THE EFFECT OF LANDUSE CHANGE IN THE TROPICAL DRY FORESTS OF MORELOS, MEXICO ON CARBON STOCKS AND FLUXES

J Návar[1], A Estrada-Salvador[2] & E Estrada-Castrillón[3]

[1] *CIIDIR-IPN Unidad Durango, Av. Sigma S/N, Colonia 20 de Noviembre II, Durango, Dgo, Mexico 34220. E-mail: jnavar@ipn.mx*
[2] *Forestal Av del Trabajo No 959, Acatlipa, Temixco, Morelos, Mexico CP 62590*
[3] *de Ciencias Forestales, UANL Km 136, Carr Nacional Linares NL, 67700 Mexico*

Received June 2009

NÁVAR J, ESTRADA-SALVADOR A & ESTRADA-CASTRILLÓN E. 2010. The effect of landuse change in the tropical dry forests of Morelos, Mexico on carbon stocks and fluxes. The burning of fossil fuels, deforestation and cement manufacturing contribute to carbon emission. The aim of this research was to study how carbon stocks and fluxes are influenced by landuse changes in the tropical dry forest of the state of Morelos, Mexico. The biomass of standing vegetation was estimated from 40 quadrats (400 m^2 each). The biomass of 20 soil samples distributed across this ecosystem was also measured. Data on forest cover changes for 1976 and 1993, soil organic matter and soil organic carbon were used to predict carbon stocks and fluxes in this ecosystem. The annual deforestation rate for the period 1976–1993 was 0.81%, indicating that approximately 1200 ha of subtropical dry forest were lost every year. On the other hand, intensive agriculture, including induced grasslands increased 0.88% annually in the study area (1300 ha $year^{-1}$). From 1950 till 2000, landuse changes from tropical dry forest to agriculture contributed to carbon emissions of 7.03 (± 4.8) Tg C, of which standing biomass averaged 66% and soil organic carbon averaged 34%. Projected landuse changes will likely contribute to an additional carbon flux of 3.89 (± 0.73) Tg by the year 2050. Practices to conserve, sequester and transfer carbon stocks in this ecosystem are discussed as managing landuse is a means to reduce carbon emissions.

Keywords: Biomass, carbon, soils, aboveground vegetation, roots

NÁVAR J, ESTRADA-SALVADOR A & ESTRADA-CASTRILLÓN E. 2010. Kesan perubahan penggunaan tanah di hutan kering tropika Morelos, Mexico terhadap stok karbon dan aliran karbon. Pembakaran bahan api fosil, pembasmian hutan dan pembuatan simen menyumbang kepada pengeluaran karbon. Kajian ini menyelidiki kesan perubahan penggunaan tanah di hutan kering tropika di negeri Morelos, Mexico terhadap stok karbon dan aliran karbon. Biojisim pokok hidup di dalam 40 kuadrat (masing-masing 400 m^2) dianggar. Biojisim 20 sampel tanah yang merentasi ekosistem ini juga diambil. Data bagi perubahan litupan hutan tahun 1976 dan tahun 1993, bahan organik tanah dan karbon organik tanah digunakan untuk menganggar stok karbon dan aliran karbon dalam ekosistem ini. Kadar pembasmian hutan tahunan bagi tempoh 1976–1993 ialah 0.81%. Ini menunjukkan yang lebih kurang 1200 ha hutan kering subtropika hilang setiap tahun. Sebaliknya, pertanian intensif termasuk padang rumput yang dihasilkan bertambah sebanyak 0.88% setiap tahun di tempat tersebut (1300 ha $tahun^{-1}$). Dari tahun 1950 hingga tahun 2000, perubahan penggunaan tanah daripada hutan kering tropika kepada pertanian menyumbang kepada pengeluaran karbon sebanyak 7.03 (± 4.8) Tg C. Sebanyak 66% daripada jumlah ini berpunca daripada biojisim dirian manakala 34% daripada karbon organik tanah. Perubahan penggunaan tanah dijangka akan menambah aliran karbon sebanyak 3.89 (± 0.73) Tg pada tahun 2050. Amalan memulihara, mensekuester dan memindah stok karbon dalam ekosistem tersebut dibincangkan kerana pengurusan penggunaan tanah dapat mengurangkan pengeluaran karbon.

INTRODUCTION

The greenhouse gases (GHG) that are of anthropogenic importance in climate change are carbon dioxide (CO_2), methane (CH_4), nitrous (N_2O), chlorofluorocarbons (CFC-11), hydrofluorocarbon-23 (HFC-23) and the perfluorocarbon of methane (CF_4) (IPCC 2001). Carbon dioxide is the primary greenhouse gas and represents 60% of the total concentrations of all the GHG. The CO_2 concentration in the atmosphere in 1750 was 280 ppm and the concentration had increased to 384 ppm by 2004 (IPCC 2007). The observed increase is due to organic carbon oxidation caused by burning of fossil fuels (76%), deforestation practices (22%) and cement manufacturing (2%) (IPCC 2001, 2007).

Deforestation is a global problem for several reasons. It contributes to global warming by producing carbon emissions, diminishes biological diversity because forests provide habitat for numerous species and alters the cycles of several elements including water, carbon and nitrogen. FAO (2009) estimated that 13.7 million hectares of forest were converted between 1990 and 1995 in developing countries. Countries such as Brazil, Indonesia, Congo Republic, Bolivia, Mexico, Venezuela, Malaysia, Myanmar, Sudan and Thailand are responsible for the loss of 7.4 million hectares of forests, representing approximately 50% of all annual deforestation (Roper & Roberts 1999). In Mexico, annual deforestation averages 600 000 ha (Masera *et al.* 1997, CONAFOR 2005).

The tropical dry forests of Mexico are distributed from southern Sonora to Chiapas in southern Mexico in the western coast of the Pacific Ocean and from southern Tamaulipas to Chiapas in the eastern coast of the Gulf of Mexico. This is one of the ecosystems that face high anthropogenic pressure for landuse changes. Although evaluations of carbon emissions that are produced by deforestation have been conducted at the global (Brown 1997, Achard *et al.* 2002, 2004, DeFries *et al.* 2002, Houghton 2005, Hansen *et al.* 2008), national (Masera *et al.* 1997) and regional levels (Návar-Cháidez 2008), data on carbon emissions produced by landuse changes in the tropical dry forests of Morelos, Mexico have not been reported. This information is required in order to develop sustainable management plans for native vegetation. More specifically, different protocols propose economic incentives that will increase forestation, reforestation and changes of landuse practices that sequester carbon from the air, reduce the rate of carbon emissions or transfer carbon to stable sinks. The present report was aimed at (a) calculating how carbon stocks and fluxes were influenced by deforestation practices, (b) projecting carbon stocks and emissions for the period 1950–2050 and (c) recommending practices for the sustainable management of tropical dry forests in the state of Morelos, Mexico.

