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# Environmental sustainability of oil palm cultivation in Papua New Guinea

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Paul N. Nelson, Michael J. Webb, Ian Orrell, Harm van Rees, Murom Banabas, Suzanne Berthelsen, Marcus Sheaves, Felix Bakani, Otto Pukam, Michael Hoare, William Griffiths, Graham King, Peter Carberry, Rachel Pipai, Ann McNeill, Petra Meekers, Simon Lord, James Butler, Tony Pattison, John Armour and Charles Dewhurst

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Cover: Hoskins (West New Britain) smallholders with harvested oil palm fruit (Photo: Richard Dellman)

# Foreword

Papua New Guinea (PNG) is one of the most culturally and geographically diverse countries, and also one of the most rural. More than 80% of its 6.7 million people live outside urban centres and depend on subsistence agriculture for their livelihoods. Along with food crops, cash crops are a crucial part of the economy, generating virtually all of the country's non-mining income and supporting rural communities throughout the country. Of all the crops grown in PNG, oil palm is the most important in terms of export income; palm oil exports earned more than 1,000 million kina in 2008, considerably more than coffee, cocoa and all other agricultural exports.

The PNG oil palm industry is small by international standards (about 130,000 hectares and 1% of global production), but is very important for the country, underpinning the economies of the provinces where it is mostly grown: West New Britain, Oro, Milne Bay and New Ireland. More than 18,000 smallholder growers and two companies cultivate oil palm, which grows well in the coastal lowlands of PNG. Smallholder growers cultivate 45% of the area under oil palm and produce 32% of the fruit. The two plantation companies mill all the fruit, extracting palm oil and selling it, mostly to Europe. An estimated 200,000 people live in households that depend on oil palm as their principal source of income. It is vital for the future livelihoods of these people, and for others living in surrounding areas, that the crop is grown in a way that maintains the ecological integrity of the land and surrounding ecosystems.

As for any crop, poor management of oil palm can damage the environment. Both producers and consumers need to be confident that production is not causing environmental harm. To avoid environmental degradation, vulnerabilities and risks for the environment must be identified, and growers must work to minimise or eliminate those risks.

The Australian Centre for International Agricultural Research (ACIAR) supported a project aimed at identifying the main issues relating to environmental sustainability of oil palm cultivation in PNG, with particular reference to smallholder farms. The study resulted in recommendations for maintaining and improving environmental sustainability. The results of the study, including challenges that were identified for research and implementation, are presented in this report. It is hoped that the recommendations will lead to increased productivity and sustainability of this important tree crop.

Nick Austin
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# Abbreviations

| | |
|---|---|
| ACIAR | Australian Centre for International Agricultural Research |
| CEC | cation exchange capacity |
| EFB | empty fruit bunches |
| FFB | fresh fruit bunches |
| ha | hectare |
| HCVF | high conservation value forest |
| HOPL | Hargy Oil Palms Limited |
| ISO | International Organization for Standardization |
| $kmol_c$ | kilomoles of charge |
| kg | kilogram |
| m | metre |
| $mmol_c$ | millimoles of charge |
| NAAR | net acid addition rate |
| NBPOL | New Britain Palm Oil Limited |
| NGO | non-government organisation |
| OPIC | Oil Palm Industry Corporation (of PNG) |
| pHBC | pH buffering capacity |
| PNG | Papua New Guinea |
| PNGOPRA | PNG Oil Palm Research Association |
| RSPO | Roundtable on Sustainable Palm Oil |
| t | tonne |
| WWF | World Wide Fund for Nature |

# Summary

Papua New Guinea's oil palm industry is the country's largest agricultural export earner. Oil palm is grown on about 130,000 hectares by more than 18,000 smallholder growers supporting an estimated 200,000 people, and by two companies. Environmental sustainability of the industry is increasingly coming under scrutiny by growers, palm oil purchasers and various interest groups in Papua New Guinea and worldwide. The oil palm industry and the high population associated with it both have an impact on the land used for oil palm, as well as on surrounding ecosystems.

This report focuses on the effects of oil palm cultivation on soil, water and the atmosphere. For nutrient balances to be sustainable, inputs and losses should be balanced and minimised. Nutrient cycling factors that are difficult to estimate include loss of nitrogen by leaching (the main factor of concern), gaseous losses of nitrogen and biological nitrogen fixation. The carbon balance is generally favourable, except for large losses of carbon dioxide during initial plantation establishment (where oil palm replaces forest) and probably also during replanting. Net soil erosion from fields appears to be generally small, except for bare connected areas on moderate slopes and some in-field roads. Health of soil is influenced by net acid addition rate (largely related to fertiliser use), return of organic residues and traffic. Health of aquatic ecosystems may be affected by nitrogen inputs leached from fields and poor riparian vegetation. There is limited availability of data that are specifically relevant to these environmental sustainability issues in Papua New Guinea.

The Papua New Guinean oil palm industry has committed itself to certification of environmental stewardship, particularly through the Roundtable on Sustainable Palm Oil. There is thus a need for practical and meaningful indicators of environmental sustainability that are based on a clear understanding of the oil palm agroecosystem, to underpin certification and to guide improvements in management.

# Introduction

## Background and aim

Oil palm (*Elaeis guineensis*) is an important crop in the global production of vegetable oil (contributing about 30% of vegetable oil) and in the economic development of tropical countries. Indonesia and Malaysia grow the vast majority of oil palm, but other tropical countries also have significant oil palm industries. In Papua New Guinea (PNG), the palm oil industry drives the cash economies of the four main provinces in which oil palm is grown and earns the greatest export income. Export earnings from palm oil overtook those from coffee in 2001, and were more than 1,000 million kina in 2008. Because oil palm is likely to remain an important crop for PNG, sustainability of its cultivation is imperative for ongoing productivity and income generation.

Expansion of the area under oil palm and other crops, along with associated logging, has been identified as a major driver of forest destruction in the tropics globally in recent times and into the future (Fitzherbert et al. 2008; Koh and Wilcove 2008; Butler and Laurence 2009). In many cases this expansion is into areas with high conservation values, rather than into heavily logged or otherwise degraded areas. There are still large areas of forest left in the tropics, but they are being lost at an unprecedented and alarmingly rapid rate. Deciding how much forest we want to retain, where it should be, and how the owners can be compensated if they wish to clear it are critical issues for PNG and throughout the tropics.

This review takes the position that agriculture is necessary and desirable in the tropics, but that the area, location and type of land devoted to agriculture and the management of that land are all important and negotiable factors. Furthermore, it is important for conservation (by reducing pressure to expand plantings), sustainability and rural livelihoods that the productivity of existing plantings, especially smallholder blocks, are maximised. There is active work in PNG to improve oil palm yields, and those of smallholder growers in particular. However, the important issues of planning, biodiversity conservation and intensification of oil palm production are beyond the scope of this report. This report concentrates on the sustainability of oil palm cultivation; its effects on soil, water and the atmosphere in-field and in the surrounding environment; and the ability of the land to sustain biological productivity into the future. The focus is on PNG, which differs from the main oil palm growing areas in Indonesia and Malaysia in several ways.

The aim of this report is to identify and describe the main issues relating to environmental sustainability of oil palm cultivation in PNG, with particular reference to smallholder farms. The content is mainly drawn from presentations and discussions in a workshop held at Walindi in West New Britain in February 2009.

## The palm oil industry in Papua New Guinea

### Overview

Palm oil, which is extracted from oil palm fruit, is produced in several forms. Oil palms produce fruitlets in bunches (fresh fruit bunches, FFB), which are cut from the palm when ripe and taken to a mill for extraction of the oil. Oil extracted from the mesocarp, termed crude palm oil, is the main product that is sold and traded. It makes up approximately 22% of the FFB mass. Oil extracted from the kernel, termed palm kernel oil, makes up approximately 5% of the FFB mass. Crude palm oil and palm kernel oil are further processed in refineries for use in various products. By-products of oil extraction include ‘palm kernel expeller’, which is sold for stock feed; fibre and kernel shell, which are used to fuel the mills; empty fruit bunches (EFB), which are applied back to the field directly or via compost; and palm oil mill effluent, which is applied back to the field or treated in effluent ponds.

Currently, about 130,000 hectares (ha) are under oil palm cultivation in PNG, mostly in West New

Britain province, followed by Oro province, Milne Bay province, New Ireland province and Morobe/Madang provinces (Table 1). In PNG, all oil palm is grown either by the companies New Britain Palm Oil Limited (NBPOL) and Hargy Oil Palms Limited (HOPL), or by smallholders. NBPOL recently (April 2010) purchased CTP Holdings, which had operated several plantations and mills until then (Table 1). There are currently 12 palm oil mills in the country, all owned by NBPOL and HOPL. The smallholders, numbering 18,313 in December 2009, own oil palm blocks that are usually 2–6 ha in size. About 45% of the area under oil palm plantations is in smallholder blocks, but these produce only about 32% of PNG's palm oil. The total area under oil palm in PNG increased from approximately 112,000 ha in 2002 to about 130,000 ha in 2009, and the total FFB production increased from 1,597,498 tonne (t) in 2002 to 2,438,190 t in 2009.

