Journal of Oil Palm Research Vol. 22 December 2010 p. 887-894

LIFE CYCLE ASSESSMENT FOR OIL PALM FRESH FRUIT BUNCH PRODUCTION FROM CONTINUED LAND USE FOR OIL PALM PLANTED ON MINERAL SOIL (Part 2)

ZULKIFLI, H*; HALIMAH, M*; CHAN, K W*; CHOO, Y M* and MOHD BASRI, W*

ABSTRACT

Life cycle assessment (LCA) is an important tool for identifying potential environmental impacts associated with the production of fresh fruit bunches (FFB) from specific operations in Malaysian oil palm plantations. This LCA study is to make available the life cycle inventory for cradle-to-gate data so that the environmental impacts posed by FFB production in the plantation can be assessed. The results of the study provide the Malaysian palm oil industry with information, and identify ways and measures to reduce the environmental impacts.

Most of the foreground data were collected directly from the oil palm plantations (site specific) from a detailed survey of the estates throughout Malaysia. The inventory data were collected from 102 plantations (based on feedback to a questionnaire) covering 1.1 million hectares of planted area, which is approximately 25% of the total area under oil palm. This survey area consisted of immature (1- to 2-year-old palms) and mature (3- to 25-year-old palms) areas, with both data sets included in the inventory for an amortized period of 25 years. Data gaps were filled by information obtained through literature and public databases, or calculated using published models. The inputs and outputs from upstream activities were quantified on the basis of a functional unit of production of 1 t FFB, while the life cycle impact assessment (LCIA) was carried out using the Sima Pro version 7.1 software and the Eco-indicator 99 methodology.

The weighted results of LCA for the production of 1 t FFB from continued land use (replanting) show significant environmental impacts in the fossil fuels, respiratory inorganics and climate change categories. The most significant process contributing to these environmental impacts comes from the production and usage of the various fertilizers (especially N fertilizers) from the use of field machinery (tractors) during operations in the plantation, and the use of transport vehicles bringing inputs to the plantations and transporting FFB to the mills. Producing FFB from continued land use (replanting) has no effect on land use.

The results clearly show that nitrogenous fertilizer production and application in the plantation is the most polluting process in the agricultural stage of FFB production; this is followed by the energy used by the machinery in the plantations and for transportation of FFB to the mills. Ways of reducing the environmental impacts are by increasing the FFB yield through the use of high-yielding oil palm planting materials which will result in increased fruit production, by applying more organic sources of nitrogen fertilizer instead of chemical fertilizers, by returning the nutrient-rich slurry from palm oil mill effluent (POME) treatment ponds to the field, or by applying compost (empty fruit bunches + POME) as fertilizer.

* Malaysian Palm Oil Board,
P. O. Box 10620,
50720 Kuala Lumpur,
Malaysia.
E-mail: zulhashim@mpob.gov.my

Keywords: Malaysia, oil palm plantation, fresh fruit bunches (FFB), life cycle assessment (LCA), life cycle impact assessment (LCIA).

Date received: 11 October 2010; **Sent for revision:** 13 October 2010; **Received in final form:** 19 October 2010; **Accepted:** 20 October 2010.

INTRODUCTION

The cultivation of oil palm in Malaysia began in 1917. Today, an approximate land area of 4.69 million hectares is planted with oil palm, producing about 17.56 million tonnes of palm oil (MPOB, 2009). The oil palm industry is continually expanding to meet the demand for oil for use as food and biodiesel. The key for increased production is mainly by intensifying production per unit area through yield advancement with improved planting materials and good agricultural practices. However, the continuous increase in oil palm area has generated negative perceptions by the NGOs concerning issues in biodiversity, erosion and greenhouse gas (GHG) emissions that lead to global warming. There is also greater public awareness in climate change, and a growing demand for green biofuel especially by the European Union (EU). Therefore, for sustainable production of oil palm, a long-term balance between inputs and outputs across the boundary system of oil palm production must be maintained during its life cycle.