MATERIALS AND METHODS

The state of Morelos is located to the south of the metropolitan area of Mexico. The state covers 4888 km^2. It is one of the smallest states in the Mexican republic (INEGI 2002) (Figure 1). Morelos has an average annual rainfall and temperature of 1130 mm and 20.5 °C respectively (Aguilar 1999). The arboreal strata of plant cover are represented by *Conzattia multiflora, Amphipterygium adstringens, Ipomoea wolcottiana, Lysiloma divaricata, Ceiba parvifolia, Wimmeria persicifolia, Bursera ariensis, Lysiloma tergemina, Bursera copallifera, B. glabrifolia, B. bipinnnata, B. longipes* and *B. morelensis*, among others. In the state of Morelos, the following types of soils exist: fluvisoles, andosoles, leptosoles, feozems, regosoles, arenosoles, vertisoles, lixisoles, castañozems, cambisoles and chernozems (Aguilar 1999). Feozems are present in large portions of Morelos.

Carbon stocks in tropical dry forests were estimated from several biomass components: (a) aboveground vegetation, (b) belowground compartment (roots) and (c) soils (organic carbon). Carbon content in litter was not accounted for in these measurements because preliminary observations indicated that the organic layer of the top soil was very thin.

The aboveground biomass of the tropical dry forest community was estimated using dasometric variables measured in quadrats and applying the allometric equation described by Návar (2009) for dry forests. This equation is $0.081D^{2.413}$. It produces aboveground biomass estimates that are similar to the equation proposed by Brown (1997) for worldwide tropical dry forests: $34.4703 - 8.0671 \times D + 0.6589 \times D^2$, where D = diameter at breast height (dbh). The equation presented by Návar *et al.* (2002) was used to estimate coarse root biomass: $Br = 2.93 + 0.56\ BA$, where Br= coarse root biomass and BA = aboveground biomass. This equation was developed for roots with diameters greater than 0.5 cm for the tamaulipan thornscrub of north-east Mexico. The equation uses total aboveground biomass as the independent variable to predict coarse root biomass of the A and B horizons.

A total of 40 quadrats (400 m^2 each one) distributed throughout the tropical dry forest were plotted for dasometric measurements. The quadrats were 40 × 10 m, and all trees and shrubs with dbh greater than 7.5 cm were measured.

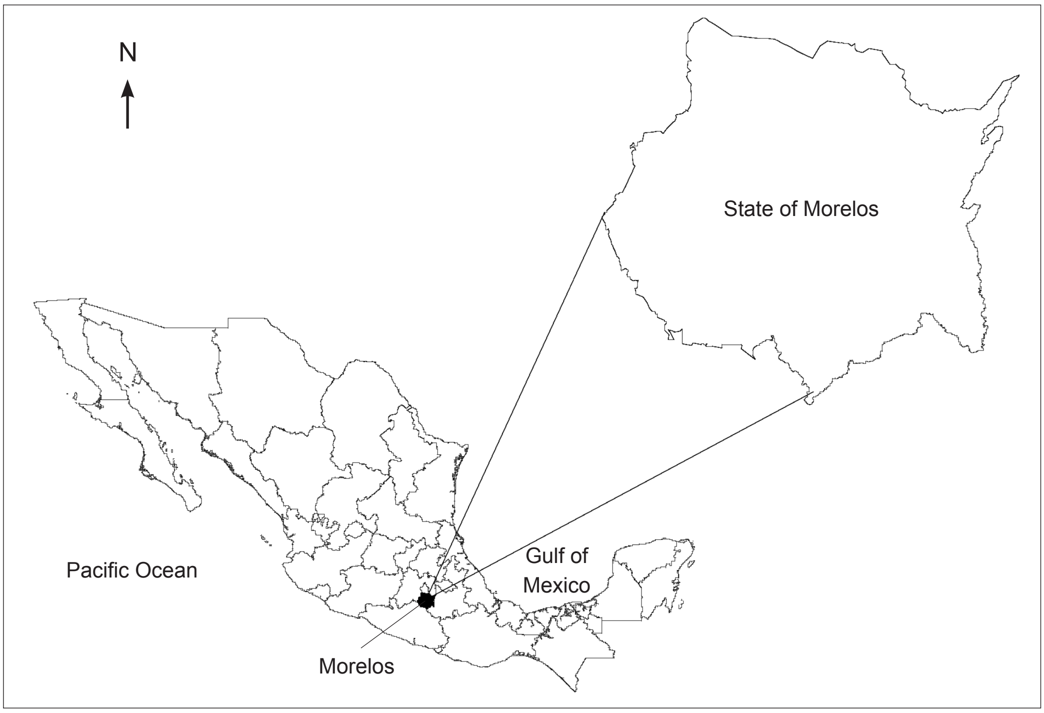

Figure 1 The location of the state of Morelos in Mexico

Within each quadrat, a subplot with an area of 12.56 m^2 (3.54 × 3.54) was established to sample saplings with dbh < 7.5 cm and height ≥ 25 cm. Within each subplot a surface of 1 m^2 was established and used to measure herbaceous cover. Quadrats were placed systematically across the distribution of the tropical dry forest in the region, mainly in the centre and the southern parts of Morelos state. In each region, quadrats were randomly located in order to sample the typical conditions and the main sources of spatial variation in the physical characteristics of plant cover. The measured values for the vegetation were top height, height of clean bole, basal diameter, dbh and canopy cover.

For the estimation of soil organic carbon, the following variables were measured: depth by soil horizon, content of organic matter, content of organic carbon and bulk density. Soil samples were collected from 20 sites, 10 within the tropical dry forest and 10 in adjacent areas dedicated to conventional agriculture. This data points provided the required information to measure the soil carbon content to a depth of 50 cm. For this calculation, the following physical equation was used:

$$M = Pb \times V \qquad (1)$$

where

M = soil mass (Mg ha^{-1})
Pb = soil bulk density (Mg m^{-3})
V = volume of the soil (m^3)

The soil bulk density (Pb) generally changes with soil depth. This trend was previously anticipated by Post (2002) and further developed for local use by Návar-Cháidez (2008). Therefore, the parameter estimates were calibrated using using the equations:

$$Pb(z) = \alpha Z^{\beta}$$
$$SOC(z) = \alpha \times Exp^{-\beta Z} \qquad (2)$$

where

z = soil depth (cm)
α and β = statistical parameters
SOC = soil organic carbon

Measured soil bulk density and soil organic carbon (SOC) content take the initial value from α. The parameter of change for soil bulk density and SOC content as related to changes in soil depth was taken from Návar-Cháidez (2008) for vertisolic soils of the coastal plain of the northern Gulf of Mexico.