It is worth noting that, in addition to the areas described above, there has recently been a rapid expansion in projects proposing oil palm developments using 'special agricultural and business leases' on large tracts of tropical forest throughout PNG. These projects are accompanied by applications for forest clearance authority that permit the commercial sale of the timber cleared for the proposed agricultural development. There is considerable concern among the country's actual palm oil producers that these developments are little more than a means of accessing saleable timber resources in the name of agricultural (oil palm) development. There is little evidence that these proposals will lead to viable palm oil production. Current indications are that there is in excess of one million ha under such leases. These projects are not discussed further in this report.

Most oil palm in PNG is planted on coastal plains with a lowland humid climate and annual mean rainfall between 2,200 mm and 3,500 mm. A high proportion (77%) is grown in West New Britain and Oro provinces on relatively coarse-textured, free-draining soils that are formed on ash, alluvium or colluvium of recent volcanic origin. These areas are highly suited to oil palm production and can produce some of the highest oil palm yields in the world.

Although the development of PNG's oil palm industry was initiated in areas of relatively low population, the subsequent economic development in these areas has led to a significant increase in population, and currently an estimated 200,000 people live in households that depend on oil palm as their principal source of income. The increased population pressure has significant impacts on the environment, particularly through conversion of forested areas to gardens, and increased fishing.

In 2008, Malaysia and Indonesia produced 87% of the world's palm oil; PNG ranks sixth in palm oil

**Table 1.** Oil palm area and production for Papua New Guinea, 2009

| Province | Company[a] | Plantation[a] | Smallholder | Total |
|---|---|---|---|---|
| *Area estimates (hectares)* | | | | |
| Milne Bay | Milne Bay Estates[b] | 11,629 | 1,699 | 13,328 |
| Morobe and Madang | Ramu Agri-industries[c] | 7,668 | 260 | 7,928 |
| New Ireland | Poliamba Estates[b] | 5,689 | 2,613 | 8,302 |
| Oro | Higaturu Oil Palms[b] | 8,994 | 14,285 | 23,279 |
| West New Britain | Hargy Oil Palms | 9,906 | 13,163 | 23,069 |
| West New Britain | New Britain Palm Oil | 32,228 | 21,902 | 54,130 |
| TOTAL | | 76,114 | 53,922 | 130,036 |
| *Fresh fruit bunch production estimates (tonnes)* | | | | |
| Milne Bay | Milne Bay Estates[b] | 210,711 | 10,536 | 221,247 |
| Morobe and Madang | Ramu Agri-industries[c] | 56,072 | 124 | 56,196 |
| New Ireland | Poliamba Estates[b] | 108,440 | 16,203 | 124,643 |
| Oro | Higaturu Oil Palms[b] | 196,679 | 131,481 | 328,160 |
| West New Britain | Hargy Oil Palms | 211,416 | 200,699 | 412,115 |
| West New Britain | New Britain Palm Oil | 876,497 | 419,332 | 1,295,829 |
| TOTAL | | 1,659,815 | 778,375 | 2,438,190 |

[a] Companies own the mills and 'plantation'
[b] Owned by CTP Holdings until April 2010, and thereafter by New Britain Palm Oil Limited
[c] Owned by New Britain Palm Oil Limited

production, representing about 1% of global production.

The first observational plantings of oil palm in PNG occurred in the 1920s. Commercial development did not begin until 1967, with the establishment of the Hoskins oil palm project in West New Britain province. This development was a joint venture between the private sector and government, and was set up using a nucleus estate and smallholder model. The company behind this initial development is now known as New Britain Palm Oil Limited. Further commercial oil palm developments followed in 1969 in Bialla (West New Britain province) and in 1976 in Popondetta (Oro province), both following the nucleus estate and smallholder model. All three developments included a land settlement program to initiate the smallholder production base. In the 1980s, the Commonwealth Development Corporation followed its Popondetta development with new projects in Milne Bay province (1985) and New Ireland province (1987). In 2006, Ramu Agri-Industries established new oil palm plantings in the Ramu Valley (Madang province) by converting some of its existing pastoral land.

Since the mid 1980s, the continuing growth of oil palm plantations in PNG has been through the expansion of existing projects, except for the Ramu Valley project. Much of the plantation expansion has been on customary-owned land and implemented using a lease/lease-back arrangement, whereby customary land owners form Incorporated Land Groups, register their land for development and lease the land to the government. The government in turn leases the land back to the oil palm company to develop and manage. The landowners and Incorporated Land Groups receive revenue from the development through rentals and royalties. The lease period is typically one or two crop cycles (20 or 40 years). At the end of the lease, the landowners can choose to either take back their land with all established infrastructure or renew the lease arrangement.

In 2008, exports of oil palm product exceeded 1,080 million kina. In contrast, PNG's next largest agricultural exports were coffee (520.2 million kina) and cocoa (345.6 million kina). The principal oil palm exports are crude palm oil and palm kernel oil. In 2004, NBPOL established a palm oil refinery in West New Britain that processes about a third of the company's crude palm oil into palm stearin and palm olein, which supply the domestic market as well as being exported.

When the company that is now NBPOL started its oil palm development activities in PNG in the late 1960s, it established seed gardens from genetic material brought into the country from its plant breeding program in Malaysia. This led to the development of NBPOL's plant breeding and seed production enterprise. NBPOL's oil palm seed production has a worldwide reputation for high quality and is a very successful export business.

PNG does not currently have a body that oversees the country's oil palm subsector. Instead, three national organisations, with different functions, represent stakeholders:

- The Oil Palm Industry Corporation (OPIC) is a statutory organisation formed under the *Oil Palm Industry Corporation Act 1992* to provide agricultural extension services to the country's oil palm smallholders.
- The Palm Oil Producers Association represents the interests of the country's palm oil milling companies.
- The PNG Oil Palm Research Association (PNGOPRA) is a non-government organisation responsible for providing research and development, and scientific technical services to all oil palm growers (smallholders and plantations) in PNG.

Smallholders have a close relationship with the plantation and milling company in their region; they sell all their fruit to the company, which then sells the oil. Smallholders also obtain credit and various agricultural supplies from the company. Importantly, their environmental accreditation is also driven by the companies. Therefore, although this report focuses on smallholders, company operations are also considered because they are integral to environmental sustainability on smallholder farms as well as on their own plantations.

## Companies

NBPOL (until the purchase of CTP Holdings in April 2010) managed 35,000 ha of oil palm along the north coast of West New Britain. In addition, the company supports and buys fruit from more than 7,000 registered smallholders growing oil palm on a further 24,000 ha. It has five oil palm mills with a combined processing capacity, in March 2009, of 260 t of FFB/hour. In 2003, it commissioned a refinery in West New Britain with the capacity to refine 100,000 t/year of crude palm oil. Approximately 7,500 people are employed, including 134 PNG national executives and 42 expatriate executives.

NBPOL is the only PNG company involved in breeding and production of oil palm seed, which is a major business, at the Dami Oil Palm Research Station in West New Britain province. Another significant contributor to NBPOL's profitability is the Numundo Beef operation, currently carrying 4,000 cattle. In 2008, NBPOL purchased Ramu Agri-Industries, which grew primarily sugarcane, but also oil palm, on the mainland. In 2006, it purchased the abandoned Solomon Islands Plantation Ltd and re-established palm oil production in Solomon Islands under the company name Guadalcanal Plains Palm Oil Ltd. NBPOL is a public company listed on the Port Moresby and London stock exchanges.

HOPL is the other plantation and milling company operating on the north coast of West New Britain (Figure 1). It operates 9,906 ha of plantations and two mills with a combined capacity of 90 t/hour. Construction of an additional mill will begin in June 2010. The project is a nucleus estate project, with smallholders providing up to 50% of the crop. In 2009, there were 3,162 smallholders, with 13,200 ha planted. The smallholders produced 200,123 t of fruit in 2009, earning more than 33 million kina for the smallholder families. More than 17% of this income was paid directly to women through the 'loose fruit mama' scheme, whereby women collect loose fruit and sell it directly to the company. HOPL employs 3,500 people, including 12 expatriates. The company has embarked on a plantation expansion program, with an additional 10,000 ha to be planted by 2016.

HOPL is 100% owned by S.A. SIPEF N.V. Belgium Group, which is listed on the European Stock Exchange in Brussels. SIPEF was established in Antwerp, Belgium, in 1919 and has plantation interests in West Africa (oil palm), Indonesia (oil palm, rubber and tea) and PNG (oil palm and rubber). HOPL was established as a result of a decision by the then colonial administration to diversify the country's agricultural export base by introducing oil palm. The land along the north coast of West New Britain was recognised as having a high potential for oil palm because of its fertile volcanic ash soils and high rainfall.

