The greenhouse gas balance of the oil palm industry in Colombia: a preliminary analysis.
II. Greenhouse gas emissions and the carbon budget

Balance de gases de efecto invernadero de la agroindustria de la palma de aceite en Colombia: análisis preliminar.
II. Emisión de gases de efecto invernadero y balance de carbono

Ian E. Henson[1], Rodrigo Ruiz R.[2], and Hernán Mauricio Romero[2, 3]

ABSTRACT

In the preceding paper we examined carbon sequestration in oil palm plantations and in mill products and by-products as part of a study of the greenhouse gas balance of palm oil production in Colombia, showing how this has changed over time. Here, we look at the opposing processes of greenhouse gas (GHG) emission and calculate the resulting net carbon budget for the industry. The main emission sources, in decreasing order of magnitude, assessed using 'default' or 'most probable' options, were found to be land use change (40.9% of total), mill methane production (21.4%), direct use of fossil fuel (18.5%), indirect use of fossil fuel (11.9%) and nitrous oxide production (7.3%). The total (gross) emissions, expressed in carbon equivalents (Ceq.), were less than the amount of sequestered carbon, resulting in a positive net Ceq. balance. All oil palm growing regions showed a net gain with the exception of the western zone, where emissions due to land-use change were judged to be substantial. Of the 11 alternative scenarios tested, only three resulted in Ceq. balances lower than the default and only two gave a negative balance.

Key words: carbon footprint, CO_2 balance, climate change, land use change.

RESUMEN

Se evaluó el secuestro de carbono por parte de plantaciones de palma de aceite y en los productos del procesamiento y sus subproductos, como parte de un estudio del balance de gases de la producción de aceite de palma en Colombia, mostrando como este ha cambiado a través del tiempo. Se examinaron los procesos opuestos de la emisión de gases de efecto invernadero y calcula el balance neto de carbono resultante para la industria. La principales fuentes de emisiones en orden decreciente de magnitud, usando las opciones "por defecto" o "más probables" fueron el cambio de uso de tierra (40,9% del total), producción de metano en las plantas de procesamiento (21,4%), uso directo de combustibles fósiles (18,5%), uso indirecto de los combustibles fósiles (11,9%) y producción de óxido nitroso (7.3%). El total de emisiones (valor bruto) expresadas en carbono equivalente (Ceq.) fue menor que la cantidad de carbono secuestrado, resultando en un balance positivo neto de Ceq. Todas las zonas palmeras mostraron una ganancia neta con excepción de la zona Occidental en donde las emisiones dadas por el cambio de uso de tierra fueron sustanciales. De los 11 escenarios alternativos analizados solamente tres resultaron en un menor balance de Ceq. comparado al utilizado por defecto y solamente dos de ellos tuvieron un balance negativo.

Palabras clave: huella de carbono, balance de CO_2, cambio climático, cambio de uso de tierra.

Introduction

The net impact of a process on climate change is determined by the balance between carbon uptake and sequestration from the atmosphere by photosynthesis, and emission to the atmosphere of GHGs. In addition to CO_2, the main GHGs associated with oil palm cultivation and processing are methane (CH_4) and nitrous oxide (N_2O), which have global warming potentials (GWPs) of 25 and 298 respectively, rendering them more effective per unit mass than CO_2 (based on an assumed residence time of 100 years) in increasing mean surface air temperature (IPCC, 2006).

Colombia is currently the world's fifth largest producer of palm oil, the second largest producer outside Southeast Asia, and the largest producer in South and Central America. In a previous paper (Henson *et al*., 2012), we examined the amount of carbon sequestered in Colombia in oil palm plantations and in processed materials stored at palm oil mills. Changes in carbon sequestration were followed over a

Received for publication: 11 April, 2012. Accepted for publication: 30 October, 2012.

---

[1] Consultant. Bristol (UK).
[2] Oil Palm Biology and Breeding Research Program, Colombian Oil Palm Research Center, Cenipalma. Bogota (Colombia).
[3] Department of Biology, Universidad Nacional de Colombia. Bogota (Colombia). hmromeroa@unal.edu.co

50-year period and separate assessments were made for the four regions of the country in which oil palm plantations are located. While information on sequestration is itself of interest, it is the net balance in terms of greenhouse gas (GHG) emissions that determines whether cultivation of a crop contributes to climate change and exacerbates global warming. In this paper, we complete the balance sheet by assessing the GHG emissions associated with palm oil production in Colombia and compare a number of alternative scenarios that affect the balance. We quantify the emission of the main GHGs, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), show a range of probable budgets and compare the results to those obtained for major palm oil producing countries in Southeast Asia.

Materials and methods

We constructed separate budgets for the four regions of Colombia (eastern, northern, central and western) where oil palm is grown aided by data on oil palm planted areas and previously presented production (Henson *et al*., 2011).

The following emissions were considered in the budgets:

i) CO_2 emission by vegetation cleared for planting new oil palm or re-planting old. Both are included in the term land use change (LUC).

ii) CO_2 emission due to the direct use of fossil fuels (diesel consumed in plantation vehicles and machinery).

iii) CO_2 emission due to the indirect use of fossil fuels (fuels consumed during the production and transport of plantation inputs such as fertilizers and crop protection chemicals).

iv) carbon equivalent (Ceq.) emissions in the form of N_2O (mainly produced from inorganic N fertilizers).

v) Ceq. emissions in the form of CH_4 produced by open palm oil mill effluent (POME) ponds, mill boilers and plantation livestock.