Landuse changes or changes in plant cover were analysed using digital cartography tools as well as landuse and vegetation data acquired from the Mexican Institute of Statistics, Geography and Informatics (INEGI). These data are called the Series data and so far comprises Series I, which was developed for landuse/cover of 1976 and Series II, which was developed for landuse/cover of 1993. Vegetation maps for 1976 and 1993 were overlaid in order to estimate the fate of land cover with special emphasis on tropical dry forest ecosystems, agricultural uses and grasslands. The rate of deforestation was calculated as the area covered by tropical dry forest that shifted to agricultural or grassland areas from 1976 till 1993. With this information, the annual rate of deforestation was estimated. Using other deforestation rates (2.70, 1.40, 1.26 and 2.31%) calculated for Mexican tropical dry forests (Trejo & Hernández 1996, Trejo & Dirzo 2000, PEOT 2000, SEMARNAT 2002), in addition to this estimate (0.81%), we calculated the mean (1.70%) and confidence intervals (0.69%) for the deforestation rate. An average deforestation rate has the advantage that it is consistent with other regional landuse change estimates and it smoothens the short spatial and temporal changes. However, it has the disadvantage in that it is fixed over time, since land-cover change is a disjointed process, with irregular periods of rapid change (Geist & Lambin 2005). This information was used to project backwards to 1950 and forward to the year 2050 for the area covered by tropical dry forest in Morelos (model 3). The current land cover of the tropical dry forests in Morelos was taken from Palacios Prieto *et al.* (2000) for the year 2000 since these statistics were more precise than the area covered by tropical forests for the 1996 map.

$$A_{t=x} = (A_{2000}) \times 1 \pm r\ (\pm \mathrm{Cl}) \qquad (3)$$

where

r = annual rate of deforestation
t = time (years)
x = year (1950–2050)
A = area covered by tropical dry forests (ha)
Cl = confidence limits

The procedure of estimating carbon stocks and fluxes consisted of four steps: (1) estimating the mean annual rate of deforestation (and confidence interval), including estimates derived from this study, (2) projecting the area covered by tropical dry forest, taking the area covered by tropical dry forest in 2000 as the basis (Palacios-Prieto *et al.* 2000), (3) calculating the carbon stocks in vegetation and soils covered by tropical dry forests and agricultural lands, using a carbon factor transformation of 0.50 (Mohren & Klein Goldewijkt 1990, Silva-Arredondo & Návar-Cháidez 2009) to transform biomass to carbon density and (4) estimating carbon fluxes by subtracting the carbon stocks of year i from year i – 1. This procedure did not take into account the abandonment of agricultural lands and the recovery of the vegetation, nor did it consider gradual changes of soil carbon after clearings due to a lack of data. This is technically justified because the agricultural lands remain as such in most of the cases, with fertilisers used to maintain the fertility. On the other hand, in many cases it took no more than five years to reduce carbon stocks to 60–80% of the original carbon level (Návar-Cháidez 2008). Projections of gradual shifts in carbon stocks have a very small influence on the balance of soil carbon when projections of agricultural degradation of soil carbon reach 80% (Návar-Cháidez 2008). Finally, practices are recommended to mitigate the loss of carbon in the tropical dry forest of Morelos, Mexico.

Three viable alternative practices to reduce carbon emissions or to conserve carbon stocks of the tropical dry forests in the state of Morelos, Mexico are proposed: (a) the elimination of landuse changes; (b) the implementation of agro-silvicultural practices in ¼ of the deforested area; and (c) the continuation of deforestation with zero tillage practices implemented in deforested lands. The elimination of landuse changes assumes that business as usual scenarios remain constant over time, with a constant area covered by tropical dry forests. The second alternative includes the quick establishment of trees on ¼ of the area in the already deforested landscape. Desirable trees are selected by farmers for shade, forage, fruits, timber, etc. This alternate practice assumes that all trees have the same growth rate over time. The last practice is to keep the rate of deforestation constant over time, however, soils remain under zero tillage practices. Soil carbon is conserved and carbon in trees is gone with shifting cultivation.

RESULTS AND DISCUSSION

Aboveground and root biomasses, and carbon stocks on the plant cover of this ecosystem are reported in Figure 2. Large confidence intervals were related to the differential degree of disturbance by human-induced activities such as overgrazing and selective cutting of trees. The SOC and organic matter contents are reported in Figure 3. As expected (Figure 3), there were greater contents of soil organic matter and SOC in temperate forests (13.83 and 8.02%) in comparison with the tropical dry forest (8.19 and 4.75%) and agricultural lands (4.18 and 2.43%). This means that the conversion of a temperate coniferous forest or a tropical dry forest to agricultural use releases an average of 5.6% or 2.3% of the carbon stored in the soil to a depth of 50 cm, in addition to all carbon contained in aboveground biomass.

The soil bulk density averaged 1.47 g cm^{-3} with a standard deviation of 0.173 g cm^{-3} and a confidence interval of 0.170 g cm^{-3} (Table 1). This level is relatively high and can be explained by natural disturbances such as the extent of soil compaction that occurs during tillage practices. Other sources of error in the estimation of this parameter include error in the calculation of the displaced volume by paraffin during the immersion process and during collection of soils in the field.

The data for soil bulk density and the amount of carbon indicated that soils covered by temperate forests, tropical dry forests and neighbouring agricultural lands next to tropical and temperate forests at a depth of 50 cm averaged 59 (± 34), 34 (± 6), 8 (± 29) and 18 (± 4) Mg C ha^{-1} respectively. These figures varied between 6 and 12 kg of C m^{-2}. They are in complete agreement with the global distribution of SOC developed by Post (2002) for tropical dry forests.

The annual rate of deforestation for the tropical dry forest from 1976–1993 was estimated at 0.81% (Table 2). The rates of deforestation for the tropical dry forest as estimated by different researchers for different periods are displayed in Table 2. Landuse changes resulted in a loss of approximately 20 000 ha of tropical dry forest and a little over 2000 ha of temperate oak and oyamel forests, predominately as part of conversion to agriculture and induced grasslands during the study period (Table 3, Figure 4).