CTP Holdings was a subsidiary of the privately owned companies Cargill and Temasek Holdings. CTP Holdings operated three milling/plantation operations: Higaturu Oil Palms in Oro province, Milne Bay Estates in Milne Bay province and Poliamba Estates in New Ireland province (Figure 1). These operations had previously been

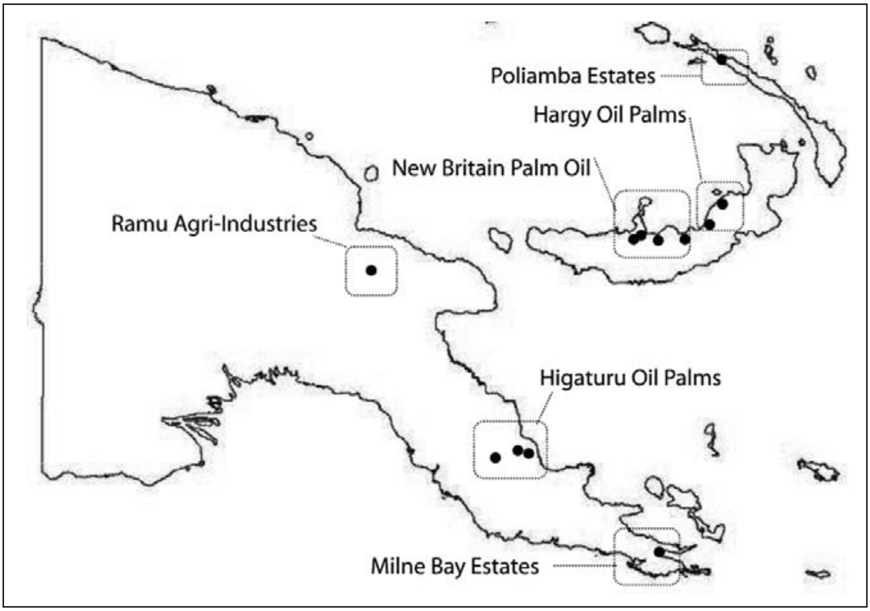



**Figure 1.** Location of palm oil mills in Papua New Guinea, showing company names

purchased from Pacific Rim Estates, formerly the Commonwealth Development Corporation. In April 2010, CTP Holdings was purchased by NBPOL.

## Smallholders

Initially, the smallholder component of the nucleus estate and smallholder system in West New Britain and Oro provinces involved land settlement schemes, in which settlers were given 99-year leases on alienated land (land purchased by the government from customary landowners), typically 6 ha in size. No new smallholdings have been established under this scheme since the mid 1990s due to a shortage of available alienated land and also the resistance of customary landowners to such schemes. When the land settlement scheme blocks were planted to oil palm, a few hectares were set aside for gardens. However, nearly all of the blocks are now fully planted to oil palm, resulting in a shift of gardening to surrounding areas. The spread of gardening around oil palm blocks has been enhanced by increased populations on the blocks themselves (Koczberski and Curry 2005).

In addition to oil palm smallholdings under the land settlement scheme, village communities have been encouraged and assisted in setting up their own oil palm plantings. These village oil palm plantings usually comprise blocks of about 2 ha, and their establishment is based on a Clan Land Use Agreement. Currently in PNG, the ratio of plantings under the land settlement scheme to plantings under the village oil palm scheme is approximately 1:1.

In the older oil palm project areas (with higher population pressures), a third type of smallholding has emerged—Customary Rights Purchase Blocks. Papua New Guineans who do not have traditional access rights to a particular block of land can establish usage and access rights to establish an oil palm smallholding through the use of a Clan Land Use Agreement.

Oil palm is an attractive crop for PNG farmers for a variety of reasons. Profits are high relative to other crops, and income is earned regularly. The price smallholders receive for their fruit is set nationally and is linked directly to the world market price, unlike crops such as cocoa, copra and coffee, where middlemen have a large influence on the price received by the grower. The income from oil palm has led to considerable benefits for rural communities, but also problems, such as immigration of people to oil palm areas and resulting population pressure and social discord. Another feature of the crop is that it does not need a high level of management to achieve reasonable productivity, unlike crops such as cocoa, which require intensive management. An important advantage of this is that growers can attend to other activities, and when they return to harvesting their oil palm it is still producing.

Despite the attractiveness of the oil palm crop to smallholders, yields of smallholders are on average much lower than those of plantation companies. Low smallholder yields can be attributed primarily to incomplete harvesting and low fertiliser inputs. Reasons for low levels of management inputs include: competition for growers' time by non oil palm–related activities, high populations and associated social problems on land settlement scheme blocks, low availability of labour, and land disputes and tenure insecurity, which undermine grower commitment to productivity (Koczberski et al. 2001; Koczberski and Curry 2003, 2005). Various strategies are being employed to overcome these limitations (e.g. Koczberski 2007), but there is still much scope for improving smallholder productivity.

Agricultural extension services are provided to smallholders by OPIC in each of the 'project' areas. Coordination and management of OPIC extension activities revolves around a local planning committee established in each project area. The committee comprises smallholder representatives (through the growers' association) and representatives from PNGOPRA, the milling company, the provincial government and the National Development Bank.

# Perspectives on environmental sustainability of oil palm

## Stakeholders and interest groups

Concerns about environmental sustainability of oil palm cultivation in PNG come from four broad groups:

- environmental activists and non-government organisations (NGOs)
- palm oil buyers and consumers
- producers
- local people who are not producers.

The last three groups overlap to some extent. For example, oil palm smallholders, as well as being producers, are also part of local communities that depend on the terrestrial, aquatic and marine ecosystems and resources surrounding oil palm plantations. There are also overlaps among the companies. Cargill is a large producer (FFB and oil), but is also a trader and processor. NBPOL was only a producer until 2002, when it opened a refinery in PNG. It is currently planning a refinery in the United Kingdom that will process exclusively certified sustainable oil. However, although these four groups are not necessarily mutually exclusive or clearly defined, their viewpoints on sustainability differ in significant ways.

Environmental NGOs, such as Greenpeace, the World Wide Fund for Nature (WWF), Friends of the Earth, the Rainforest Alliance, The Nature Conservancy and Conservation International, have a high profile, expressing concerns about sustainability of the palm oil industry worldwide. The Nature Conservancy (in West New Britain) and Conservation International (in Milne Bay) are the most active of these organisations in PNG. In addition to these large international organisations, several PNG NGOs have expressed concerns about the sustainability of oil palm cultivation.

The main purpose of the NGOs is to influence public perceptions, mostly relating to human rights and environmental concerns. Human rights issues relate especially to land rights, pay levels, child labour, loss of the traditional way of life and disenfranchisement of Indigenous people by activities of multinational corporations. The main environmental concerns are rainforest destruction and biodiversity conservation. They include both general concerns, such as conservation of 'high conservation value forests' (HCVFs) and coral reefs, and more specific concerns, such as the conservation of iconic species—for example, the orangutan in Indonesia and the Queen Alexandra birdwing butterfly in PNG. NGOs also have concerns about water quality; greenhouse gases, carbon footprint and related issues; and land degradation issues, such as erosion and degradation of soils.

The NGOs have significantly influenced perceptions of consumers and governments in the western world about the palm oil industry. Their engagement with the industry ranges from outright hostility to close involvement in the Roundtable on Sustainable Palm Oil (RSPO), described below. Groups with an extreme anti–oil palm view hold oil palm responsible for rainforest destruction and advocate consumer boycotts of palm oil. They include the Palm Oil Action Group, a coalition of Australian and New Zealand NGOs that was formed specifically to 'stop the clearing of critical rainforest ecosystems for use as palm oil plantations' (Figure 2). Among the NGOs that have engaged with the oil palm industry to ensure sustainability is WWF, which is a prominent member of the RSPO.

Although much of the sentiment among NGOs and consumers about clearing of rainforests and loss of habitat has been directed at the oil palm crop itself, the forest is cleared to generate income, not to grow oil palm per se. Oil palm is often the crop of choice following forest clearing in the humid tropics, but even if palm oil boycotts were to succeed and palm oil production ceased, there is little reason to expect any effect on forest clearance rates. Of all the crops that can be grown in a wet tropical environment, rainforest perennials such as oil palm and cocoa are the most environmentally sustainable options. As a rainforest perennial, oil palm requires no soil cultivation, very little pesticide and relatively little fertiliser compared with shorter lived alternatives such as soybean (de Vries et al. 2010).


**Figure 2.** Website of the Palm Oil Action Group, a coalition of environmental organisations (Source: Palm Oil Action Group 2009)

Palm oil buyers and consumers have responded to adverse publicity about palm oil and are increasingly demanding evidence of sustainability.

Most oil passes from producer to wholesaler to processor to retailer to consumer, but in many cases the same company may own two or more of the first four links in that chain. The main vegetable oil buyers and processors include Unilever, Kraft Foods, Procter and Gamble, Nestlé, Mars, Cargill, ADM and Henkel. Vegetable oils are interchangeable for many uses, but palm oil is often preferred because of its price and properties. As one of the world's largest producers of margarine, soap and cosmetics, Unilever is probably the largest buyer of palm oil. Unilever was one of the founding members of the RSPO, and in 2008 announced that by 2015 it would source all its palm oil from certified sustainable producers (Unilever 2008). Unilever also grows oil palm, but not in PNG.