Life cycle assessment (LCA) is the most holistic and comprehensive method used in assessing an environmental burden and impacts resulting from oil palm production. The results presented in this study quantify the environmental impacts associated with the processes, products or activities carried out in the plantation during the life cycle of oil palm, which is 25 years. However, it is recognized that the results of this study are specific to oil palm planted on mineral soil only as the detailed methodology on peat which includes a study on carbon (C) stock, peat oxidation and C emissions is on-going, and will be reported once all data are available. The impacts due to pesticides and heavy metal residues are small and regarded as having an insignificant effect on the environment. The effect of indirect land use change (ILUC), which is defined as the displacement of prior crop production and the possible land use induced by the movement of prior crop production to other areas, was not included in this study. It needs to be noted that this displacement may have a potentially large contribution to the overall GHG emissions. However, due to a lack of data and the complexity of the methodology, this ILUC effect was not estimated in this study.

The main objective of the study is the use of the LCA approach in identifying potential environmental impacts associated with the production of fresh fruit bunches (FFB) and in assessing GHG emissions from specific operations in an oil palm plantation for the production of FFB. This study only considered continued land use by oil palm from a previous generation (replanting) and not from other land use resulting in a change from the primary or degraded forest, or from other tree crops.

BACKGROUND OF FFB PRODUCTION

Oil palm is a monoecious crop as it bears both male and female flowers in the same plant. The palm produces compact bunches of 10 to 25 kg each, bearing 1000 to 3000 fruits, and are almost spherical or elongated in shape. Generally, the fruit is dark purple, almost black when unripe, turning to orange red when ripe. The fruit comprises a hard kernel (seed) enclosed in a shell (endocarp) which is surrounded by a fleshy mesocarp.

The oil palm may grow to a height of approximately 10 m before it is replanted after about 25-30 years. The harvested FFB contains around 25% oil, 25% seeds (5% kernels), 13% mesocarp fibre, 7% shell, and 23% empty fruit bunches (Corley and Tinker, 2003). In Malaysia, the oil palm planted is mainly the *tenera* variety, a hybrid between *dura* and *pisifera. Tenera* yields about 4 to 5 t of crude palm oil (CPO) per hectare in a year, and about 1 t of kernels. Oil palm is the most efficient oil-bearing crop in the world, requiring only 0.26 ha of land to produce 1 t of oil, whereas soyabean, sunflower and rapeseed require 2.22, 2.00 and 1.52 ha, respectively, to produce the same (Yusof and Chan, 2004).

The oil palm nursery is the first link in the palm oil supply chain. From the economic point of view, the major significant aims of the nursery phase are to minimize the immature period in the field and to ensure the highest possible early yield, whilst at the same time to keep nursery costs as low as possible. The palms are grown in polybags in the nursery. In the pre-nursery, germinated seeds are sown in small polybags (15 cm × 23 cm, or 6″ × 9″) until the seedlings are approximately three to four months, at which time they are transplanted into large polybags (38 cm × 45 cm, or 15″ × 18″) and grown without protective cover until they are 12 to 15 months old. In the main nursery, the polybags are arranged at 0.9 m × 0.9 m × 0.9 m, or 0.75 m × 0.75 m × 0.75 m, measured centre to centre, for an equilateral triangular spacing. All seedlings are irrigated with 0.5 litre water per day in the pre-nursery, and with 1.5-2.5 litres per day in the main nursery. Watering is normally done twice daily, before 11.00 am and after 4.00 pm. The seedlings are fertilized, and sprayed with pesticides for crop protection. Dithiocarbamate is the most commonly used fungicide. Fertilization is carried out manually. However, some nurseries use 'fertigation' for premature seedlings (<4 months), *i.e.* applying nutrients together with the irrigation water.

The seedlings are field-planted when they are 12-15 months old at a density of 136-148 plants per hectare on mineral soils (assuming an average of 142 ha^{-1}). Before planting, the soil is ploughed and a legume cover sown, typically *Mucuna bracteata*. The cover crop prevents soil erosion and fixes nitrogen (N) from the atmosphere, an important source of N especially when the palms are young. Clear weeding is done in a circle around each palm to prevent weed competition. The weeded circle is maintained in the mature palms to allow access for harvesting and to facilitate the picking up of scattered loose fruits. These weeded circles are kept weed-free by spraying with herbicides.