Based on the forest inventory of Palacios-Prieto *et al.* (2000), the area covered by tropical dry forest in Morelos for the year 2000 was slightly greater than 105 800 ha. Assuming a similar deforestation rate in the past and projected into the future, estimates for 1950 indicated that the mean (confidence interval) area covered by tropical dry forests was 242 374 ha (310 695 and

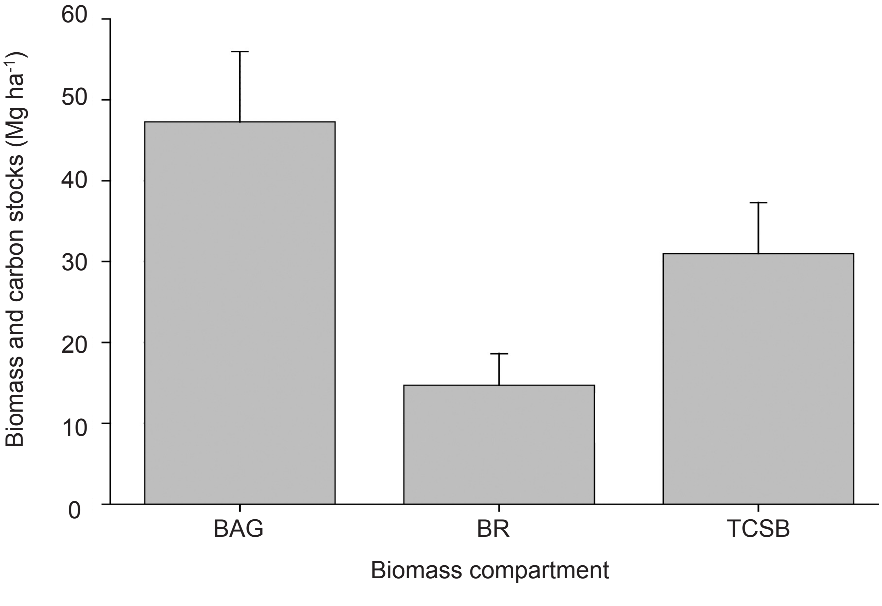

Figure 2 Mean (confidence interval) above- and belowground biomass components and total carbon stocks in the tropical dry forest of Morelos, Mexico. BAG = aboveground biomass, BR = root biomass and TCSB = total carbon content in tree biomass.

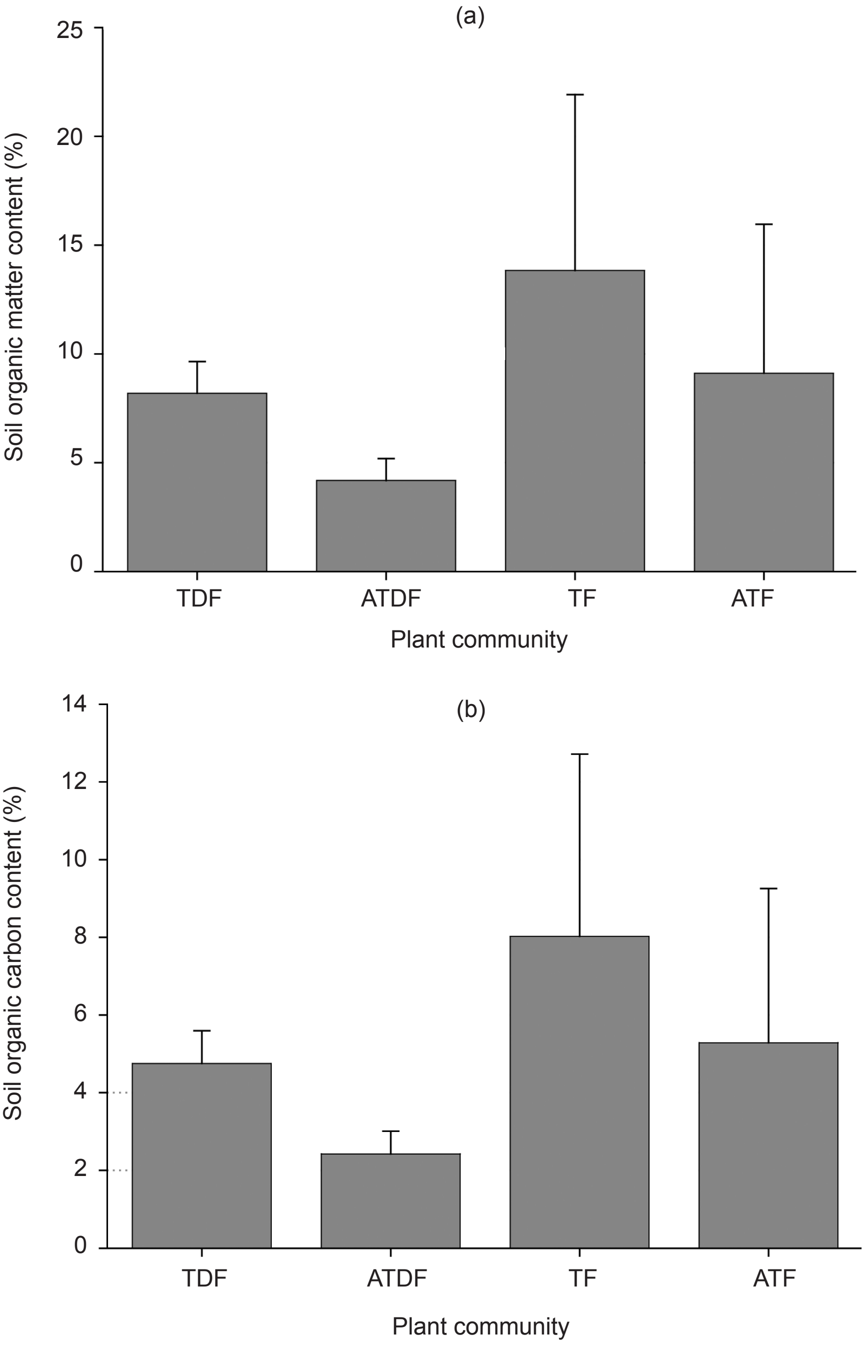

Figure 3 Soil organic matter (a) and soil organic carbon (b) contents of the tropical dry forest, agricultural areas and temperate forest in the state of Morelos, Mexico. TDF = tropical dry forest, TF = temperate forest, ATDF = dry land agriculture next to tropical dry forest and ATF = irrigation agriculture next to temperate forest.

165 758 ha) and estimates for the year 2050 show that the area will be reduced to 51 832 ha (67 256 and 63 366 ha) (Figure 5).

Mean (confidence interval) carbon stocks in tropical dry forests for year 2000 was 6.87 (0.38) Tg C (Figure 6). In the 1950s, mean (confidence interval) carbon stocks was 14.76 (5.43) Tg C. For the year 2050, estimates indicate a mean (confidence interval) of 3.17 (0.88) Tg C of remaining tropical dry forests in the state of Morelos, Mexico.

