980-2000.

Change in land use and Vegetation (Polygons) 1980-2000		Area (ha)	Initial SOC	Predicted SOC	SOC changes Polygon	Total (Gg)
			(Mg ha^{-1})			
Agriculture	Agriculture	31079	89	89	2766	
Broadleaf forest	Agriculture	2576	139	113	291	
Pine forest	Agriculture	557	192	114	80	
Wet tropical forest	Agriculture	8250	140	114	943	
Moist tropical forest	Agriculture	7968	98	90	717	
Moist montane	Agriculture	18489	140	114	2103	
No applicable	Agriculture	158	-	89	14	
Scrubland	Agriculture	375	70	74	28	
						6943

Trends in SOC changes obtained with the IPCC method and the RothC model

In the period 1980-2000 the sequestered SOC estimated by the RothC model and the IPCC method, respectively, for the three regions were the following: Mixe (3404 and 3379 Gg ha) > Mazateca (1962 and 2821 Gg) > Cuicateca (1040 and 998 Gg). This order is the same when precipitation and clay content observed in the regions are compared: > 2000 mm and 36.5% clay soil (Mixe), 1500-2000 mm and 34.5% clay (Mazateca, and 500-700 mm and 17% clay (Cuicateca). In the three regions, during both periods (1990-2000 and 1980-2000), the changes in estimated and predicted SOC had correlation coefficients between 0.86 and 0.99 (Figure 4). The two methods concurred in that soil clay content and precipitation were related to the quantity of SOC captured in the regions for both periods. These results coincide with those reported by Kimble (2006), who highlighted that climate, mainly precipitation, has a marked influence on growth of biomass and thus on significant changes in SOC. This is due in part to the fact that the RothC model used information from the IPCC method, such as vegetation and soil categories and their SOC values, as well as areas of land use change.

As determined by parameter b (slope) of the regression models and relative to the IPCC method, the RothC model overestimated SOC changes by 6 to 25% relative to the data obtained with the IPCC method (Table 6). This may explain why the IPCC method assumes that the rate of change in land use and management are constant for a given period of time and that the changes in SOC stocks are the result of changes in land use (Eve *et al.*, 2002). Contrasting with these results, studies using the GEFSOC modeling system conducted in four non-temperate areas (Kenya, India, Jordan, and Brazil) with the RothC and Century models and the IPCC method showed that estimations of regional SOC stocks and changes were higher with the IPCC method than those obtained by the models mainly because IPCC estimations consider the upper 30 cm, while the models consider only the upper 20 cm (Milne *et al.*, 2007).

MRE and SRME values with the RothC model and the IPCC method for the three regions and the 20 year period, were higher than those for the ten-year period, mainly because the C change rate generated by the model in the shorter period was lower (Table 6). In spite of these results and according to IPCC (2003), the uncertainty of the method is less for trends over time than for absolute values of C stocks at a given point.