There are other GHG emission sources associated with oil palm cultivation and milling but these are relatively small or poorly quantified, and are thus ignored in this preliminary analysis. An example is CO_2 emission due to oxidation of peat soil after drainage to plant oil palm. While substantial on a per hectare basis, the area of oil palm on peat in Colombia is estimated to be no more than 800 ha or <0.2% of the total (2009) oil palm area. While ways to reduce emissions are being developed (*e.g.* biogas production from POME ponds), they are yet to be widely practiced and thus have not been factored into the present analysis. Information gathered from different sources (Colombian Federation of Palm Growers, the Instituto Geográfico Agustín Codazzi, and the Colombian Ministry of Environment, Colombian Oil Palm Research Center) was used in the calculation of greenhouse gas emissions and the carbon budget, and the results of processing this information are presented.

Results and discussion

Emissions due to land-use change

The establishment of new oil palm plantings involves a change in land use resulting in loss of carbon present in the previous vegetation and possibly some carbon loss from oxidation of soil organic matter. Such losses are partly or wholly replaced or possibly exceeded by carbon sequestration in the oil palm crop. Quantifying these changes requires information on previous biomass, the data for which are often uncertain. During natural decay, carbon is released as CO_2, while the use of fire to aid clearance results in the additional release of trace gases (N_2O, CH_4). When oil palm is replanted, there may be little if any change in the time-averaged carbon stock (*i.e.* the standing carbon stock averaged over the lifespan of the crop) as the loss from the first crop is replaced during growth of the succeeding one. In other cases, there may be either a loss or a gain of carbon depending on whether the biomass cleared is greater or less than the time-averaged carbon stock of the oil palm.

Information on LUC in Colombia as a result of oil palm expansion is sparse. For the period 1990 to 2005, Pagiola *et al*. (2004) reported that areas of annual crops and forests declined while those of permanent crops (which would include oil palm), permanent pasture and other land use categories increased (Tab. 1). However, although suggestive, these data are insufficient for calculating carbon stock changes resulting from oil palm expansion.

TABLE 1. Land use and land use change in Colombia, 1990 to 2005.

Land use class	Land use areas				Land use change 1990 to 2005
	10^3 ha		Percentage of total land		
	1990	2005	1990	2005	10^3 ha $year^{-1}$
Annual crops	3,305	2,818	3.2	2.7	-48.7
Permanent crops	1,662	1,766	1.6	1.7	10.4
Oil palm	115	157	0.1	0.2	4.2
Other	1,547	1,609	1.5	1.6	6.2
Permanent pasture	40,094	40,925	38.6	39.4	83.1
Forest	51,520	49,650	49.6	47.8	-187.0
Other land	7,289	8,711	7.0	8.4	142.2

Notes: Annual crops include temporary pasture, permanent crops include oil palm and other perennial crops. Other land was calculated assuming the total land area to be $103{,}870{\cdot}10^3$ ha. Adapted from Tab. 5 of Henson *et al.* (2011), based on data from Pagiola *et al.* (2004), MPIC (2005), MPOB (2008); FEDEPALMA (2009a).

Gómez *et al.* (2005) quoting Rodríguez and Van Hoof (2004), reported that up to 87% of land used for oil palm was previously occupied by annual crops and pasture, vegetation that has a much lower biomass than oil palm.

In a detailed study of the eastern region summarized in Tab. 2, Rincón (2009) found the majority of land converted to oil palm between 1972 and 2009 was either pasture and savanna, herbaceous vegetation or annual crops, while very

TABLE 2. List of default and alternative options tested.

Item	Default option	Alternative options
Oil palm growth curve	National average	OPRODSIM OP
Replanting cycle time	Mean of 20, 25 and 30 years	20, 25 or 30 years
Method of estimating oil palm replanted area	Mean of two methods, M1 and M2	M1 or M2
(%) area of forest converted for oil palm in Western region	50	25 or 75
Methane production by POME ponds	Free emission	Emitted methane flared
Fertilizer use	Based on Wood and Corley (1993)	Based on data for two Colombian estates

TABLE 3. Greenhouse gas balance per hectare for individual regions of Colombia, 1959 to 2009, based on default options.

Source	Eastern	Northern	Central	Western	Whole country
	Ceq. (t ha^{-1} year^{-1})				
			Sequestration		
Oil palm standing biomass	1.427	1.492	1.285	1.585	1.425
Plantation litter and ground cover	0.378	0.384	0.337	0.326	0.364
Felled oil palm residues	0.052	0.025	0.025	0.029	0.033
Other residues	0.013	0.010	0.005	0.068	0.016
Wood harvest	0.001	0.001	<0.001	0.044	0.005
Mill products	0.071	0.088	0.092	0.015	0.076
Mill by-products	0.036	0.036	0.050	0.011	0.037
Offsets	0.263	0.282	0.328	0.278	0.288
Total	2.241	2.318	2.122	2.356	2.244
			Emission		
Land-use change	0.756	0.666	0.453	2.729	0.861
Direct fossil fuel use	0.363	0.383	0.430	0.379	0.388
Indirect fossil fuel use	0.251	0.251	0.251	0.252	0.251
Methane emission	0.412	0.442	0.512	0.436	0.450
Nitrous oxide emission	0.155	0.150	0.157	0.152	0.154
Total	1.937	1.892	1.803	3.948	2.104
			Balance		
	0.304	0.426	0.319	-1.592	0.140

TABLE 4. Greenhouse gas balance per tonne of crude palm oil (CPO) for different regions of Colombia, 1959 to 2009, based on default options.