For the year 2000, mean (confidence interval) carbon fluxes was in the order of 0.093 (0.038) Tg C (Figure 6). Mean (confidence interval) cumulative carbon emissions for the period 1950–2000 was 7.01 (4.8) Tg C and for the period of 1950–2050

Table 1 Soil bulk density of diverse landuse/cover of Morelos, Mexico

Soil	Bulk density ($g\ cm^{-3}$)
Soil 1	1.687
Soil 2	1.525
Soil 3	1.286
Soil 4	1.386
Mean	1.471
Standard deviation	0.173
Confidence interval	0.170

total (confidence intervals) carbon emissions would be 12.94 (4.76) Tg C from the deforestation of tropical dry forests in the state of Morelos, Mexico.

Some of the viable alternative practices to reduce carbon emissions or to conserve carbon stocks of the tropical dry forests in the state of Morelos, Mexico are (a) the elimination of landuse changes (Figure 7), (b) the implementation of agro-silvicultural practices in ¼ of the deforested area and (c) the continuation of deforestation with zero tillage practices implemented in deforested lands. These practices would conserve (alternative practices – baseline scenario) a total of 2.77, 1.69 and 1.95 Tg respectively for the period of 2010 till 2050. Eliminating deforestation and implementing zero tillage practices in deforested lands would reduce carbon emissions the most.

The mean total biomass was 47.3 Mg ha^{-1} (Figure 2), an amount that is somewhat similar since Návar (2009) reported a mean estimate of 51 Mg ha^{-1} for total aboveground biomass for two tropical dry forests of eastern Sinaloa, Mexico. Several sources and degrees of disturbances in Morelos are likely to have an impact on aboveground biomass. When adding together below- (root) and aboveground biomasses, total stand biomass had a mean (confidence interval) of 64 (14) Mg ha^{-1}. Castellanos *et al.* (1991) estimated for the tropical dry forest of Jalisco, Mexico a mean of 73.6 Mg ha^{-1}. Thus, based on the present study, the carbon content in plant cover averaged 31 (7) Mg ha^{-1} which is in agreement with the estimations of Castellanos *et al.* (1991) of 33 Mg ha^{-1} for a tropical dry forest of Jalisco, Mexico and of Hughes *et al.* (2000) of 44 Mg ha^{-1} for a tropical deciduous forest of southern Mexico.

The soil contains an important C pool. To a depth of 50 cm, the tropical dry forest had a mean (confidence interval) of 34 (6) Mg ha^{-1}. This figure is 3.5 g kg^{-1} and when interpolated to 1 m soil depth (70 Mg ha^{-1}) results in 7.0 g kg^{-1}. This figure is within Holdridge zones of deserts, thorn steppes and dry forests elaborated by Post (2002). Either of these figures is somewhat low in contrast, for example, to the tamaulipan thornscrub ecosystem, which has a weighted mean of approximately 136.5 Mg ha^{-1} (Návar-Cháidez 2008). De Jong *et al.* (2000) reported between 120 and 140 Mg ha^{-1} for deep soils of tropical evergreen forests of southern Mexico.

Projections of landuse cover indicated that from the period 1950–2000, the Mexican state of

Table 2 Rates of deforestation as estimated by different researchers for the tropical dry forests of Morelos, Mexico

Researcher	Time period	Forest	Rate of deforestation %
Trejo and Dirzo (2000)	1973–1989	Tropical dry forest	1.40
PEOT (2000)	1900–2000	Tropical dry forest	1.26
SEMARNAT (2002)	1983–2000	Tropical forest	2.31
Mas *et al.* (2004)	1976–2000	Tropical forest	0.76
Trejo and Hernández (1996)	1976–1983	Tropical dry forest	2.70
This report	1973–1996	Tropical dry forest	0.81
Mean			1.64
Standard deviation			0.80
Confidence interval ($\alpha = 0.05$)			0.64

Table 3 Landuse change from the period of 1976–1993 in the state of Morelos, Mexico

1976 1993	AR	AT	CA	BP	BP/Q	BQ	BQ/P	BO	BMM	PI	PAM	SBC	ZU
AR	63629	12541	9.0	0	0	13.1	0	0	0	557.7	0	3530	14.9
AT	3822.1	150497	27.9	864.7	753	1392	456.9	6.8	128.4	3743.8	0	18319	0.4
CA	27.1	65.4	916	17.1	0	0	0	0	0	113.3	0	38.9	0
BP	61.6	961.0	0	11209	217.3	143.9	11.8	933.1	156.8	516.1	224	25.8	0
BP/Q	0	224.9	0	169.0	7116	137.0	276.3	46.9	401.3	27.6	0	20.0	0
BQ	0	606.7	0	60.0	60.5	12836	37.3	84.0	38.1	119.6	0	851.8	0
BQ/P	0	298.7	0	77.8	111.3	835.5	2132	0	36.6	10.8	0	12.4	0
BO	0	8.1	0	213.6	57.6	14.7	0	3384.0	0	55.2	0	0	0
BMM	0	117.2	0	50.8	22.1	161.9	3.4	0	5133	25.7	0	78.7	0
PI	298.5	3455.3	4.3	287.6	54.3	99.6	22.6	137.2	61.0	31001	0	5394	0
PAM	0	0	0	0	0	0	0	0	0	0	0.140	0	0
SBC	899.2	7141.5	0.7	0	9.3	592.2	6.0	0	57.7	3788	0	107074	0
ZU	3978.7	7959.7	0	0	0	14.45	0	0	4.4	526.7	0	624.7	3020

AR = Irrigated agriculture, AT = dry agriculture, CA = water body, BP = pine forest, BQ = oak forest, BQ/P = oak–pine forest, BO = oyamel forest, BMM = cloud forest, PI = irrigated pastureland, PAM = native pastureland, SBC = tropical dry forest, ZU = urban area

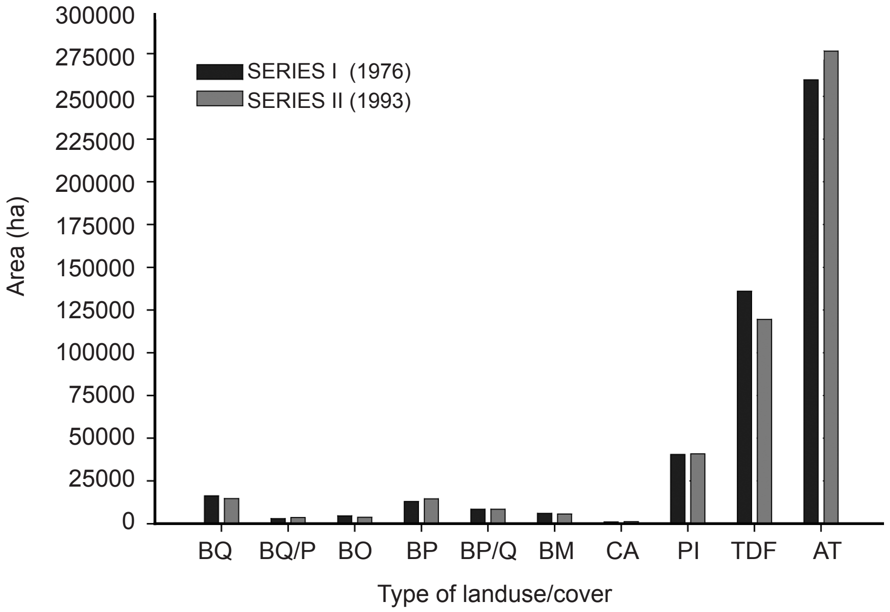

Figure 4 Landuse/cover for 1976 and 1993 for the Mexican State of Morelos. Oak forest (BQ), oak–pine forest (BQ/P), oyamel forest (BO), pine forest (BP), pine–oak forest (BP/Q), cloud forest (BM), water body (CA), grassland (PI), tropical dry forest (TDF) and dry agriculture (AT)