The palm bears fruits within two to three years, and continues to do so for the next 20 to 25 years, producing one FFB every 10 to 21 days. Harvesting at every 10-15 days is done manually, using a sickle attached to an aluminium pole. Normally, the two fronds under the fruit bunch are pruned and stacked in neat piles between the palms as mulch. The harvested FFB are brought to the roadside where they are collected by 5- to 10-t lorries to be transported to the mill.

Fertilizers are sourced from suppliers and transported to the plantation by road. The most common fertilizers applied to oil palm are muriate of potash, ammonium sulphate, kieserite and rock phosphate. The fertilizers, brought by tractors from the store to the field, are broadcast manually.

Herbicides are usually sprayed only when the palms are immature and their canopy has not covered the soil surface fully to prevent light from reaching the weeds. Most of the herbicides used are water-based formulations, and are manually applied using knapsack sprayers. Insecticides are the major pesticides used in oil palm, but their use is minimal. The application of phosphorus-based or organophosphate insecticides for bagworm control is very specific, being done through manual trunk injection. Often, it is possible to reduce the use of insecticides and rodenticides by practicing integrated pest management with components of biological control, such as the use of barn owls, *Bacillus thuringiensis* (Bt), *etc*.

Oil palm is replanted after 25 to 30 years when yield becomes increasingly poor and there is difficulty in harvesting the tall palms. The palms are felled and chipped, and the chips applied in the plantation as a nutrient source for the replants. The felled palms contain about 95 t of dry weight per hectare (Khalid *et al*., 2000; 2009), and will decompose within two years. Due to the undesirable emissions from fires, open burning has been prohibited in Malaysia since 1989, and zero burning is currently being practiced for land preparation prior to replanting.

METHODOLOGY

The LCA study was conducted according to the ISO standards on LCA described in ISO 14040 and ISO 14044 (ISO, 2006a, b). LCI and LCIA were performed using SimaPro 7 (Netherlands). This software contains US and European databases on a wide variety of materials, in addition to an assortment of European- and US-developed impact assessment methodologies. The methodology selected to conduct LCIA was the Eco-indicator 99 (Goedkoop and Spriensma, 1999).

Scope and Boundaries

The system was defined by a cradle-to-gate approach, starting from land conversion and transplanting of seedlings to the plantation until FFB are delivered to the mills during the 25 years' lifetime of the oil palm (*Figure 1*).

The agricultural operations considered under this study were divided into four stages during the palm's life cycle. They are (i) the conversion stage from previous land use, (ii) the immature plantation (not yet bearing FFB), (iii) the mature plantation, and (iv) the replanting stage for the next generation. The data collected were applied as an average of the four stages over a lifetime of 25 years. Only carbon dioxide (CO_2) and nitrous oxide (N_2O) emissions were considered for global warming potential (GWP) assessment.

Functional Unit

The reference flows (input and output) of this cradle-to-gate LCA study were based on a mass basis (functional unit of 1 t) of FFB produced.

Items Excluded from the Study

Disposal of polybags which are brought from the nursery to the plantation during transplanting was not taken into account due to the difficulty in getting a suitable model or representative data. It was assumed that the polybags are collected and sold back to the factory for recycling.

Data on the inputs and outputs were gathered from plantations on mineral soils only. LCA for oil