Oil palm growers, including smallholders, have an intimate interest in environmental sustainability, although their concerns have a much lower public profile than those of the NGOs. Oil palm growers in PNG are either traditional landowners or long-term leaseholders of the land; both are committed to maintaining the land's fertility and productivity. For traditional owners, this implies maintaining productivity of oil palm, as well as safeguarding the potential of the land to support other crops in the future. Leaseholders are predominantly companies that have made large investments in mills and other infrastructure and therefore have a strong incentive to maintain productivity in the long term. Oil palm growers, especially smallholders, live in the environment surrounding oil palm growing areas, and rely on it for food, water and other needs. PNG is the only country in which all oil palm growers and palm oil producers are party to the RSPO.

People living around oil palm plantations and smallholder blocks also express concerns about the environmental aspects of oil palm growing. The most commonly raised issue is degradation of water quality, with possible effects on health and ecosystems, especially fisheries. Other concerns centre around the decreasing availability of land as oil palm expands and populations increase.

All the people concerned about environmental sustainability of oil palm cultivation assess it against benchmarks; different interest groups tend to use different benchmarks. At one extreme of benchmarking is the most sustainable ecosystem: the complex forest that was usually the original vegetation and evolved in that particular environment. All agriculture falls short of the more complex system that it replaces. Agricultural systems are not only less complex, but also involve outputs, which must be balanced by inputs. Balancing inputs and outputs is extremely difficult because of the amount of information required and economic drivers. Another benchmark, commonly used in agricultural circles, is 'best management practice', which is the standard of management that uses the best possible knowledge and is economically and practically feasible. Finally, some approaches, such as that of certification by the International Organization for Standardization (ISO), do not rely on benchmarks, but emphasise continual improvement.

## The Roundtable on Sustainable Palm Oil

The RSPO is a coalition of industry, NGOs, financial institutions, environmental and conservation groups, retailers and consumer product companies that have come together since 2004 to develop and implement global standards for sustainable palm oil production.

The RSPO has developed a set of principles and criteria that define the practices for sustainable palm oil production. These principles and criteria address the legal, economic, environmental and social requirements for producing sustainable palm oil (Table 2; RSPO 2007).

The RSPO principles and criteria provide a global standard; however, the legal, economic, environmental and social requirements vary significantly between countries. To appropriately accommodate these differences, the process of national interpretation was initiated. National interpretation, developed through a National Interpretation Working Group, ensures congruence or compatibility between the generic principles and criteria and their implementation (through indicators and guidance) in a certification system adapted to the norms of the producing country (RSPO 2008).

Smallholders are a major component of the world's palm oil production. Smallholder growers are obviously very different from commercial plantations in their ability to comply with the demanding technical and legal requirements of the RSPO principles and criteria. To avoid excluding smallholders from the RSPO process (and potentially depriving them of their livelihoods), it was necessary to find a way of including them without compromising the sustainability credentials of the RSPO. The RSPO Task Force on Smallholders was formed by a Resolution of the RSPO's General Assembly in Jakarta 2005 to develop an adjusted RSPO standard suited to smallholders and to ensure that smallholders were directly represented in RSPO processes. The task force has the mandate to 'ascertain the suitability of the RSPO principles and criteria for smallholders and make proposals on how best these can be adjusted, nationally and/or generically, to ensure favourable smallholder involvement in RSPO production'. The work of the Task Force on Smallholders continues.

Currently, smallholders are classified into two groups:

- schemed smallholders, who are regarded as being closely controlled and managed by the milling companies to which they sell
- independent smallholders, who are independent from any controlling authority of a milling company.

This binary classification, which was developed with Malaysian and Indonesian smallholders in mind, does not accommodate PNG smallholders very well. PNG smallholders seem to fall somewhere between these classifications, and a third classification, 'associated', is therefore being developed.

## PNG producer perspectives

### Oil Palm Industry Corporation (authors: Otto Pukam and Felix Bakani)

OPIC works closely with smallholders across the country, providing them with extension services. Assessing and improving environmental sustainability is particularly challenging for smallholder oil palm growers and requires much thought. For example, will smallholders cope with proposed changes and the cost of these changes? Will they benefit from the hard work they put in? One of the biggest challenges facing any sustainability compliance scheme is to include the smallholder sector in a meaningful way, and to avoid excluding some smallholders from the system.

*New plantings*

To guide sustainable oil palm development, OPIC developed Planting Approval Forms in 2004. For blocks that are to be planted or replanted, growers should be made aware of the RSPO standards 2–3 years before planting or replanting. This is to make growers aware that they may not be allowed to replant on land already planted—for example, if it is too steep, too close to rivers, or with no proper title.

Before development of a new planting, the following checklist (according to the Planting Approval Form) is followed:

- Check land ownership.
- Check proposed planting area, especially that the land is flat.
- Check access.
- Check buffer zone requirement.
- Check for natural habitats and HCVFs.
- Check distances with respect to milling company catchment area.

- Check total area to be developed.
- Hold awareness meeting on RSPO standards.
- Mark out the road line (10 m wide for feeder roads).
- Sign Irrevocable Fertiliser Order agreeing to 10 years delivery of fertiliser from the milling company.
- Process applications for authorities to inspect and give approval to start the clearing of existing vegetation, and get planting materials delivered.
- Ensure correct spacing (9.75 m).
- Ensure plantings are standard (2 ha and more).
- Establish legume groundcover to control surviving weeds.

**Table 2.** Principles of the Roundtable on Sustainable Palm Oil (RSPO)

| | |
|---|---|
| **Principle 1.** | **Commitment to transparency** |
| Criterion 1.1. | Oil palm growers and millers provide adequate information to other stakeholders on environmental, social and legal issues relevant to RSPO criteria, in appropriate languages and forms to allow for effective participation in decision-making. |
| Criterion 1.2. | Management documents are publicly available, except where this is prevented by commercial confidentiality or where disclosure of information would result in negative environmental or social outcomes. |
| **Principle 2.** | **Compliance with applicable laws and regulations** |
| **Principle 3.** | **Commitment to long-term economic and financial viability** |
| **Principle 4.** | **Use of appropriate best practices by growers and millers** |
| Criterion 4.1. | Operating procedures are appropriated documented and consistently implemented and monitored. |
| Criterion 4.2. | Practices maintain soil fertility at, or where possible improve soil fertility to, a level that ensures optimal and sustained yield. |
| Criterion 4.3. | Practices minimise and control erosion and degradation of soils. |
| Criterion 4.4. | Practices maintain the quality and availability of surface and groundwater. |
| Criterion 4.5. | Pests, diseases, weeds and invasive introduced species are effectively managed using appropriate integrated pest management (IPM) techniques. |
| Criterion 4.6. | Agrochemicals are used in a way that does not endanger health or the environment. |
| Criterion 4.7. | Occupational health and safety. |
| Criterion 4.8. | All staff, workers, smallholders and contractors are appropriately trained. |
| **Principle 5.** | **Environmental responsibility and conservation of natural resources and biodiversity** |
| Criterion 5.1. | Aspects of plantation and mill management, including replanting, that have environmental impacts are identified, and plans to mitigate the negative impacts and promote the positive ones are made, implemented and monitored, to demonstrate continual improvement. |
| Criterion 5.2. | The status of rare, threatened or endangered species and high conservation value habitats, if any, that exist in the plantation or that could be affected by plantation or mill management shall be identified and their conservation taken into account in management plans and operations. |
| Criterion 5.3. | Waste is reduced, recycled, re-used and disposed of in an environmentally and socially responsible manner. |
| Criterion 5.4. | Efficiency of energy use and use of renewable energy is maximised. |
| Criterion 5.5. | Use of fire for waste disposal and for preparing land for replanting is avoided except in specific situations, as identified in the ASEAN guidelines or other regional best practice. |
| Criterion 5.6. | Plans to reduce pollution and emissions, including greenhouse gases, are developed, implemented and monitored. |
| **Principle 6.** | **Responsible consideration of employees and of individuals and communities affected by growers and mills** |
| **Principle 7.** | **Responsible development of new plantings** |
| Criterion 7.1. | A comprehensive and participatory independent social and environmental impact assessment is undertaken prior to establishing new plantings or operations, or expanding existing ones, and the results are incorporated into planning, management and operations. |

**Table 2.** (Cont'd) Principles of the Roundtable on Sustainable Palm Oil (RSPO)

| | |
|---|---|
| Criterion 7.2. | Soil surveys and topographic information are used for site planning in the establishment of new plantings, and the results are incorporated into plans and operations. |
| Criterion 7.3. | New plantings since November 2005 have not replaced primary forest or any area required to maintain or enhance one or more high conservation values. |
| Criterion 7.4. | Extensive planting on steep terrain, and/or marginal and fragile soils, is avoided. |
| Criterion 7.5. | No new plantings are established on local peoples' land without their free, prior and informed consent, dealt with through a documented system that enables Indigenous peoples, local communities and other stakeholders to express their views through their own representative institutions. |
| Criterion 7.6. | Local people are compensated for any agreed land acquisitions and relinquishment of rights, subject to their free, prior and informed consent and negotiated agreements. |
| Criterion 7.7. | Use of fire in the preparation of new plantings is avoided other than in specific situations, as identified in the ASEAN guidelines or other regional best practice. |
| **Principle 8.** | **Commitment to continuous improvement in key areas of activity** |
| Criterion 8.1. | Growers and millers regularly monitor and review their activities and develop and implement action plans that allow demonstrable continuous improvement in key operations. |

ASEAN = Association of South-East Asian Nations

Notes:

1. For the principles directly relevant to environmental sustainability, the criteria are also given.
2. Principles and criteria not directly relevant to environmental sustainability are shaded.