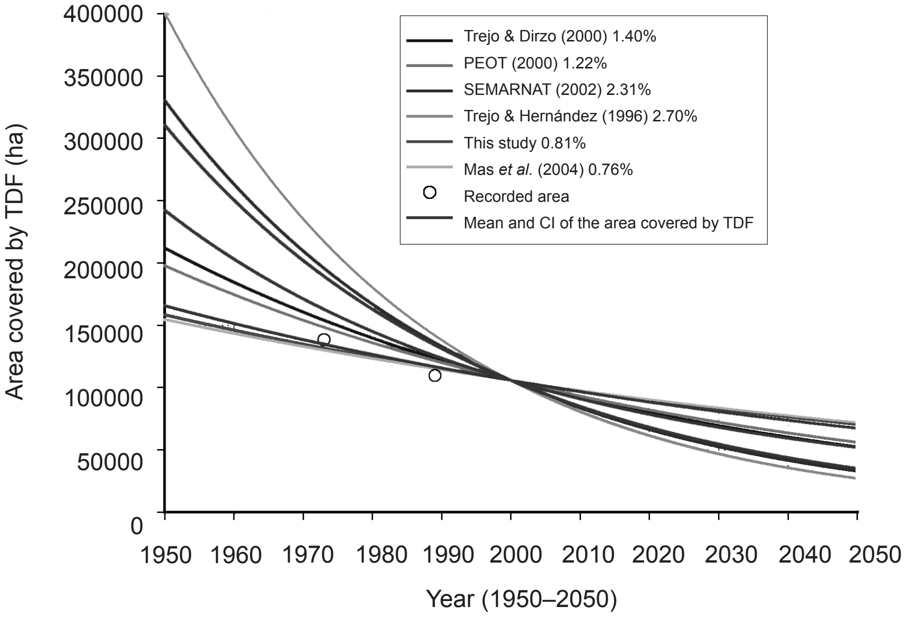

Figure 5 The means and confidence intervals on the area covered by tropical dry forests (TDF) in the state of Morelos, Mexico

Morelos had lost 121 366 ha or a little above 50% of the original tropical dry forest that existed in the 1950s. In Mexico, tropical dry forests in the 1950s covered approximately 16 million hectares, less than a third of which remains today because of deforestation (Quadri de la Torre 2000). By 1990, only 27% remained intact and at the local scale, close to 60% of the original vegetation had been lost and only 19% remained in a forested condition (Trejo & Dirzo 2000). In Costa Rica, tropical dry forests once made up 42% of all forests in the tropics, but half of the dry forests had been cut down and others faced similar threats. These ecosystems support a large fraction of the human population in the tropics, and as a result, are under intense pressure (Murphy &

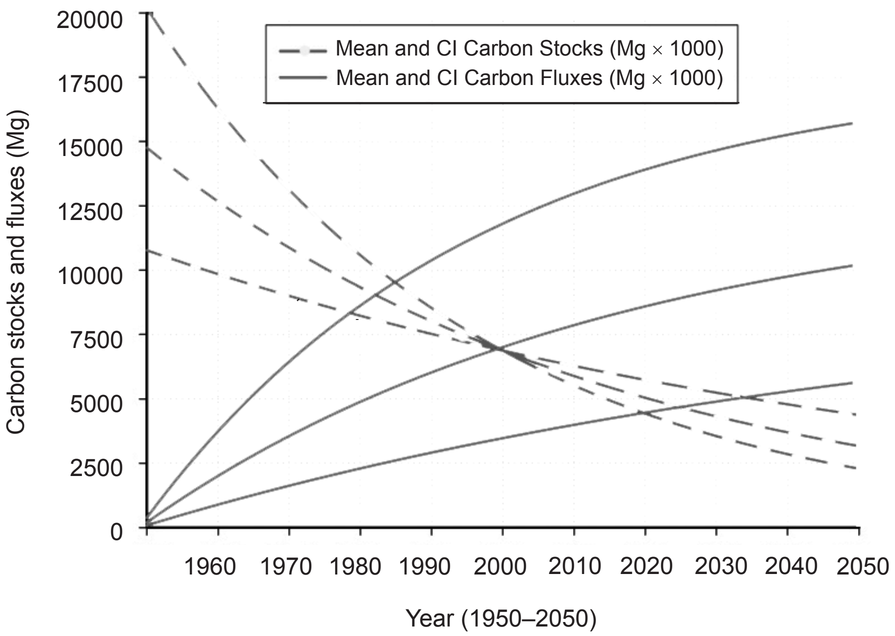

Figure 6 Means and confidence intervals of carbon stocks and fluxes caused by deforestation in the tropical dry forest of Morelos, Mexico

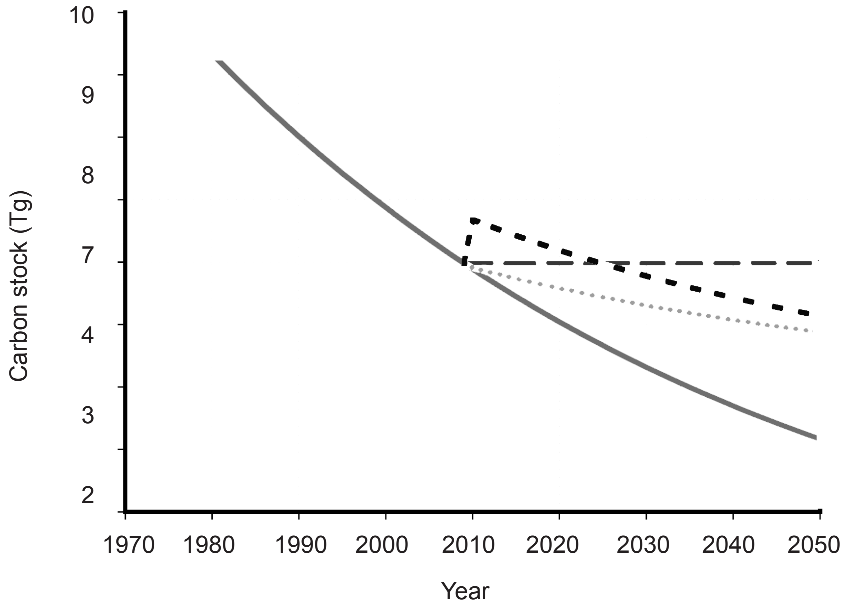

Figure 7 Baseline and alternative practice scenarios in carbon stocks and fluxes in tropical dry forests in the state of Morelos, Mexico. — — — Elimination of landuse changes; ▪ ▪ ▪ Implementation of agrosilvicutural practices in ¼ of deforested area; ······· Continuation of deforestation with zero tillage practices