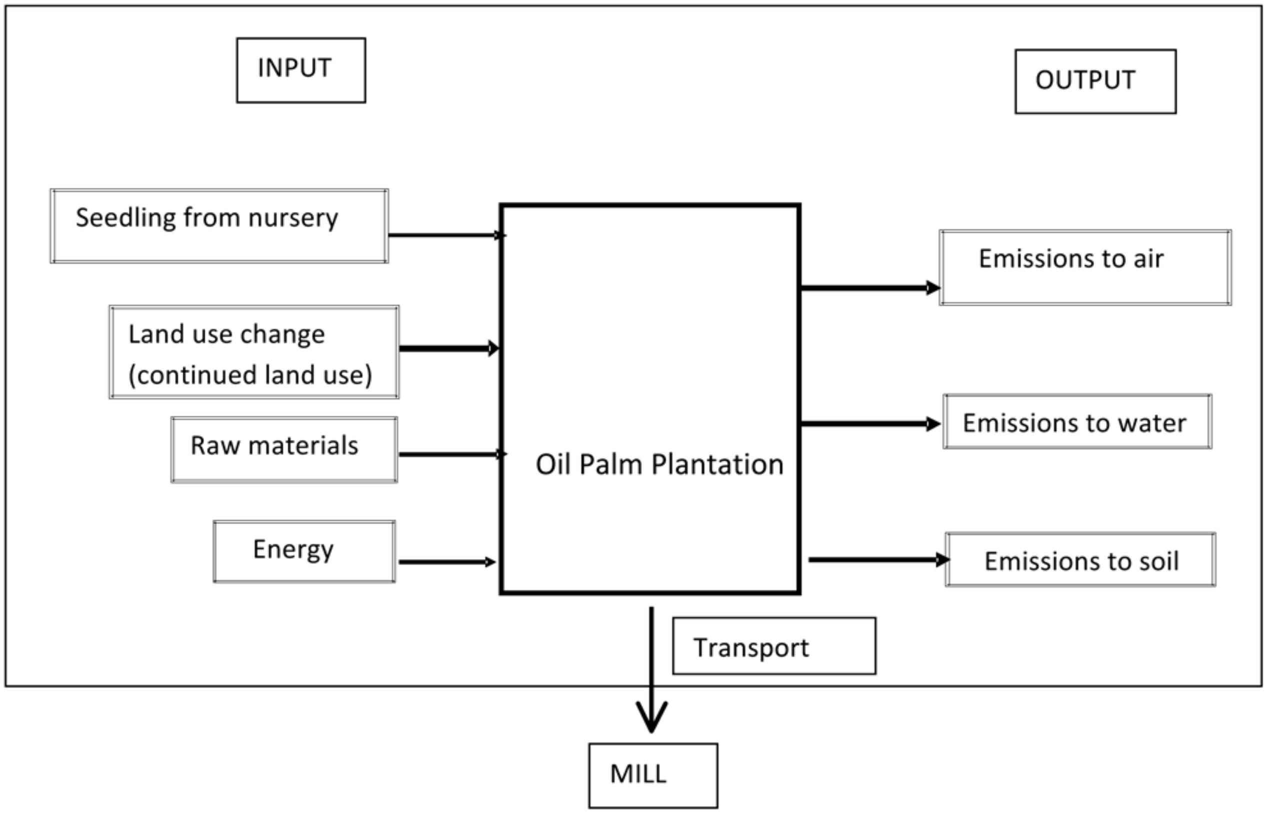

Figure 1. System boundary for fresh fruit bunches (FFB) production.

palm on peat was not included in this study as the detailed methodology on peat, which includes a study on C stock, peat oxidation and C emissions, is currently being carried out by the Tropical Peat Institute (TROPI) of MPOB. The complete LCA study on peat will be reported once the data from peat are made available. With the available data, the input and output data as an indicator at the national level will then be computed.

The impact of heavy metals is also small and regarded as insignificant to the environment. GHG emissions from the production of machinery, equipment and the construction of buildings were also excluded as they are minor compared to the overall emissions in the system.

In this LCA study, starting from cradle-to-gate, all operations in the plantations, including intermittent transportation of inputs and products by road were considered relevant unless excluded based on the system boundary definition criteria listed in *Table 1*.

Sources of Data

Input data required are on materials or energy that go into the cultivation stage, while outputs are emissions to air, water and soil, during the production of 1 t FFB. The cultivation stage for oil palm includes activities in the field for the immature/mature palms. Most data on cultivation practices in Malaysia have been collected through surveys. The yield of FFB is the average yield from the survey.