Source	Eastern	Northern	Central	Western	Whole country
	(t Ceq./t pear year CPO)				
			Sequestration		
Oil palm standing biomass	0.606	0.620	0.455	0.643	0.568
Plantation litter and ground cover	0.160	0.160	0.119	0.132	0.145
Felled oil palm residues	0.022	0.010	0.009	0.008	0.013
Other residues	0.005	0.004	0.002	0.026	0.006
Wood harvest	<0.001	<0.001	<0.001	0.017	0.002
Mill products	0.030	0.036	0.033	0.006	0.030
Mill by-products	0.015	0.015	0.018	0.004	0.015
Offsets	0.112	0.117	0.116	0.113	0.115
Total	0.950	0.962	0.752	0.949	0.894
			Emission		
Land-use change	0.321	0.277	0.160	1.106	0.343
Direct fossil fuel use	0.154	0.159	0.152	0.154	0.155
Indirect fossil fuel use	0.107	0.104	0.089	0.102	0.100
Methane emission	0.175	0.184	0.181	0.177	0.179
Nitrous oxide emission	0.066	0.062	0.056	0.062	0.061
Total	0.823	0.786	0.638	1.601	0.838
			Balance		
	0.127	0.176	0.114	-0.652	0.056

little land with high biomass such as forests was used. This is despite there being a significant area of forested land in the region (Tab. 6).

TABLE 5. Land use classes converted to oil palm in the eastern region of Colombia, 1972 to 2009.

Land use class converted to oil palm	Land use change 1972 to 2009	
	(ha year^{-1})	% of total
Annual crops	565	19.1
Pasture and savannas	1305	44.0
Herbaceous vegetation	646	21.8
Forest	4	0.2
Bare/degraded lands	446	15.0
Total	3,608	100

Source: Rincón, (2009).

TABLE 6. Land use and land use change in the eastern region of Colombia, 2001 to 2007.

Land use class	Area in 2001 (10^3 ha)	Percentage of total area in 2001	Area in 2007 (10^3 ha)	Change in area 2001-2007 (10^3 ha)
Barren	0	0	3	3
Cropland	148	0.6	187	39
Excluded	96	0.4	90	-6
Forest	1,1451	46.6	11,537	86
Grassland	2638	10.7	3,731	1,093
Mixed	4426	18.0	4,945	519
Savanna	5197	21.2	3,651	-1546
Shrubland	378	1.5	277	-101
Wetland	230	0.9	143	-87
Total	24,564	100.0	24,564	0

Notes*:* data were obtained using revised MODIS remote sensing data for the four palm oil producing states in the eastern region (Caquetá, Casanare, Cundinamarca and Meta). Oil palm areas in the table would have been included, depending on age, in either the cropland or forest class. Sources: Harris *et al.* (2009); N Harris, pers com. (2010).

On a national basis, the total area of forest in Colombia has changed only slightly since the 1960s and the area covered by forest still remains high, at around 58% of total land area. Thus, the increase in area of oil palm (c. 361·10^3 ha in 2009) has had little impact on the nation's forest cover.

The type of LUC in Colombia is likely to have differed between regions but data for other regions comparable to those for the eastern zone in Tab. 5 are not available. Unfortunately, remote sensing satellite data for Colombia, such as those provided by MODIS (Harris *et al.*, 2009), have yet to produce an unambiguous determination of the oil palm area, as oil palms are not easily distinguished from forest once the canopy is closed (N Harris, pers. com. 2010).

A later study (Cenipalma, 2010) summarized in Tab. 7, provides LUC data for the northern and central, as well as for the eastern, regions, but over a shorter period than that of Rincón (2009). The survey may not cover all the oil palm areas in these regions, as the numbers of municipalities surveyed were less than the number with oil palm plantations. Also, for the eastern region, the data are less detailed than those given by Rincón (2009). Nevertheless, the conclusions are broadly similar, showing that most LUC from other uses to oil palm has involved pastures and other crops.

TABLE 7. Land use change in the eastern, northern and central regions of Colombia, 2000 to 2005.

Land use class converted to oil palm	Eastern		Northern		Central	
	(ha year^{-1})	(% of total)	(ha year^{-1})	(% of total)	(ha year^{-1})	(% of total)
Forest	0	0	5	0.4	6	0.2
Scrub	0	0	105	7.9	0	0
Wetland	0	0	16	1.2	1	0
Pastures and crops	1,253	100	1,205	90.6	2,148	88.3
Beaches and dunes	0	0	0	0	9	0.4
Other natural areas	0	0	0	0	270	11.1

Source: Cenipalma (2010).