Source: RSPO 2007

*Management practices*

The following best management practice rules have been established:

- Harvest regularly as scheduled by milling company to ensure all fruit is delivered to the mill.
- Always harvest on time, when bunches have 2–5 loose fruits on the ground.
- Harvest all ripe fruit across the whole block (100% harvest), and deliver all bunches and every loose fruit to the nets at roadsides for evacuation by fruit trucks.
- Keep the estate clean and free from weeds. The palm base and harvest path must be clean at all times.
- Accept fertiliser and sign Irrevocable Fertiliser Order.
- Always apply the correct amount of fertilisers to every oil palm each year.
- Regularly walk through the block, checking for pests and diseases.
- Carry out proper pruning; leave 1–2 fronds below bunches.
- Never shift the crop to another block or to the next harvest.
- Maintain quality standards of the crop.

Herbicides are an efficient management tool and the fastest means of cleaning blocks, although they can be expensive if not used properly. Standards for safe use of herbicides need to be enforced. In some projects, OPIC officers have run courses on safety standards for using chemicals for weed control. Under RSPO standards, an effective system needs to be in place for maintaining safety standards, particularly with regard to safe and secure storage of herbicides and disposal of empty containers.

A weekly walk through the block by the owner is essential to check on pest and disease attack. A well-managed block should have a low incidence of pests and diseases. Growers should be informed of pest management practices.

Management for health and hygiene must be adequate on all blocks, including a separate toilet pit and garbage pit.

*Issues for improvement*

The following are OPIC's suggestions for improvements in the way environmental sustainability is maintained:

- Make the OPIC team who monitor RSPO standards a 'watchdog', together with the milling company and PNGOPRA, with inspection of standards twice a year.
- Establish demonstrations of various good crop management practices, such as benching, buffer zoning, good and even application of fertiliser, and preserving habitat, wildlife, water life, birds, flora and fauna.
- Educate growers on simple farm management standards by producing a cash flow budget and informing them of costs associated with production.

- Lands Secretary gives authority to OPIC lands unit to speed up the process of title transfers and processing and signing the last will.
- Issue herbicide certificates to growers who meet the safety requirements to allow them to use chemicals for weed control. Make purchase of herbicide from dealers contingent on presentation of the certificate. Limit access to spraying equipment to growers with a certificate.
- Run workshops for OPIC officers to ensure that they fully understand and are aware of the RSPO code of conduct and practices, and information from research.
- Improve awareness of the RSPO among growers through radio broadcasts, meetings in new areas and presentations at field days.
- Give growers warning notices of substandard crops, under RSPO standards.
- Milling companies impose rules for crop collection.
- Undertake leaf sampling and analysis on smallholder blocks.
- OPIC and PNGOPRA set up a database for the oil palm industry in the country.
- OPIC works very closely with the project growers associations and encourages them to report on how growers' money is being collected and spent.
- Investigate the feasibility and availability of oil palm kernel expeller for livestock feeding, especially chickens.
- Milling companies make available methane gas in bottles for cooking.
- Improve OPIC staff qualifications.
- Educate the growers association executives about the roles and responsibilities of the Growers Association, OPIC, the milling company and PNGOPRA.
- For any new oil palm projects to be developed in provinces other than those with existing projects, establish a land task force to secure the land. The land task force would be the only contact point for land required by new investors intending to develop new oil palm projects in PNG. It would coordinate plans for developing oil palm projects with relevant agencies and bodies to support the growth of a sustainable oil palm industry. The developer must be a palm oil producer with RSPO certification so that the industry will be sustainable from the beginning of the development. A feasibility study should assess the likely economic, environmental and social impacts of the project. For the smallholder component, OPIC would undertake intensive awareness training on the RSPO code of conduct and practices before the development begins.

*Conclusion*

OPIC suggests the following be seriously considered:

- a continuing philosophical and moral debate about the appropriate nature of sustainable oil palm industry development, building on good relations and the empowerment of local communities to manage their own future
- the development of human resources and organisational capacity for environmental management, linking governments, business and community groups in a sense of common purpose—the focus should be on the constraints to improved human resource management and organisational capacity, and the means to improve that capacity
- fundamental research and development, especially in energy, agriculture and manufacturing processes.

To work towards a sustainable oil palm industry in PNG, a network approach to environmental management should be developed, focusing on the main challenges for sustainable development.

## New Britain Palm Oil Ltd (author: Mike Hoare)

Over the past decade, NBPOL has put a large effort into sustainability. NBPOL's environmental sustainability activities started around 2002, when it began complying with ISO14001, which sets out requirements for an environmental management system. After a 2-year process covering all departments, certification was achieved in 2004. During this time, NBPOL was also involved in the formulation of the RSPO and, between 2004 and 2007, in the national interpretation of the RSPO principles and criteria. NBPOL went through a self-assessment exercise, a pre-audit and an audit between 2006 and 2008. Despite this preparation, the company initially failed to qualify for RSPO certification and had to address and rectify four major non-conformances. Certification was awarded in September 2008. Compliance with ISO14001 and RSPO standards was audited in March and July 2009, respectively.

Following certification, the challenge is to demonstrate continuous improvement and maintenance of certification standards. An analysis of strengths, weaknesses, opportunities and threats (SWOT analysis) for NBPOL led to the following conclusions.

*Strengths*

- NBPOL has a very capable management team, a 'can-do' corporate culture and many high-performing and motivated leaders.
- The disciplines and rigour of ISO14001 have helped NBPOL to develop comprehensive and company-wide monitoring, recording and reporting systems, providing accurate, documented evidence of compliance. These systems grow and evolve to meet the requirement of continuous improvement.
- NBPOL has established a sustainability team to help drive, advise and police sustainability issues.
- The policy of NGO engagement, though not always a comfortable one, has built many bridges and helped to protect NBPOL against uninformed criticism.
- There is a strong degree of corporate understanding and acceptance of being audited, and using this as a tool for improvement.
- NBPOL matured in its dealings with its workers and the larger community. Many initiatives with potential social benefits are being formally investigated and implemented, including the 'clean development mechanism' (the capture of methane from effluent ponds for use as fuel), the bilum index (a cost-of-living index developed locally and used to ensure minimum wages are sufficient for a decent living), the firewood project (assistance for workers to obtain adequate supplies of fuel), compound gardening (assistance for workers to set up small gardens adjacent to their houses, in addition to the existing food garden areas) and a gender committee (formed to investigate and resolve concerns about negative discrimination).
- NBPOL's occupational health and safety focus has moved from essentially lip service to concrete risk and hazard analysis, recording, monitoring and improving employees' working conditions.
- NBPOL has an innovative team, which has been strengthened by good selection and recruitment of staff with wide-ranging operational experience and skills.
- A great strength is NBPOL's international standing, which helps to generate economic value and competitive advantage.

*Weaknesses*

- Operational perception is a weakness. The RSPO is still seen by many as an 'add-on' and is not yet an integral part of how the industry operates. There can sometimes be a lack of commitment by operational staff to sustainable practices, and it becomes too easy to 'take the eye off the ball'.
- Loss of key people, especially with inadequate safeguards on data management, is a significant weakness.

Mature and immature oil palm plantation (foreground) and smallholder blocks (background) in West New Britain (Photo: Richard Dellman)

- In some areas, there is no clear formal management structure or acceptance of responsibility, which allows areas to be neglected (e.g. effluent pond compliance monitoring).
- For NBPOL, the RSPO has moved focus away from ISO14001, raising the question of whether the company needs to maintain both certifications.
- The company has too much information concentrated in the arms of very few; there is a need to build up and spread the knowledge base.
- There is a strong feeling that sustainability issues are being driven by 'remote control' from outside PNG, which can cause frustration and uncertainty on the ground.
- The sustainability team is still relatively inexperienced. With smallholders having to be RSPO compliant within 3 years, the current set-up and function of OPIC is unlikely to help deliver this requirement.

*Opportunities*

- With its early RSPO certification, NBPOL is ideally placed to offer sustainable crude palm oil, as well as appeal to a broader base of potential investors.
- NBPOL is feeling its way with developing techniques and models for the practical application of HCVF assessment. Although this can be frustrating, it provides an opportunity to have input into the process.
- NBPOL should look at training numerous staff in auditing skills. It has been fortunate in sourcing high-quality and relevant training providers.
- NBPOL has a great opportunity to use what it has learnt to influence change in other companies in the group.
- NBPOL has good sustainability credentials and the chance to widen its customer base.
- The RSPO has steered the company towards a much higher level of corporate social responsibility.
- NBPOL has seen continuous improvement in most operational areas.
- NBPOL has the opportunity to strengthen its smallholder affairs team. To maintain RSPO certification for NBPOL's total supply base, the smallholders who supply approximately one-third of NBPOL FFB are required to meet full compliance within 3 years of the initial certification, which was in late 2008. OPIC is acutely short of capacity and resources to successfully train, guide and encourage smallholders to comply. As a result, NBPOL is prepared to increase resources within its own smallholders department to ensure that all smallholders are visited, spoken to and assisted to produce sustainably and attract premium prices for its certifiably sustainable products.