The foreground data which describe the specific production sub-systems included in the production of FFB were obtained through responses to questionnaires, observations, communication by telephone and interviews, and by on-site verification of the data. Data gaps were filled by information obtained from scientific literature and public databases, or calculated using published models.

Emissions at the Plantation

Emissions from the oil palm plantation are determined by the establishment of nutrient balances, and by the use of models for the emissions of N_2O, NO, NH_3, N_2, NO_3, P (Schdmit, 2007) and for CO_2 from energy generated from the use of fossil fuels. The models are described by IPCC (2000; 2007), FAO and IFA (2001), and Vinther and Hansen (2004).

GHG emissions from the production of fertilizers and pesticides used in the plantation are determined by the Ecoinvent methodology in the Simapro version 7.0 software, while total emissions from usage of pesticides are based on the EPA report (EPA report, 1994) where it is assumed that an applied pesticide evenly distributed emissions to air, water and soil (Schdmidt, 2007). The various

TABLE 1. SYSTEM BOUNDARY DEFINITION CRITERIA

Category	Included	Excluded			
			Difficult to obtain representative data	Part of a different system	Not directly relevant to scope and goal of study
Production, maintenance and replacement of capital equipment	-	✓	✓	✓	-
Production of kieserite fertilizer, borate fertilizer, NPK compound fertilizer	-	✓	✓	-	-
Indirect land use change	-	-	✓	✓	-
Disposal of polybags at the plantation	-	-	✓	✓	-
Production of urea	✓	-	-	-	-
Production of ammonium sulphate	✓	-	-	-	-
Production of phosphate rock	✓	-	-	-	-
Production of muriate of potash	✓	-	-	-	-
Impact of heavy metals to the environment	-	✓	✓	-	-
Usage of pesticides	✓	-	-	-	-
Capital goods	✓ but too small	-	-	-	-
Production of plantation pesticides	✓	-	-	-	-
Transportation of raw materials from the port to plantation	✓	-	-	-	-
Transportation of FFB to mill	✓	-	-	-	-
Plantation input *e.g.* fertilizers, pesticides	✓	-	-	-	-
Seedling from the nursery	✓	-	-	-	-
Land use change	Only considerred on continued land use with oil palm	-	-	-	-
Energy use in machinery in the plantation	✓	-	-	-	-
Output to air	✓	-	-	-	-
Output to water	✓	-	-	-	-
Output to soil	✓	-	-	-	-

GHG emissions from the plantation are then summed up per hectare, and converted to per 1 t of FFB produced by dividing the emissions by the FFB yield.

The three most important GHG determined in oil palm plantations are CO_2, N_2O and CH_4. The concept of GWP is applied to compare these GHG following the guidelines of IPCC. The GWP for CO_2 is 1 kg CO_2-eq, for CH_4 is 23 kg CO_2-eq and for N_2O is 296 kg CO_2-eq. The other main GHG (hydrofluorocarbons, perfluorocarbons and sulphurhexafluoride), although their GWP are high, were not taken into account as they are insignificant in FFB production chains.

Method for LCIA

The Eco-indicator 99 methodology was adopted. This methodology uses the damage-oriented approach or end-point approach for impact assessment. Impact categories considered in this methodology include carcinogens, respiratory organics and inorganics, climate change, ionizing radiation, ozone layer depletion, ecotoxicity, acidification/eutrophication, land use, minerals and fossil fuels.

It should be noted that the applied LCIA method for land use and biodiversity was not included due to the assumption of continued land use from previously old oil palm stands.

Uncertainty of Results

As the study considered continued land use from former oil palm plantations, no deforestation had taken place. The sensitivity analysis was estimated based on individual parameters for FFB production for which there were large ranges and deviations from the LCA results, such as FFB yield, N fertilizer use, and emission factor for the production of N fertilizers and diesel use as shown in *Table 2*. It was shown that N fertilizer use is the most sensitive parameter, especially in having a global warming effect.