One crop of special interest is rice (*Oryza sativa*), areas of which have been converted to oil palm in the eastern region. Rice fields emit CH_4, so conversion of rice land to oil palm should entail an emission reduction that would offset LUC emissions. The same may be true of natural wetlands, although areas of these converted to oil palm have been small (Tab. 7). Preliminary estimates of emission savings due to rice conversion suggested these could be quite substantial but detailed information on rice cultivation in Colombia is lacking and further analysis is required. It is also possible that new areas of rice may have been established to replace those converted to oil palm. Although the total rice area in Colombia fluctuated during 2000 to 2005, there was little change overall (FAO, 2008).

To quantify the contribution of LUC to the carbon budget, data on both areas converted and carbon loss per hectare are required. We used the emission factors estimated for Colombia by Harris *et al.* (2009), given in Tab. 8. These appear generally representative, being in good agreement with ten other sources that were consulted after allowing for minor differences in land classification.

Because of the fragmentary nature of the available data, and in order to assess carbon emissions due to LUC, it was assumed that the type and proportion of different land classes converted in the eastern region were as given in Tab. 5 and, for the northern and central regions, as given in Tab. 7. For the western region, for which data were sparse, three alternative scenarios were tested involving either

TABLE 8. Land use change emission factors for Colombia.

Land use class	Emission factor (t carbon ha^{-1})
Annual crops	4.9
Permanent pasture	7.4
Forest	146.5
Savannas	13.4
Shrubland	25.4
Mixed	46.1
Wetlands	16.4
Bare/degraded lands	0

Source: Harris *et al.* (2009).

a low, medium or high proportion of forested land with the balance made up of mixed vegetation and shrub land, selected on the basis of remotely sensed changes in total land use from 2001 to 2007 (Harris *et al.*, 2009). We further assumed that the proportions of land use types converted remained constant over time.

The emissions calculated for the four regions and for Colombia as a whole are given in Tab. 9. Specific emissions averaged for the whole country varied from 10.2 to 12.2 t C ha^{-1} year^{-1} depending on the LUC scenario adopted for the western region. The central region had the lowest LUC emissions.

TABLE 9. Carbon emissions (t ha^{-1} year^{-1}) due to land conversion to oil palm in Colombia, 1959 to 2009, assuming low, medium or high forest conversion in the western region.

Western region forest use (%)	Eastern	Northern	Central	Western	Whole country
25	8.70	8.34	5.71	68.86	10.19
50	8.70	8.34	5.71	94.74	11.24
75	8.70	8.34	5.71	117.81	12.17

Emissions due to direct and indirect use of fossil fuels

A summary of these emissions, derived from the Malaysian study (Henson, 2009), is presented in Tab. 10. Direct emissions result from use of fossil fuel for generating energy and running transport and machinery in the field and mill. In the case of mill operations, the energy requirements are largely or entirely met by burning waste biomass (fibre and shell), which minimizes the need for external energy. Indirect emissions arise from use of fossil fuel in manufacturing and transport of inputs such as fertilizers, herbicides and pesticides, together with energy expended by workers (Wood and Corley, 1993).

For fertilizers, alternative calculations were carried out based on current fertilizer use on two plantations, one located in the north and one in the central region. The mean rates per hectare were those recorded from 2005 to 2009 but were assumed to have been applied from 1959 to 2009 to all oil palm present in each region. The emissions were calculated using coefficients for fertilizer production based on average European conditions (Jenssen and Kongshaug, 2003), diesel use for transport over a distance, from source to local port, of 10,000 km, and, from port to mill, of 50 km, in accordance with Chase and Henson (2010). For some minor fertilizers, such as borate production, coefficients were not available and hence the total emissions may be underestimated. This is also the case for the 'general' assessments based on the data of Wood and Corley (1993), which likewise ignore the application of minor elements. The results (Tab. 11) show that the plantation in the north used more fertilizer than the general estimate while the plantation in the central region used less. Such variation is understandable given large differences in soil types and conditions within the country.

TABLE 10. Carbon equivalent emissions due to direct and indirect fossil fuel use and worker activity, 1959 to 2009.

Item	Eastern	Northern	Central	Western	Whole country
	Carbon eq. emissions (10^3 t year^{-1})				
Direct emissions					
Mill operations	8.29	7.91	8.38	2.85	27.43
Transport and machinery	2.79	2.47	2.26	0.91	8.43
Total direct use	11.08	10.38	10.64	3.76	35.86
Indirect emissions					
Fertilizers	6.08	5.40	4.92	1.98	18.38
Crop protection chemicals	1.22	1.08	0.99	0.40	3.69
Workers	0.36	0.32	0.29	0.12	1.10
Total indirect use	7.67	6.81	6.20	2.50	23.17

Based on the data of Wood and Corley (1993) and calculated as described by Henson (2009).

TABLE 11. Comparison of carbon equivalent emissions due to inorganic fertilizer use in two regions of Colombia, 1959 to 2009, based on standard versus plantation-specific fertilizer applications.

Region	Data source	Annual C eq. emissions	
		t ha^{-1}	10^3 t
North	Standard	0.199	5.40
	Plantation 1	0.216	6.10
Central	Standard	0.199	4.92
	Plantation 2	0.145	3.64

Methane emissions

There are several potential sources of CH_4, but most of these are minor and not well quantified. Tab. 12 details the more important sources, the principal one being POME. The methane emission from POME was calculated from FFB production using an emission factor determined by Yacob *et al.* (2006), with adjustments for the CO_2 taken up by the palms and subsequently released as methane (Wicke *et al.*, 2008a). It is possible to mitigate POME emissions either by trapping and then converting the methane to CO_2 by flaring or by using the trapped gas as a fuel to generate electricity. While a few mills in Colombia now undertake flaring, these technologies have yet to become widespread and so are not considered in the present analysis.