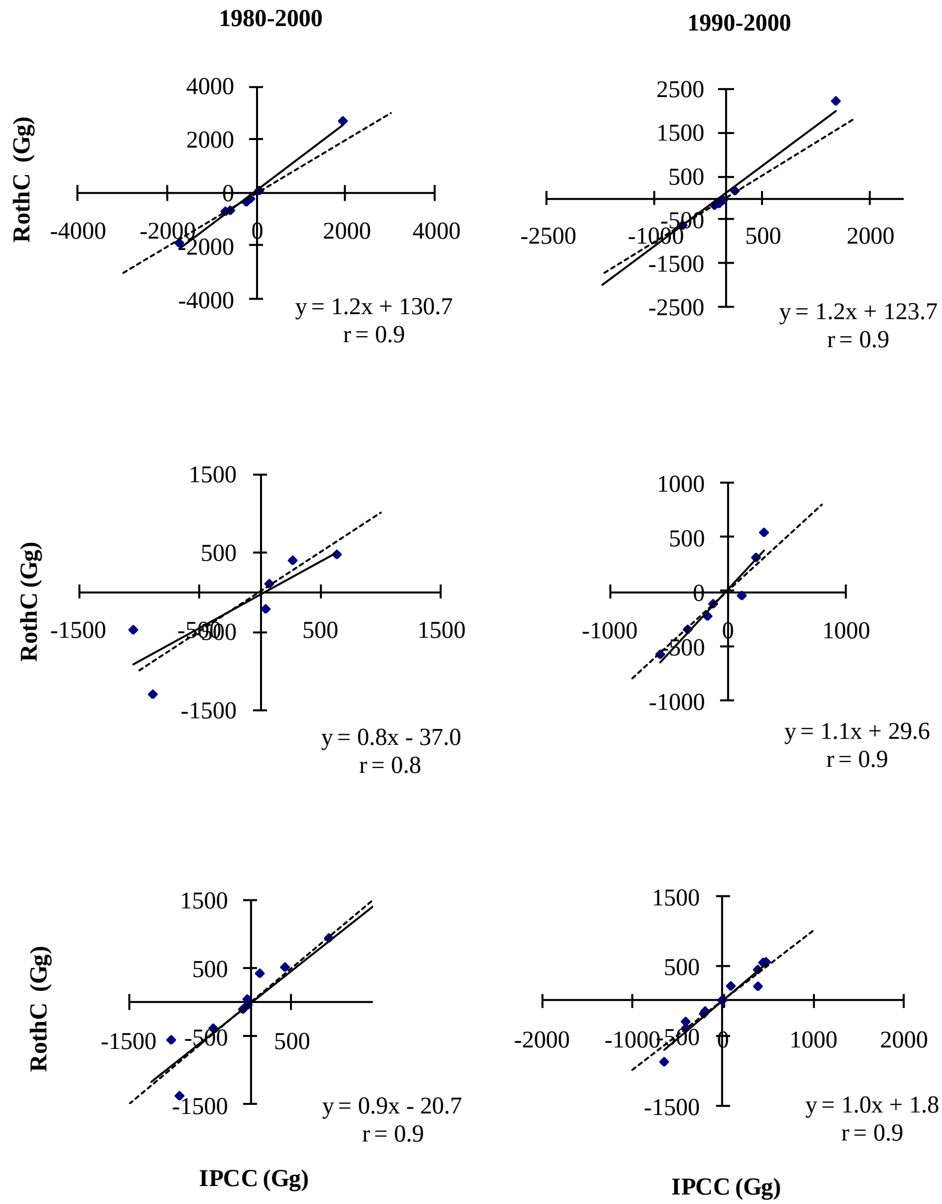

Figure 4. Trends in SOC change estimated by the RothC model and the IPCC method in the three regions studied, 1980-2000 and 1990-2000.

Table 6. Regional evaluation of SOC changes with the IPCC methods and RothC for the periods 1980-2000 and 1990-2000.

Region	1980-2000 b§ (%)	MRE† (%)	RMSE‡ (Gg)	1990-2000 b§ (%)	MRE† (%)	RMSE‡ (Gg)
Mazateca	25	-33	317	20	-18	264
Cuicateca	-3	80	319	14	-2	116
Mixe	-5	-10	278	6	-10	104

§b=parameter of the simple linear regression equation with the ordinate to origin. †MRE=mean relative error. ‡RMSE= root mean square error.

CONCLUSIONS

The IPCC method and the RothC model provide similar trends of regional SOC changes for the two time periods (1980-2000 and 1990-2000), based on the correlation (r) between the two estimations. The estimations of gains in SOC by the IPCC method and those predicted by the RothC model had a direct relationship to clay content and precipitation in the three regions studied. SOC losses in the hillside systems studied were on average 627 Gg. According to the results of this study, the RothC model can be used to estimate regional SOC changes in hillside systems using IPCC vegetation and soil categories and its corresponding area of change with information, such as SOC values, clay content, and climate, available from experimental sites, as well as C in plant residues generated by running the model inversely.

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