*Threats*

- Non-compliance with the legal, environmental and RSPO indicators that have to be consistently met is a major threat.
- External factors such as the economic downturn or government decisions can be threats. If customers have less discretionary income in their pockets, will they still take moral decisions on buying sustainable products?
- Linked to the previous point is the potential for the RSPO to become a small niche market system, which could reduce incentives for producers to be involved. Currently, the only substantial concerns about sustainability are coming from the European market, which takes some 6–7 million t of crude palm oil out of a world production of 40 million t. Major importers like China and India are not demanding sustainable palm oil; they are committed to feeding their large populations as cheaply as possible.
- Active stakeholder criticism can be a potential threat.
- On the ground, staff and workers can easily perceive that the additional workload is too onerous without some form of recompense.
- On a practical level, the shortage of degraded or non-forested land in West New Britain may significantly affect expansion.
- It is possible that NBPOL could lose ISO14001 certification if it tries to make its environmental management systems comply with RSPO requirements.
- NBPOL has limited skills and experience on the ground in following the RSPO indicators in the new development context. This is a concern because the RSPO principles and criteria still appear to be open to auditor interpretation, and measurable indicators need to be set.
- The long-term failure of the PNG government to appoint an OPIC board has serious implications for smallholders; oil producers may manage smallholders themselves to ensure RSPO compliance over the next 3 years.

*Outlook*

NBPOL's overall corporate driver is the vision of '30:30'—that is, 30 t/ha of FFB per year for palms 6 years old or more, and palm product extraction rates of 30% (crude palm oil at 24% and palm kernel oil at 6%). Plantation yields for palms more than 6 years old have steadily increased in recent years and, with increased fertiliser inputs over the past couple of years, NBPOL aims for this trend to continue.

Current annual production from plantation and smallholders combined is more than 1 million t of FFB, with a potential crude palm oil production of more than 282,000 t. At a possible premium of US$20 per tonne for the first companies to be certified, an additional US$5.6 million of revenue (around 16 million kina) would be generated. Thus, for a small amount of extra effort, there is potentially a huge gain from RSPO certification. More importantly, NBPOL believes that it may lose access to European markets without RSPO certification.

NBPOL is very keen to see that practical indicators are developed to maintain the drive to improve environmental sustainability. These indicators must be easily understood by planters and engineers, measurable, and readily auditable—the journey to sustainability involves not just doing it, but being able to demonstrate that the company is doing it.

Recommendations relating to sustainability should be written into the oil palm code of practice for PNG when it is developed. Finally, since the RSPO takes a multistakeholder approach, it should include the wishes of the entire PNG National Interpretation Working Group, not just those of the producers.

## CTP Holdings (author: William Griffiths)

*Financial benefits of RSPO accreditation and achieving the RSPO indicators*

RSPO-certified oil is not being widely traded due to the volume available (approximately 1.5 million t if all current audited companies achieve accreditation) and unwillingness of buyers to pay a higher price for certified oil. Currently, there is no financial advantage to individual plantations in being RSPO certified. Rather, being in the first batch of RSPO-certified plantations is a disadvantage, as NGO reaction to certification has been negative and focuses media attention on the certified plantations.

Cargill (of which CTP Holdings was a subsidiary) is involved in major downstream activities, ranging from refinery operations to specialised oil supply to customers such as Unilever, Nestlé, Cadbury Schweppes, McDonalds, Burger King and Hungry Jack's. These customers are requesting 'certified oil' as a result of consumer-led requests, and Cargill is very responsive to customer demand.

RSPO indicators are, in the main, very similar to those of the ISO, with added social indicators. If ISO (9000, 14000 and 18000) certification has already been obtained and is thoroughly embedded in the company management system, RSPO accreditation is not a major hurdle. Smallholder accreditation is, however, difficult. The nature of the principles and criteria that are required has not yet been determined. PNG is unique in the way that smallholders are set up and managed and in the nature of land that is converted to oil palm by smallholders.

The implementation of ISO standards does result in improved management systems in most companies, and thus usually produces a financial advantage for the company. Compliance with RSPO principles and criteria will not provide the company with any further inherent advantage, apart from advantages associated with a potential price premium or customer preference in the marketplace. PNG is unique in that all palm oil produced in the country is RSPO-certified, so it may be able to 'niche market' its oil.

RSPO principles and criteria do not measure efficiencies of production and are therefore not a good indicator of financial sustainability or sustainability of production in a true sense. Neither can they be used to rank or benchmark companies that make better use of resources than others.

It is likely that the RSPO principles and criteria will become more restrictive as the scheme progresses due to consumer pressure and increasing awareness of issues such as carbon footprints and greenhouse gases. For example, before the last RSPO meeting, a motion was tabled by Unilever and Greenpeace to stop all deforestation (not just HCVF) and to classify as peat any soils with a depth of organic layer of at least 25 cm.

*What is being done on sustainability*

Cargill is a founding member of the RSPO. Currently, Cargill is working with and funding:

- Flora & Fauna International—HCVF measurements and identification in Kalimantan, Indonesia
- WWF—identification and use of degraded land for oil palm expansion in Kalimantan, Indonesia

- Conservation International—coral reef baseline studies in Milne Bay, PNG
- Queen Alexandra birdwing butterfly conservation in Oro province, PNG.

Cargill also has several initiatives with other groups, working on other aspects of sustainability and RSPO accreditation. These include genetic marking of crude palm oil to ensure absolute traceability, installation of a clean development mechanism to trap gas from the mill effluent ponds, collaboration with the International Plant Nutrition Institute on fertiliser use and uptake and best management practice, and collaboration with The Prince's Rainforests Project on forest regeneration. Cargill has committed to not planting on HCVF and not developing new plantations on peat land (Cargill 2009).

In addition, as part of the 'normal' practice of oil palm management, Cargill is committed to implementing best management practices that ensure that plantings are sustainable, as well as improving or sustaining yield. These practices include standard agronomic measurements, such as annual leaf sampling for fertiliser recommendations, soil sampling every 5 years and at new planting and replanting, and fertiliser response trials (with PNGOPRA).

*Desirable features of an oil palm sustainability project*

Cargill would like to see the development of an oil palm sustainability project that uses pragmatic measurements that are easy to implement and can be carried out by, and on, the plantation. These measurements would be used to establish baselines, followed by periodic monitoring of the impact of oil palm on the environment. The measurements must have credibility among the wider public as useful indicators. They must be responsive to changes in management practices and must allow cause and effect to be determined so that remedial measures can be taken and the effects of those measures monitored.

The health of the waterways, streams and creeks running in and out of the plantation would provide an easy opportunity to do this. This is particularly relevant in rural areas of PNG, where water quality is an extremely sensitive issue.

Measures should be linked to the current monitoring that is required by the PNG Department of Environment and Conservation. They should not, however, ignore those being implemented by other government and environmental organisations in the major oil palm growing countries.

Other measurements could also be included, such as measuring topsoil loss, groundcover, soil compaction, biodiversity (flora and fauna) in and around the plantation, and fertiliser leaching.

Carbon balances in vegetation that may be cleared for oil palm and in oil palm plantations should also be assessed. Biomass, carbon sequestration and greenhouse gas emissions are likely to differ considerably between different types of vegetation that are being cleared for oil palm, and will also change in oil palm plantations as they age.

Any expansion of the industry in PNG will involve felling of secondary forest in good condition. Cooperation with logging companies will be needed if timber is not to be wasted in large quantities. These forests can easily be defined as HCVFs. The situation in PNG is very different from that in large areas of Indonesia, where millions of hectares are now fire climax *Imperata* grassland. It was pointed out at the recent RSPO meeting that *Imperata* is used for roofing and thus falls into the HCVF definition!

Cargill views these and similar issues as likely to become challenges for the industry within the next 5–10 years.

## Hargy Oil Palms Limited (author: Graham King)

*Vision*

The vision of HOPL is to be seen as an internationally competitive oil palm company, operating with environmental and social values and committed to meaningful rural development in the Bialla district.

The SIPEF group recognises that, in addition to its statutory and commercial obligations, it has a responsibility to the communities and environment in which it operates. The group is committed to safeguarding the environment by maintaining sound and sustainable agricultural policies. These include a zero-burn policy, integrated pest management, treatment of effluent and use of biomass (SIPEF 2009). SIPEF has been party to the RSPO since its inception, and HOPL is the first SIPEF company to be certified. HOPL has been certified since April 2009 and was due to undergo its first surveillance audit in April 2010.

*Objectives*

HOPL's objectives are:

- to acquire and plant an additional 10,000 ha of oil palm plantation—this is the physical limit, being bounded by mountains, rivers, swamps and plantation forests; however, all of the land available for oil palm is forest that could be classified as HCVF
- to increase plantation FFB yields to 40 t/ha and smallholder yields to 25 t/ha
- to use ISO14001 and RSPO certification to drive continuous improvement and financial sustainability.

*Strengths*

HOPL's strengths are:

- excellent climate and soil conditions
- high existing yield base
- adequate milling capacity and port on site
- reliable satellite communications
- a loyal workforce, with no existing industrial problems
- availability of adequate basic labour.