Other methane sources examined were combustion at the mill of EFB, fibre and shell, and livestock on plantations that emit methane due to enteric fermentation. When added up, these sources contributed less than seven per cent of the total methane produced.

TABLE 12. Carbon equivalent emissions of methane in Colombia, 1959 to 2009.

Source	Eastern	Northern	Central	Western	Whole country
	Carbon eq. emission (10^3 t year^{-1})[1]				
POME[2]	11.63	11.08	11.75	4.00	38.46
Mill boilers[3]	0.52	0.51	0.54	0.18	1.76
Livestock[4]	0.44	0.39	0.37	0.15	1.35
Total	12.59	11.98	12.66	4.33	41.57

[1] Calculated using GWPs of 298 and 25 for nitrous oxide and methane respectively

[2] Emission from open ponds at mill

[3] Burning of EFB, fibre and shell

[4] Buffalos, mules and horses used on plantations. Calculations were based on data supplied by Carlos Alberto Ospina (pers. communic.) and by Guterman (2008).

Nitrous oxide emissions

Sources of N_2O include peat soils, nitrogenous fertilizers, N-containing organic materials and biomass burnt in the field. In Colombia, there is little if any oil palm on peat, and there are few data on amounts of organic materials applied in the plantations. Hence, it is not possible to quantify this latter source of N_2O. Burning in the field is presently prohibited but occurred in the past. However, to estimate contributions from burning, it is necessary to have reliable estimates of LUC. As these are presently tentative and the emissions from burning are likely to be relatively small, they are not considered in the present analysis.

The main N_2O source is inorganic N fertilizer. The amount of N_2O emitted is a product of the amount of N applied and the emission per unit N. N_2O is formed both directly due to denitrification on-site and indirectly from N losses occurring as run off, leaching and volatilization. The latter process is only significant for urea, which is not generally used in Colombia and therefore volatilization losses can be ignored. Estimates of the amount of N applied per palm were based on the data of Wood and Corley (1993), and the direct and indirect N_2O emission factors were those adopted by IPCC (2006). N uptake efficiency was assumed to be 60% (Chase and Henson, 2010). Results are shown in Tab. 13. Alternative assessments of N_2O emission made for the central and northern regions of Colombia based on fertilizer data from the two above-mentioned plantations gave total N_2O emissions for the two regions of 5.27 and $2.80 \cdot 10^3$ t Ceq. year^{-1} respectively.

TABLE 13. Carbon equivalent emissions of nitrous oxide due to standard inorganic fertilizer use in Colombia, 1959 to 2009.

Source	Eastern	Northern	Central	Western	Whole country
	Carbon eq. emission (10^3 t year^{-1})				
Direct	3.64	3.13	2.98	1.16	10.91
Indirect	1.09	0.94	0.90	0.35	3.28
Total	4.73	4.07	3.88	1.51	14.19

Total emissions

The emissions considered above are summarized in Tab. 14. On a unit area or tonne crude palm oil (CPO) basis, the western region exhibited the highest emissions, a result of a high LUC component (Tab. 9). The central region had the lowest emissions per hectare and per tonne CPO.

TABLE 14. Mean carbon equivalent emissions per hectare, per tonne crude palm oil, and per region, in the four palm oil producing areas of Colombia, 1959 to 2009 using default options[1].

Source	Eastern	Northern	Central	Western	Whole country
	Ceq. (t ha^{-1} year^{-1})				
Land-use change	0.756	0.666	0.453	2.729	0.861
Direct fossil fuel use	0.363	0.383	0.430	0.379	0.388
Indirect fossil fuel use	0.251	0.251	0.251	0.252	0.251
Methane emission	0.412	0.442	0.512	0.436	0.450
Nitrous oxide emission	0.155	0.150	0.157	0.152	0.154
Total	1.937	1.892	1.803	3.948	2.104
	(t Ceq./t per year CPO)				
Land-use change	0.321	0.277	0.160	1.106	0.343
Direct fossil fuel use	0.154	0.159	0.152	0.154	0.155
Indirect fossil fuel use	0.107	0.104	0.089	0.102	0.100
Methane emission	0.175	0.184	0.181	0.177	0.179
Nitrous oxide emission	0.066	0.062	0.056	0.062	0.061
Total	0.823	0.786	0.638	1.601	0.838
	Ceq. (10^3 t year^{-1})				
Land-use change	23.09	18.06	11.20	27.10	79.45
Direct fossil fuel use	11.08	10.38	10.64	3.76	35.86
Indirect fossil fuel use	7.67	6.81	6.20	2.50	23.18
Methane emission	12.59	11.98	12.66	4.33	41.56
Nitrous oxide emission	4.73	4.07	3.88	1.51	14.19
Total	59.16	51.30	44.58	39.20	194.24
Percetage total	30.4	26.4	22.9	20.2	100

See Tab. 2.