Lugo 1986). Since dry climates are preferred to very wet climates in the tropics, large population concentrations occur in dry forest life zones. Tropical dry forests not only provide space for the expansion of human population but are also used intensively as a source of fuelwood and charcoal. Grazing animals are also often allowed to roam freely in dry forests. The area experiences a quick expansion of rain-fed and irrigated agriculture, and cattle beef ranching.

The conservation of tropical dry forests is of local, national and global importance. The promotion of new policies on landuse change and management can reduce carbon emissions in the agricultural sector. For example, modifying the forestry law to reduce the scale of landuse change or to increase the time allotted for abandoned lands to recover their original plant community would eventually cause fewer private and communal lands to be cleared. Conservation of carbon stocks under the new policy scenario would be a function of the area allowed for clearing and the time period to return to forests.

In recently cleared lands, conservation of the SOC must be of primary concern since only organic carbon in total aboveground biomass would be released, accounting for only 34% of the total organic carbon stocks in the system. Currently, approximately 1600 ha year^{-1} are cleared for farming in this ecosystem and this results in the loss of important quantities of SOC (34%) in five years. Since most of the newly cleared lands are used for rain-fed and irrigated agriculture, a feasible way to preserve carbon is to implement non-till, minimum tillage or tillage conservation practices at the beginning of the farming process. Of the area cleared each year, approximately 25 500 Mg C could be conserved annually if no-till conservation practices were implemented. High fertiliser and pesticide expenditures used to increase productivity and control weeds respectively may limit the ability of farmers to carry out these practices unless a carbon credit or payment to farmers is linked to non-till agricultural practices.

Carbon can be sequestered in soils that have been under agricultural use for more than 15 years by promoting non-till or conservation practices. Non-till and conservation tillage practices associated with efficient irrigation, fertiliser and pesticide applications can increase SOC (Boyd & Uri 2001, Campbell *et al.* 2001, Follett 2001, Hao *et al.* 2001). The increase can occur by improving yields and subsequent organic matter additions to the soil, reducing the rate of SOC loss, decreasing CO_2 emissions from tractors and other tillage equipment, and reducing the area cleared by increasing crop yield. Since the rate of carbon sequestration can be doubled in soil with depleted organic carbon, conservation tillage practices can be effectively carried out in abandoned irrigated lands. There are approximately 3500 ha available for this purpose within the range of the tropical dry forest in Morelos, Mexico.

The potential of sequestering carbon by shifting from conventional tillage to no-tillage practices in agricultural soils is dependent on several factors (Yang & Kay 2001). In the US, carbon can be sequestered in the range of 337 ± 108 kg C ha^{-1} year^{-1} to a depth of 30 cm. These rates vary from 300–600 kg C ha^{-1} year^{-1} in the Great Plains of US, to 100–500 kg C ha^{-1} year^{-1} in the Canadian prairie region (Follett 2001). This rate of carbon sequestration can continue for 20 years before it declines (Lal *et al.* 1999). Therefore, conversion from conventional tillage to no-till farming of 3500 ha could potentially sequester 0.024 Tg C in 20 years.

In the case that landuse/cover changes are permitted in only ¾ of the area to be deforested, then ¼ of the carbon emissions would be eliminated annually. This figure corresponds to 0.021 Tg per year. It is better to conserve carbon stocks than to sequester them using tillage conservation practices.

Economic incentives to promote carbon conservation and sequestration practices in native forests and soils are not presently recognised in the Convention on Climate Change. However, carbon sequestration in agricultural soils may be added to any Protocols that respond to climate change, making carbon credits or payments available to farmers. In the meantime, the Mexican forestry law is promoting local markets for the environmental benefits provided by forest ecosystems.

CONCLUSIONS

The conservation of the tropical dry forest in the state of Morelos, Mexico must be a primary concern as it would help to mitigate CO_2 emissions. Deforestation of the tropical dry forest is causing carbon emissions and is thus contributing to climate change. Carbon stocks were found mainly in the vegetation (66%) and soils (34%) to a depth of 50 cm. Total carbon emissions from 1950 till 2000 were in the order of 6.6 (4.6) Tg C. Business as usual scenarios for deforestation and carbon emissions will result in an additional release of 3.2 (0.60) Tg C by the year 2050. Therefore, it is recommended that efforts focus on the conservation of the tropical dry forest and soil carbon through sustainable practices such as conservation tillage and agro-silvicultural practices.

ACKNOWLEDGEMENTS

The authors thank Manqueros and MC Rafaela Ortíz for assisting in data collection.

REFERENCES

Achard F, Eva HD, Mayaux Stibig HJ & Belward A. 2004. Improved estimates of net carbon emissions from land cover change in the tropics for the 1990s. *Global Biogeochemical Cycles* 18: 1–11.

Achard F, Eva HD, Stibig HJ, Mayaux P, Gallego J, Thimothy R & Malingreau JP. 2002. Determination of deforestation rates of the world's humid tropical forests. *Science* 297: 999–1002.

Aguilar BS. 1999. *Ecología del Estado de Morelos un Enfoque Geográfico.* Morelos State Government, Mexico.

Boyd R & Uri ND. 2001. A note on the use of conservation practices in US agriculture. *Environmental Monitoring and Assessment* 72: 141–178.

Brown S. 1997. Los bosques y el cambio climático: el papel de los terrenos forestales como sumideros de carbono. In *Actas del XI Congreso Mundial Forestal: Recursos Forestales y Árboles.* Volomes 1. Turkia.

Campell CA, Zentner RP, Selles F, Liang BC & Blomert B. 2001. Evaluation of a simple model to describe carbon accumulation in Brown Chernozem under varying fallow frequency. *Canadian Journal of Soil Science* 81: 383–394.