*Weaknesses*

HOPL's weaknesses are:

- a shortage of skilled labour
- difficulties in recruiting experienced management staff
- training not being embedded as a management tool
- poor maintenance of government infrastructure
- a poor financial performance record
- high input costs—HOPL is at the end of the supply chain.

*Opportunities*

HOPL's opportunities are:

- SIPEF being willing to invest in HOPL
- availability of land for expansion
- World Bank funding for smallholder expansion
- expanding demand for palm oil
- leverage off ISO and RSPO
- using a clean development mechanism to reduce power costs.

*Threats*

Threats to HOPL are:

- an active West New Britain Oil Palm Workers Union
- natural disasters (volcanic eruption, floods)
- political interference
- minimum wage tribunal
- HIV/AIDS and malaria
- law and order
- low world prices
- road closure.

*Conclusions*

HOPL's yield target is 40 t/ha of FFB. This has been shown to be achievable in PNGOPRA trials. Yield currently averages 30 t/ha in the plantation. Smallholders are currently averaging approximately 12 t/ha, but some land settlement scheme blocks are at 20–25 t/ha, so there is much room for increasing production through improved smallholder productivity. Overall limitations to high yields are shown in Figure 3. A healthy workforce is needed to harvest and bring that volume to the mills. The greatest immediate threat to sustainability is from the poor health status of the workforce, due to malaria, water

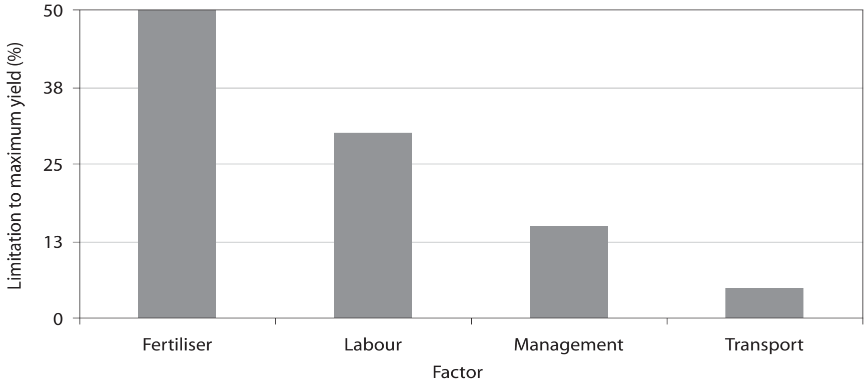



**Figure 3.** Relative importance of various factors limiting yield at Hargy Oil Palms

quality (smallholders) and HIV/AIDS, rather than from environmental issues.

## PNG government regulations

There are currently no PNG government regulations or codes of practice dealing specifically with the oil palm industry, but several regulations apply. All oil palm–related activities are assessed under the *Environment Act 2000* and the *Environment (Amendment) Act 2002*. Several statutory instruments under the Act apply:

- Environment (Water Quality Criteria) Regulation 2002
- Environment (Permits and Transitional) Regulation 2002
- Environment (Procedures) Regulation 2002
- Environment (Fees and Charges) Regulation 2002
- Environment (Prescribed Activities) Regulation 2002.

Prescribed activities include 'agricultural cultivation of an area greater than 1,000 ha' and 'palm oil extraction and processing in plants producing more than 5,000 tonnes per year'. A permit is required to discharge waste.

In addition to the regulations listed above, several codes of practice are applied to oil palm developments:

- Code of Practice for Hydrocarbons (vehicle workshops, petroleum storage etc.)
- Code of Practice for Landfill
- Code of Practice for Logging (PNG Logging Code of Practice 1996—used for land clearance applications)
- Code of Practice for Palm Oil Processing.

## Certification and incentives

Consumers interested in environmental sustainability tend to favour the codification of environmentally sustainable practices through certification schemes. Certification, clearly indicated by a label on the product, gives consumers confidence that the product is produced sustainably and allows them to choose between products on the basis of environmental certification. One problem is that most consumers probably do not even know that there is palm oil in the product, let alone its source. However, for the aware consumer, certification is the only way of knowing something about the oil's source. For the producer, there are also advantages to being certified. A transparent and widely recognised certification scheme allows them to counter criticisms, improve marketability and, possibly (although this has not yet been realised for palm oil), obtain a premium price.

Any certification scheme, such as the RSPO scheme, must be able to link oil in retail products to certified producers in some way. Identifying certified versus non-certified product poses problems for a bulk commodity such as palm oil. The RSPO scheme uses three main ways of linking oil with certified producers: segregation, mass balance and book-and-claim.

Segregation means that oil from environmentally certified plantations is kept separate from non-certified oil throughout the production chain all the way to the consumer. This is the preferred approach in terms of transparency and also for consumers, who can choose a product containing 100% certified palm oil versus a product with no certified palm oil. However, segregation is only possible at large scales, and all parts of the production chain must be set up specifically and coordinated. This is particularly challenging for the transport and trading links in the chain. Segregation is the aim of NBPOL; when its refinery in the United Kingdom is operating, NBPOL aims to transport, process and sell certified oil exclusively. On the other hand, CTP Holdings was part of Cargill (until April 2010), which buys and sells oil from a wide variety of sources, so that segregation is not currently feasible.

Mass balance is the approach whereby a stated proportion of oil in any particular shipment or product is sourced from certified producers. This avoids all the problems of segregation and allows blending to continue, as is the norm for a bulk commodity such as palm oil. It is not, however, the approach of choice for consumers, who cannot necessarily buy a product containing 100% certified palm oil, and who do not know whether or not the uncertified portion was produced in an environmentally sustainable fashion.

Lastly, book-and-claim is based on tradeable 'sustainability certificates', similar to the operation of green power or carbon trading schemes. The 'Green Palm' system works in this way. Using book-and-claim, a manufacturer or retailer can sell a product containing palm oil as 'certified', even if the actual oil in the product was not produced by a certified producer. This approach is attractive to traders; if, for example, 10% of customers demand certified oil, enough 'certification certificates' can be purchased from certified producers to satisfy that portion of the market, without having to trace the actual oil. Overall, the amount of oil produced by certified producers is at least as much as is demanded by customers. However, for obvious reasons, this approach is probably the least desirable for consumers wishing to purchase certified oil.

For any certification scheme to succeed, the benefits to the producer must outweigh the costs. The costs to producers include net costs of environmentally sensitive practices that may not be economically optimal, and costs of the certification process itself. In a global marketplace where most consumers do not demand environmental certification, the decision to join a certification scheme is not taken lightly. Most PNG palm oil is sold to the European market, where the demand for environmentally sustainable oil is relatively high. Therefore, all PNG producers see benefit in joining a certification scheme and hence all participate in the RSPO. The main benefit cited by producers is continued access to increasingly discriminating markets. Another potential benefit, frequently discussed, but with less confidence that it will eventuate, is the possibility of premiums being paid for certified oil. If premiums are paid, the PNG milling companies have stated their intention to fully pass the benefits on to the growers, including smallholders. One of the biggest challenges facing any sustainability compliance is to include the smallholder sector in a meaningful way, and to avoid excluding some smallholders from the system.

# A framework for environmental sustainability

Discussions of environmental sustainability can easily become bogged down in complexity, partly because of the intrinsic complexity of the environment, and partly because the standpoint of those involved has a large influence on concepts, definitions and approaches. In this section of the report, the concepts of sustainability are defined, especially with regard to spatial scales and the type of processes involved. In subsequent sections, the issues and processes are described, and indicators that might be useful to assess sustainability and inform managers of strengths and weaknesses are discussed.

Environmental sustainability is intimately linked with financial and social sustainability, as defined in the 'triple bottom line' concept of sustainability (Adams 2006). Any management decision that affects environmental sustainability must weigh up the financial and social implications, and vice versa. Although the links between these aspects of sustainability are in many ways inextricable, it is useful for simplicity to separate biophysical environmental aspects from social aspects (which include financial imperatives). Although social and financial issues are not discussed further in this report, they are of critical importance for environmental sustainability.

## Scope of issues

One of the problems with quantifying sustainability is that there are many types of issues, with many more interactions between them. To understand and quantify the system, it needs to be simplified (Bell and Morse 2008). However, the way it is simplified is important as certain assumptions are made. To quantify sustainability there must be clear understanding and specification of three factors:

- timescales—including the whole plantation life cycle, from conception and planning of a development to clearing existing vegetation, planting, immature phase, mature phase, felling, replanting and so on
- spatial scales—processes and management inputs
  - across a few metres
  - at the scale of an estate (for companies) or division (for smallholders)—including oil palm fields, infrastructure and mills
  - at the catchment scale—such as water quality issues
  - at the global scale—such as greenhouse gas issues
- length of the production chain being considered—this defines the boundaries of the 'system'.

These three factors determine the processes that are important, the people who are important, and the way in which sustainability can be measured.