RESULTS AND DISCUSSION

Life Cycle Inventory (LCI)

Table 3 summarizes the material and energy inputs and outputs associated with the production of FFB that were used to carry out LCIA. The LCIA results presented in this article are based on 1 t of FFB produced in the plantation.

Life Cycle Impact Assessment (LCIA)

The characterization and weighted results for all the scenarios studied are for the system boundary which starts from the nursery right up to the production of FFB in the plantation. The system boundary includes the nursery and the plantation (practicing continued land use).

TABLE 3. THE CHARACTERISTICS OF THE PLANTATIONS USED IN THE STUDY

Plantation characteristics	
FFB yield (t ha^{-1} yr^{-1})	20.7
Planting density (palm ha^{-1})	142
Soil characteristics	Mineral soils
Plantation lifetime	25 years
No of plantations	102
Total area	1.1 million ha (93.7 % mature and 6.3 % immature)

Characterized Results

Figure 2 shows the characterized results contributed by inputs used for the production of 1 t FFB in the plantation. The characterized results indicate the contribution by the inputs at the plantation in all eleven impact categories of impact assessment.

Weighted Results

The characterized results are weighted and are shown in *Figure 3*. Based on the weighted results for producing 1 t FFB from continued land use (replanting), the significant impact categories are fossil fuels, respiratory inorganics, climate change and acidification (eutrophication). The land use (nature occupation) impact category was not included because it was assumed that the land continued to be planted with oil palm.

Environmental Hotspots

For the production of FFB in the plantation, the weighted results using Eco-indicator 99 show that

TABLE 2. INPUT DATA: PARAMETERS AND THEIR RANGES FOR SENSITIVITY ANALYSIS

Parameters	Unit	Low	Base	High	Source
FFB production	t FFB ha^{-1} yr^{-1}	17	20	31	FRIM, IPCC
N fertilizer use	t N ha^{-1} yr^{-1}	50	73	120	*Survey
EF for AS fertilizer production	kg CO_2 eq/kg N	0.9	2.7	7.6	Syahrinuddin (2005)
EF for urea fertilizer production	kg CO_2 eq/kg N	0.9	1.3	4	
EF N_2O from managed soil	Kg N_2O-N/t N	3	10	30	Syahrinuddin (2005)
Diesel consumption	Gj ha^{-1} yr^{-1}	2.1	3.2	5.1	Syahrinuddin (2005)