Greenhouse gas balance

The default case – mean balances

Tab. 15 gives the mean annual GHG balance for Colombia for 1959 to 2009, calculated using the default options listed in Tab. 2. Data for individual regions are presented in Tab. 16 while values per hectare and per tonne CPO are given in Tab. 3 and 4. For the whole country, the net Ceq. GHG balance was positive with total carbon sequestration exceeding GHG emissions by 12.83·10^3 t year^{-1} (6.6% of gross emissions). The west was the only region that showed a negative balance, with emissions exceeding sequestration by 68%.

TABLE 15. Greenhouse gas balance for palm oil production in Colombia, 1959 to 2009 based on default options[1].

Carbon sequestration		Carbon equivalent emission	
Source	**10^3 t year^{-1}**	**Source**	**10^3 t year^{-1}**
Oil palm standing biomass[2]	131.57	Land-use change[3]	79.45
Plantation litter and ground cover[4]	33.54	Direct fossil fuel use	35.86
Felled oil palm residues	3.08	Indirect fossil fuel use	23.17
Residues from other vegetation	1.46	Methane emission	41.57
Harvested wood products	0.49	Nitrous oxide emission	14.19
Mill products[5]	6.98		
Mill by-products[6]	3.40		
Offsets from use of mill by-products[7]	26.55		
Total carbon sequestration	207.07	Total carbon emission	194.24
		Net carbon balance	12.83

[1] See Tab. 2.

[2] Fronds, trunk and roots.

[3] Vegetation from previous land use (grassland, crops, scrub, forest).

[4] Frond piles, shed frond bases, male inflorescences, cover crops and other ground vegetation.

[5] CPO, PKO, PKC.

[6] EFB, bunch ash, fibre, shell, POME, losses.

[7] Use of fibre and shell as boiler fuel and EFB, bunch ash and POME as nutrient sources.

Effects of alternative options

The effects on the GHG balance of using several alternative options are shown in Tab. 17. Of the 11 alternatives tested, only three resulted in Ceq. balances lower than the default and only two gave a negative balance, while the remaining eight options gave balances higher (positive) than the default. This suggests that use of the default options may underestimate the probable balance.

Fig. 1 shows changes over time in sequestration, emissions and GHG balance for the default options and for the two most contrasting scenarios (results are given as 10-year means in order to remove fluctuations in individual years that were most prominent for emissions). For the 'standard' and 'minimum' scenarios, the GHG balance remained relatively constant over time.

Conclusions

This report provides only a preliminary estimate of the GHG balance resulting from cultivating oil palm and milling FFB in Colombia. We have nevertheless attempted to make the analysis as comprehensive as possible, to identify which factors need to be better accounted for and to indicate their relative importance in determining the overall GHG balance. Hopefully, this will promote further studies, aimed at improving the estimation.

TABLE 16. Greenhouse gas balance of palm oil production in individual regions of Colombia, 1959 to 2009, based on default options [1].

Source	Eastern	Northern	Central	Western
	Ceq. (10^3 t year^{-1})			
	Sequestration			
Oil palm standing biomass	43.59	40.47	31.76	15.74
Plantation litter and ground cover	11.54	10.42	8.34	3.24
Felled oil palm residues	1.59	0.68	0.61	0.20
Other residues	0.40	0.26	0.12	0.68
Wood harvest	0.02	0.03	0.01	0.43
Mill products	2.17	2.38	2.27	0.15
Mill by-products	1.09	0.96	1.24	0.11
Offsets	8.03	7.65	8.11	2.76
Total	68.42	62.85	52.46	23.31
(%) of total	33.0	30.4	25.3	11.3
	Emission			
Land-use change	23.09	18.06	11.20	27.10
Direct fossil fuel use	11.08	10.38	10.64	3.76
Indirect fossil fuel use	7.67	6.81	6.20	2.50
Methane emission	12.59	11.98	12.66	4.33
Nitrous oxide emission	4.73	4.07	3.88	1.51
Total	59.16	51.30	44.58	39.20
Percentage total	30.4	26.4	22.9	20.2
Balance	9.26	11.55	7.88	-15.89

[a)] See Tab. 2.

TABLE 17. Greenhouse gas balance for Colombia, 1959 to 2009, based on alternative options[1].

Case	Options tested	Carbon sequestration	GHG emission (Ceq.)	Net GHG balance (Ceq.)
			10^3 t yr^{-1}	
1	Default case	207.07	194.24	12.83
2	Use of OP2 oil palm growth curve	232.54	194.24	38.30
3	20-year replanting cycle	181.74	194.24	-12.50
4	25-year replanting cycle	215.69	194.24	21.45
5	30-year replanting cycle	223.82	194.24	29.58
6	25% forest conversion in western region	206.66	186.85	19.81
7	75% forest conversion in western region	207.44	200.85	6.59
8	POME CH_4 flared[2]	207.07	159.63	47.44
9	Fertilizer use based on northern plantation	207.07	193.62	13.45
10	Fertilizer use based on central plantation	207.07	181.84	25.23
11	High sequestration and low emission combination[3]	259.84	139.74	120.10
12	Low sequestration and high emission combination[4]	182.11	200.85	-18.74

[1] See Tab. 2. [2] 90% of CH_4 converted to CO_2 [3] OP2 growth curve, 30-year RCT, 25% forest conversion in the west, POME flaring, central rate of fertilizer use. [4] NA growth curve, 20-year RCT, 75% forest conversion in the west, no POME flaring, standard rate of fertilizer use.