Castellanos J, Maass M & Kummerow J. 1991. Root biomass of a dry deciduous tropical forest in Mexico. *Plant and Soil* 131: 225–228.

CONAFOR. 2005. *Disminuye Tasa de Deforestación en México en los Ultimos Cinco Años.* Estudio sobre la Dinámica de Cambio de la Vegetación Forestal de México. http://www.agricultura.com.mx/CGI-BIN/modules.php?name=News&file=article&sid=893.

DeFries RS, Houghton RA, Hansen MC, Field CB, Skole D & Townsend J. 2002. Carbon emissions from tropical deforestation and regrowth based on satellite observations for the 1980s and 1990s. *Proceedings of the National Academy of Sciences.* Doi 10.1073/pnas.182560099. 99: 14256–14261.

De Jong BHJ, Ochoa-Gaona S, Castillo-Santiago MA, Ramírez-Marcial N & Cairns MA. 2000. Carbon flux and patterns of land-use/land-cover change in the selva Lacandona, México. *AMBIO* 29: 504–511.

FAO (Food and Agriculture Organization). 2009. *State of the World Forests.* FAO, Rome.

Follett RF. 2001. Soil management concepts and carbon sequestration in cropland soils. *Soil and Tillage Research* 61: 77–92.

Geist HJ & Lambin EF. 2005. Dynamic causal patterns of desertification. *BioScience* 12: 817–829.

Hansen MC, Stehman SV, Potapov PV, Loveland TR, Townsend JRG, DeFries RS, Pittman KW, Arunarwati B, Stolle F, Steininger MK, Carrol M & DiMiccelli C. 2008. Humid tropical forest clearing from 2000 to 2005 quantified by using multitemporal and multiresolution remotely sensed data. *Proceedings of the National Academy of Sciences.* Doi 10.1073/pnas.0804042105. 105: 9439–9444.

Hao X, Chang C & Lindwall CW. 2001. Tillage and crop sequences on organic carbon and total nitrogen content in an irrigated Alberta soil. *Soil and Tillage Research* 62: 167–169.

Houghton RA. 2005. Tropical deforestation as a source of greenhouse emissions. In Moutinho P & Schartzman S (Eds.) *Tropical Deforestation and Climate Change.* IPAM, Belem.

Hughes RF, Kauffman JB & Jaramillo VJ. 2000. Ecosystem-scale impacts of deforestation and land use in a humid tropical region of Mexico. *Ecological Applications* 10: 515–527.

INEGI (Instituto Nacional de Estadística Geografía e Informática). 2002. *Estado de Morelos.* www.inegi.gob.mx/geo/default.asp?c=124&e=17.

IPCC (Intergovernmental Panel on Climate Change). 2001. *Third Assessment Report—Climate Change. The Scientific Basis: Summary for Policymakers.* www.ipcc.ch.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge.

Lal R, Kimble JM, Follett RF & Cole CV. 1999. *The Potential of US Cropland to Sequester Carbon and Mitigate the Greenhouse Effect.* Ann Arbor Press, Chelsea.

Mas JF, Velázquez A, Díaz-Gallegos JR, Mayorga-Saucedo R, Alcántara C, Bocco G, Castro R, Fernández T, & Pérez-Vega A. 2004. Assessing land use/cover changes: a nationwide multidate spatial database for Mexico. *International Journal of Applied Earth Observation and Geoinformation* 5: 249–261.

Masera O, Ordóñez M & Dirzo R. 1997. Carbon emissions from Mexican forests: current situation and long-term scenarios. *Climatic Change* 35: 265–295.

Mohren GMJ & Klein Goldewijkt GM. 1990. *CO_2 Fix: A Dynamic Model of CO_2 Fixation in Forest Stands.* Report 624. Research Institute for Forestry and Urban Ecology, Wageningen.

Murphy PG & Lugo AE. 1986. Ecology of tropical dry forest. *Annual Review of Ecology and Systematics* 17: 67–88.

Návar J. 2009. Allometric equations for tree species and carbon stocks for forests of northwestern Mexico. *Forest Ecology and Management* 257: 427–434.

Návar J, Mendez E & Dale V. 2002. Estimating stand biomass in the tamaulipan thronscrub of northeastern Mexico. *Annals of Forest Science* 59: 813–821.

Návar-Cháidez JJ. 2008. Carbon fluxes resulting from land-use changes in the tamaulipan thornscrub of northeastern Mexico. *Carbon Balance and Management.* Doi 10.1186/1750–0680–3–6. 3: 6

Palacios-Prieto JL, Bocco G, Velázquez A, Mas JF, Victoria A, Luna-González L, Gómez-Rodríguez G, López-García J, Palma M, Trejo-Vázquez I, Peralta A, Prado-Molina J, Rodríguez-Aguilar A, Mayorga-Saucedo R & González F. 2000. La condición actual de los recursos forestales en México: resultados del Inventario Forestal Nacional 2000. *Investigaciones Geográficas* 43: 183–203.

PEOT (Programa Estatal de Ordenamiento Territorial). 2000. *Secretaría del Medio Ambiente y Recursos Naturales.* Gobierno del Estado de Morelos, Morelos.

Post MW. 2002. Global distribution of soil organic matter in world ecosystem. *Encyclopedia of Soil Science*.

Quadri de la Torre G. 2000. *Incendios Forestales y Deforestación en México: una Perspectiva Analítica*. Comisión de estudios del sector privado para el desarrollo sustentable (CESPEDES), México. http://www.cceorg.mx /céspedes /publicaciones /otras /deforestacion/contenido.htm.

Roper J & Roberts R. 1999. *Deforestación: Bosques Tropicales en Disminución*. Red de asesores forestales de la ACDI (RAFA), México. http://www.rcfa-cfan.org/spanish/s.issues.12.html.

SEMARNAT. 2002. *Informe de la Situación del Medio Ambiente en México*. http://portal.semarnat.gob.mx/semarnat/portal.

Silva-Arredondo FM & Návar-Cháidez JJ. 2009. Estimación de factores de expansión de carbono en comunidades templadas del norte de Durango, Mexico. *Revista Chapingo: Serie Recursos Naturales y Medio Ambiente* 15: 155–160.

Trejo I & Dirzo R. 2000. Deforestation of seasonally dry tropical forest: a national and local analysis in Mexico. *Biological Conservation* 94: 133–142.

Trejo I & Hernández J. 1996. Identificación de la selva baja caducifolia en el estado de Morelos, México, mediante imágenes de satélite. *Investigaciones Geográficas* 5: 11–18.

Yang XM & Kay BD. 2001. Impacts of tillage practices on total, loose- and occluded-particulate, and humified organic carbon fractions in soils within a field in southern Ontario. *Canadian Journal of Soil Science* 81: 149–156.