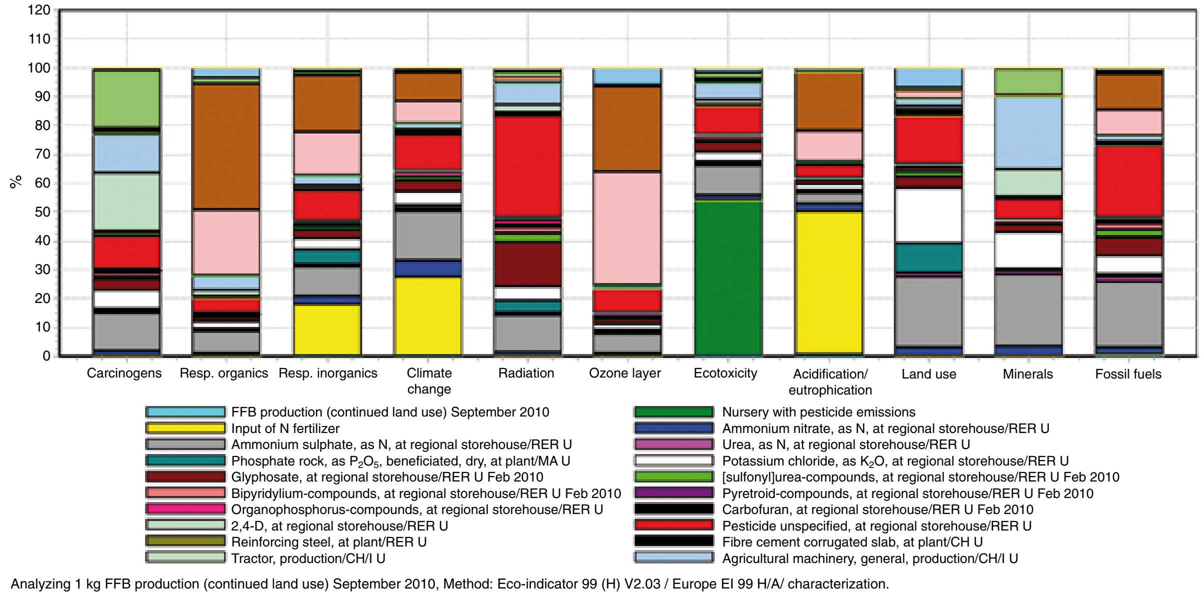

Figure 2. Life cycle impact assessment (LCIA) for the production of 1 t fresh fruit bunches (FFB) from continued land use – characterized results.

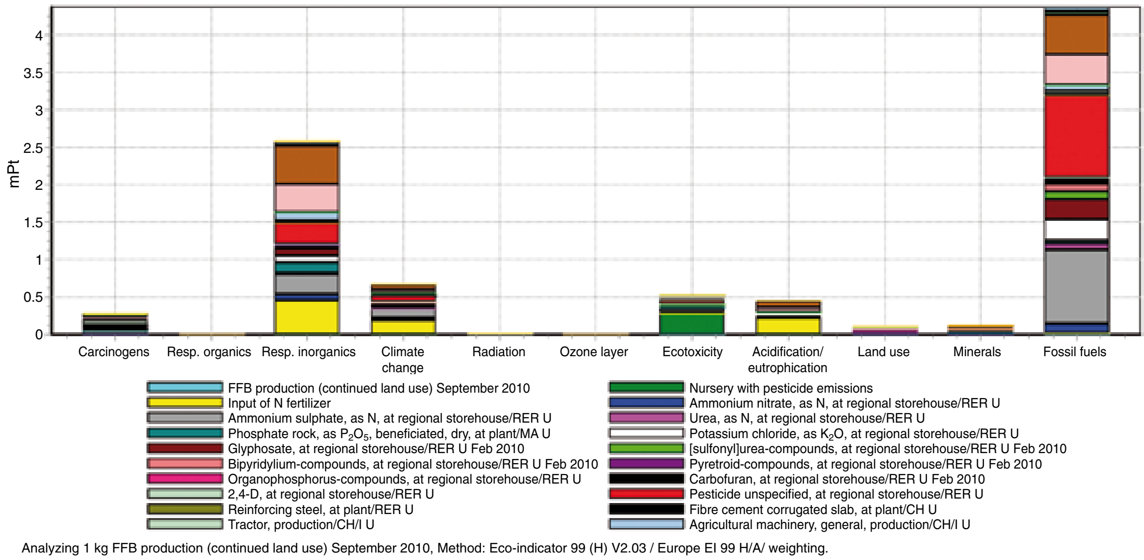

Figure 3. Life cycle impact assessment (LCIA) for the production of 1 t fresh fruit bunches (FFB) from continued land use – weighted results.

the most significant impacts are in the following order:

- fossil fuels;
- respiratory inorganics;
- climate change;
- ecotoxicity; and
- acidification.

The impacts on respiratory inorganics, fossil fuels, climate change and acidification/ eutophication come from the production and use of the various fertilizers, especially N fertilizers, and from the use of field machinery (tractors) during operations in the plantation and the use of transport vehicles bringing the materials to the plantations and transporting FFB to the mills. The impact on toxicity mainly comes from the use of pesticides, especially in the nursery. The fossil fuels, respiratory inorganics and climate change impact categories relate to air emissions while the acidification/eutrophication impact category relates mainly to water emission.

Acidification potential is explained mainly by emissions of ammonia into air, nitrates leaching into ground water, and land provision for oil palm cultivation. In the case of FFB production, the acidification potential is mainly due to nitrogen oxide emissions. A significant contribution also comes from ammonia emissions to air in the plantation.