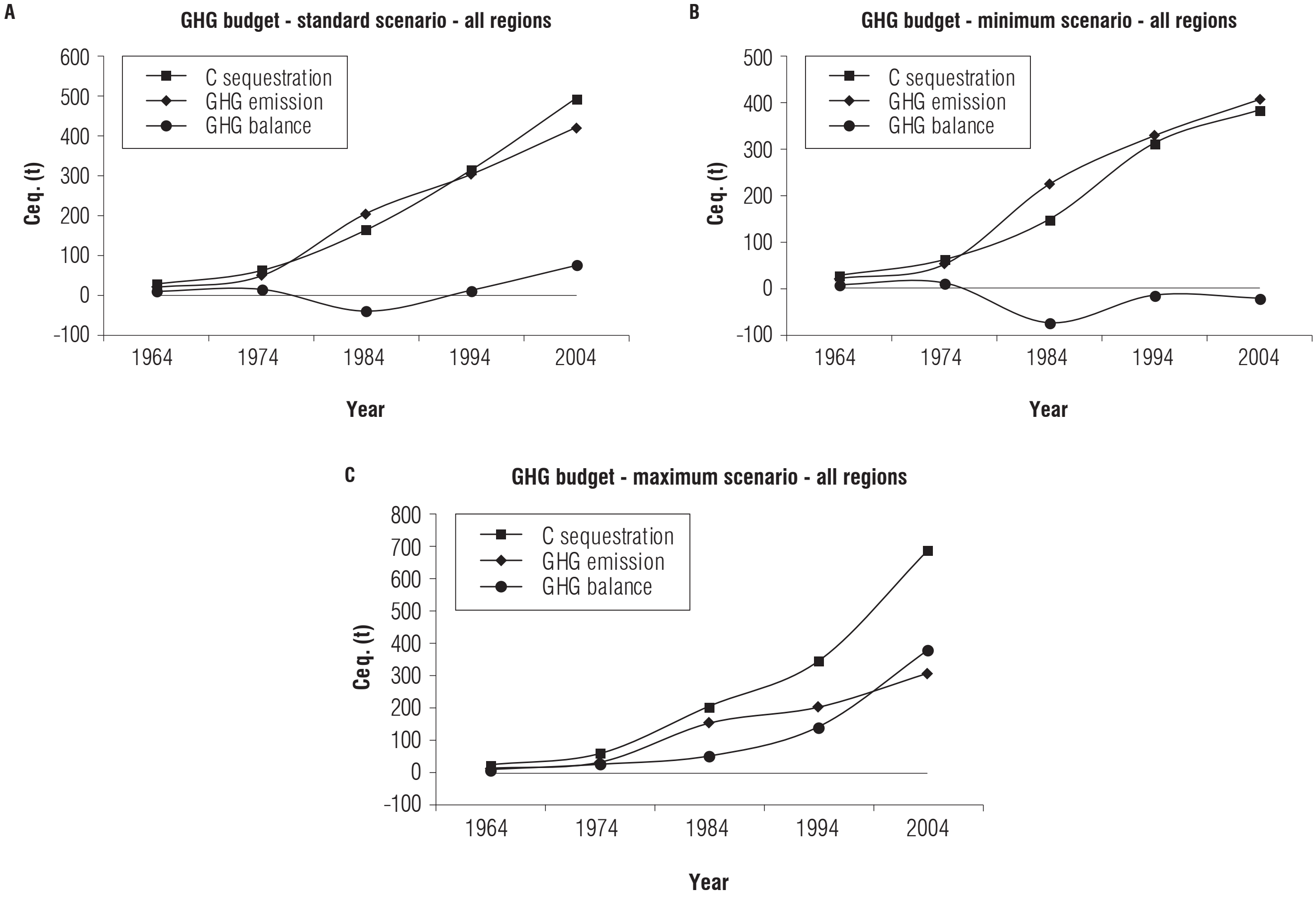

FIGURE 1. Changes in annual sequestration, GHG emissions, and Ceq. balance in Colombia averaged over 10-year periods, calculated using default options for (A), the standard scenario, (B), the scenario using the minimum option combination, and (C), the scenario using the maximum option combination. The years on the x-axis are the middle years for each period. The black lines represent zero. Both sequestration and emissions are given positive values to facilitate comparisons.

The principal finding was that the average annual GHG balance for Colombia over the 50 or so years of its history has been positive; *i.e.* sequestration has exceeded emission. This contrasts with findings for Indonesia (Wicke *et al.,* 2008b) and Malaysia (Henson, 2009), which show large negative balances. However, there are similarities in terms of the relative impacts of individual components on the budgets. Thus, the principal carbon sink (sequestration) was the oil palm itself (58% of total sequestration in Malaysia, 64% in Colombia), and the principal emission source was LUC (62% in Malaysia, 41% in Colombia). The lower LUC in Colombia was the principal reason for the small positive GHG balance versus the large negative balances found in Southeast Asia that arise from converting land with high carbon stocks. The estimation of LUC in Colombia is, however, very rough due to the lack of comprehensive and accurate data for the type of land converted and the initial carbon stocks. This is a deficiency that clearly needs to be rectified and it is anticipated that future estimates will become more precise with refinements in analyzing remote sensing data based on satellite images.

Acknowledgements

We are most grateful to the staff of Fedepalma and Cenipalma for providing primary data on the oil palm industry in Colombia. Thanks are due to Drs. Nancy Harris and Claire Chudziak for generously providing data on remote sensing and emission factors, and to Laurence Chase for help in interpreting fertilizer use. Mr. Carlos Alberto Ospina provided information on plantation livestock. We thank Dr. J Sanz Scovino, Executive Director of Cenipalma, for his interest and permission to publish this paper.

Literature cited

Cenipalma, Centro de Investigación en Palma de Aceite. 2010. Analisis multitemporal de coberturas en areas de interes para el cultivo de la palma. (Multi-temporal analysis of coverage in areas of interest for oil palm cultivation.) 2000-2002; 2005-2007. Internal report. Bogota.

Chase, L.D.C. and I.E. Henson. 2010. A detailed greenhouse gas budget for palm oil production. Intl. J. Agric. Sustain. 8(3), 1-16.

FAO. 2008. FAOSTAT Database, Statistics Division. Rome.

Fedepalma, Federación Nacional de Cultivadores de Palma de Aceite. 2009a. Statistical Yearbook, 2009. Bogota.

Fedepalma, Federación Nacional de Cultivadores de Palma de Aceite. 2009b. What oil palm has to offer. Leaflet. Bogota.

Fedepalma, Federación Nacional de Cultivadores de Palma de Aceite. 2010. Earlier editions. statistical yearbook. Bogota.

Gómez, P.L., M. Mosquera, and C. Castilla. 2005. Oil palm: a sustainable agro-industry in Colombia. Oleagineux, Corps Gras, Lipides 12, 121-124.

Guterman, D. 2008. Actualización de costos de producción de aceite de palma. Final Report. Fedepalma, Bogota.

Harris, N.L., S. Grimland, and S. Brown. 2009. Land use change and emission factors: Updates since proposed RFS rule. Report submitted to EPA. Winrock International, Arlington, VA.

Henson, I.E. 2009. Modelling carbon sequestration and greenhouse gas emissions associated with oil palm cultivation and land-use change in Malaysia. A re-evaluation and a computer model. MPOB Technol 31, 116.

Henson, I.E., R. Ruiz R., and H.M. Romero. 2011. The growth of the oil palm industry in Colombia. J. Oil Palm Res. 23, 1121-1128.

Henson, I.E., R. Ruiz R., and H.M. Romero. 2012. The greenhouse gas balance of the oil palm industry in Colombia: a preliminary analysis. I. Carbon sequestration and carbon offsets. Agron. Colomb. 30(3), 370-378.

IPCC. 2006. Guidelines for national greenhouse gas inventories. Vol. 4 Agriculture, forestry and other land use. WMO; UNEP, Geneva.

Jenssen, T.K. and G. Kongshaug. 2003. Energy consumption and greenhouse gas emissions in fertiliser production. Proceedings 509 International Fertiliser Society, York, UK.

MPIC, Ministry of Plantation Industries and Commodities. 2005. Statistics on commodities. 19th ed. Malaysia.

MPOB, Malaysian Palm Oil Board. 2008. Malaysian oil palm statistics. Kelana Jaya, Selangor, Malaysia.

Pagiola, S., P. Agostini, J. Gobbi, C. de Haan, M. Ibrahim, E. Murgueitio, E. Ramirez, M. Rosales, and J.P. Ruiz. 2004. Paying for biodiversity conservation services in agricultural landscapes. FAO Environmental Department Paper No. 96. Rome.

Rincón, V. 2009. Dinámica de la expansión del área cultivada con palma de aceite y su impacto en la cobertura del suelo: Zona Oriental palmera de Colombia (1972-2009). M.Sc. thesis. Universitat de Girona, Girona, Spain.

Rodríguez, M. and B. Van Hoof. 2004. Desempeño ambiental del sector palmero en Colombia. Fedepalma, Bogota.

Romero, C., A. Moreno, and F. Munevar F 1999. Evaluación edafoclimática de las tierras del trópico bajo colombiano para el cultivo de la palma de aceite. Cenipalma; Corpoica, Bogota.

Wicke, B., V. Dornburg, A. Faaij, and H.M. Junginger. 2008a. Different palm oil production systems for energy purposes and their greenhouse gas implications. Biomass and Bioenergy, 32, 1322-1337.

Wicke, B., R. Sikkema, V. Dornburg, H.M. Junginger, and A. Faaij. 2008b. Drivers of land use change and the role of palm oil production in Indonesia and Malaysia. Overview of past developments and future projections. Copernicus Institute Science, Universiteit Utrecht, Utrecht, The Netherlands.

Wood, B.J. and R.H.V. Corley. 1993. The energy balance of oil palm cultivation. pp. 130-143. In: Proceedings of 1991 PORIM International Palm Oil Conference, Agriculture. Palm Oil Research Institute of Malaysia, Kuala Lumpur.

Yacob, S., A. Mohd Hassan, Y. Shirai, M. Wakisaka, and S. Subash. 2006. Baseline study of methane emission from anaerobic ponds of palm oil mill effluent treatment. Sci. Total Environ. 366, 187-19.