CONCLUSION

The results presented in this study reflect the current management practices used in oil palm plantations, and they are only valid under these circumstances. The major hotspots identified in the plantations are N fertilizer use, the production of N fertilizer, and energy use in transport. Improvement options exist to mitigate the environmental burden, which among others are: by applying more organic sources of N fertilizer and increasing the yield of FFB. Returning the nutrient-rich slurry from the palm oil mill effluent (POME) treatment ponds to the field or applying compost (from empty fruit bunches and POME) as fertilizer, will help reduce N_2O emission from inorganic fertilizer application. Increasing the yield of FFB can be achieved by growing the latest improved oil palm planting materials which have the potential for increased fruit production. More improvements can be obtained by disseminating to the growers information on the best management practices in relation to reducing environmental impacts during the production of FFB.

ACKNOWLEDGEMENT

We kindly acknowledge the oil palm plantations in Malaysia for provision of data. We are grateful to Director-General of MPOB, for permission to publish this article.

REFERENCES

CORLEY, R H V and TINKER, P B (2003). *The Oil Palm*. Fourth edition. Blackwell publishing.

ECOINVENT (2004). Ecoinvent data v1.3. *Final Reports Ecoinvent 2000 No. 1-15*. Swiss Centre for Life Cycle Inventories, Dübendorf.

EPA CONTRACT EMISSION No. 68-D2-0159 (1994). Factor documentation for AP-42 Section 9.2.2. *Pesticide Application*. Midwest Research Institute, Kansas City, MO.

FAO and IFA (2001). *Global Estimates of Gaseous Emissions of NH_3, NO and N_2O from Agricultural Land*. Food and Agriculture Organization of the United Nations (FAO) and International Fertiliser Industry Association (IFA), Rome.

FAO (2006b). Global planted forests thematic study: results and analysis by A Del Lungo; J Ball and J Carle. *Planted Forests and Trees Working Paper 38*. Rome.

GOEDKOOP, M and SPRIENSMA, R (1999). *The Eco-Indicator 99 – A Damage Oriented Method for Life Cycle Impact Assessment – Methodology Report*. Third edition. Pre Consultants. Amersfoort. 14 pp.

IPCC (2006). *IPCC Guidelines for National Greenhouse Gas Inventories*. Institute for Global Environmental Strategies, Hayama, Japan.

IPCC (1996). *IPCC Guidelines for National Greenhouse Gas Inventories*. Reference manual. Geneva, Switzerland.

IPCC (2000). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.* Intergovernmental Panel on Climate Change (IPCC), Geneva.

ISO 14040 (2006). *Environmental Management – Life Cycle Assessment – Principles and Framework.* International Standard Organization (ISO), Geneva.

KHALID, H; ZIN, Z Z and ANDERSON, J M (2000). Decomposition processes and nutrient release patterns of oil palm residues. *J. Oil Palm Research Vol. 12 No. 1*: 46-63.

KHALID, H; CHAN, K W and AHMAD TARMIZI, M (2009). Nutrient cycling and residue management during oil palm replanting in Malaysia. Paper presented at PIPOC 2009, 9-12 November, 2009. 27 pp.

SCHMIDT, J H (2007). *Life Cycle Assessment of Rapeseed Oil and Palm Oil*. Ph.D thesis. Aalborg University Denmark. 271 pp.

SYAHRINUDIN (2005). The potential of oil palm and forest plantations for carbon sequestration on degraded land in Indonesia. *Ecology and Development Series No. 28* (Vlek PLG, Denich, M; Martius, C; Rodgers, C; van de Giesen, N eds.). Göttingen, Germany:Cuvillier Verlag. p. 107.

VINTHER, F P and HANSEN, S (2004). SimDen – en simpel model til kvantificering af N_2O-emission og denitrifikation (English: SimDen – a simple model for quantification of N_2O-emission and denitrification). DJF rapport. Markbrug nr. 104. Danmarks Jordbrugsforskning, Ministe-riet for Fødevarer, Landbrug og Økonomi, Tjele, Denmark. p. 4.

YUSOF, B and CHAN, K W (2004). The oil palm and its sustainability. *J. Oil Palm Research Vol. 16 No. 1*: 1-10.