### *Timescale*

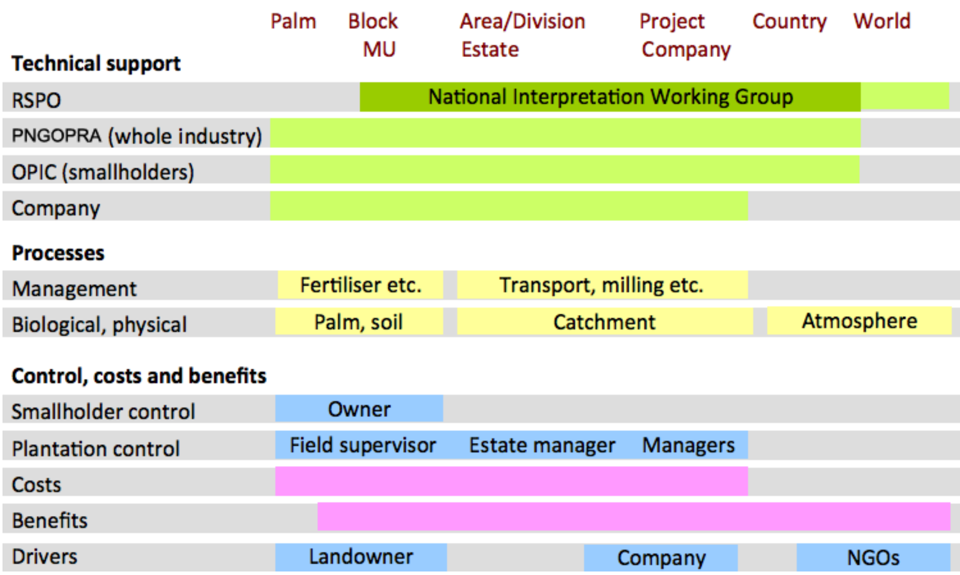
Environmental sustainability issues change considerably over the plantation cycle. The least environmentally vulnerable stage is the mature phase, when there is a dense and extensive root system, high net primary productivity, a continuous canopy and good groundcover. The most vulnerable time is when the original vegetation is being cleared and windrowed; primary productivity is low, there are few active roots, and, probably most importantly, the soil surface is bare and loose and vulnerable to erosion. The replanting stage is vulnerable for similar reasons. One consequence is that environmental sustainability might be maximised by maximising the length of the mature phase relative to the replanting phase. Also, management practices during the vulnerable stages might have effects on environmental sustainability disproportionate to the length of time in that phase. On the other hand, management during the mature phase is in place for a long time.

Another aspect of the timescale to be considered is flexibility for growing crops other than oil palm in the future. Plantation companies will grow oil palm into the foreseeable future due to the large investments in oil palm–specific infrastructure. However, the timescale for smallholders needs to include the possibility of growing other food crops or cash crops at some stage. A system that maintains fertility adequate for oil palm will not necessarily maintain the ability to grow other crops. For example, the oil palm cultivation system may lead to soil acidification; whereas oil palm is very tolerant to soil acidity, some other crops are not.

*Spatial scale*

Figure 4 illustrates the spatial scale of the various aspects of sustainability. This report is aimed at the national scale and is driven largely by the commitment of all PNG oil palm growers to the RSPO. However, implementation of management occurs in particular areas by the individual companies and on particular blocks by the individual smallholders. The processes differ in each of these areas. For example, greenhouse gas emissions may be high on flat, low-lying areas with heavy texture, whereas leaching loss of nutrients is an issue on land with high rainfall and permeable soils. Issues such as soil health impact at the block or management-unit scale, whereas issues like water quality and greenhouse gases have their impact at larger scales.

Another important issue related to spatial scale is the question of who pays the costs and who receives the benefits of environmentally sustainable practices and certification schemes. Benefits or incentives of some form must be received by managers of individual smallholder blocks or estates for practices to be sustained.




block = smallholder fields; MU = management units of the large-scale plantations; NGO = non-government organisation; OPIC = Oil Palm Industry Association; PNGOPRA = Papua New Guinea Oil Palm Research Association; RSPO = Roundtable on Sustainable Palm Oil

**Figure 4.** Spatial scale of players, processes, costs and benefits related to environmental sustainability of the oil palm industry in PNG

*Length of the production chain*

Finally, it is important to define the length of the production chain being considered. In this report, only the field operations involved in the production of FFB are considered. Mill operations are not considered, except where they directly influence field operations, such as the production and use of mill by-products like EFB. The environmental aspects of palm oil mill operations have been discussed elsewhere (e.g. Chavalparit 2006). In many ways, environmental aspects of mill and transport operations are easier to quantify and assess than field operations, because they are confined to a point in space, with relatively easily quantifiable inputs and outputs.

## Types of issues

In this report, the simplification dilemma is tackled by defining several types of issues that differ with respect to their temporal and spatial scales (Figure 5). Appropriate land use must be considered at the planning stage of development, and has critical implications for other sustainability issues. For example, nutrient balances and soil loss are largely determined by the type of land and soil on which oil palm is grown. Flat land with permeable fertile soils (not peat) is easier to manage sustainably than steep land or infertile soils. The locations and extent of agricultural land use (palms, mill, roads, villages, gardens etc.) and non-agricultural land uses (biodiversity conservation etc.) need to consider and balance long-term needs of people and the environment. Other types of issue at the landscape scale are the balances or budgets of materials and energy, and the health of aquatic ecosystems. At the field scale, the main issue is the health of the agricultural land itself, especially soil health. This simplification is not perfect, because the types of issues identified overlap and interact in numerous ways. However, as well as being conceptually distinct, the issues must be quantified in different ways.

Sustainability can be quantified in different ways (e.g. for comparisons, see Payraudeau and van der Werf 2005; Galan et al. 2007). Quantifiable indicators can be classified into two general types (Table 3). The first is measurement of a trend over time. Most sustainability issues can be quantified in this way, and it is the basis of the 'continuous improvement' concept, which underpins certification schemes such as ISO14001 and the RSPO. For example, downward trends in on-site indicators (such as soil health) or off-site indicators (such as downstream water quality) generally indicate unsustainability. For balances of materials, such as loss of soil, or inputs and losses of nutrients, rates are important. Rates are normally calculated as a function of time, but they can also be calculated per tonne of oil produced, in order to provide a ratio of sustainability to productivity.

The second type of indicator uses area and spatial arrangement. Trends or rates do not apply well to landscape-scale issues of sensible planning and biodiversity. Although trends in biodiversity can be measured, the most important determining factor is the area and arrangement of agricultural land use and other land uses in a particular region or ecosystem. Covering a whole province with oil palm, with no provision for food crops or conservation of native species, would not be sustainable.

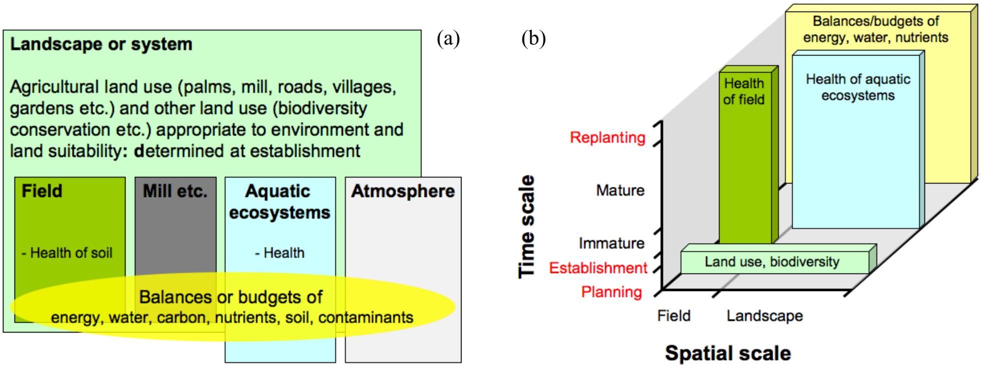



**Figure 5.** Types of environmental sustainability issues in the oil palm industry; a) their spatial relationships and b) their spatial and temporal dimensions

**Table 3.** The principal types of indicators used for quantifying different types of environmental sustainability issues

| Issue | Indicator type | |
|---|---|---|
| | Trend or rate (per year, per tonne of oil) | Area (per hectare) |
| Planning, land use, biodiversity | Not applicable | Applies |
| Balances of water, energy, nutrients | Applies | Applies |
| Balance of soil (soil erosion) | Applies | Applies |
| Health of soil | Applies | Not applicable |
| Health of aquatic ecosystems | Applies | Not applicable |

Habitat conservation can be measured in terms of areas, and location and connectivity of those areas. So the area and spatial arrangement of land uses can be quantified as an indicator of sustainability, albeit with difficulty.

All types of indicators can be compared to critical values, although critical values may be difficult or impossible to define.

Planning at the landscape scale is, for many people, the most important type of sustainability issue and is probably also the most contentious. On the one hand, it can be considered undesirable to plant oil palm on land where it replaces forest with high biodiversity or land that is necessary for food production, and more desirable to plant it on land where it replaces other, less profitable plantation crops, or land that has been heavily degraded by logging. However, spatial scale and financial viability are particularly important here. Expansion of oil palm is most viable close to existing mills, and land that is most suitable for oil palm often has diverse forests or intensive gardening.

Planning also affects other aspects of sustainability. For example, planting oil palm on steeply sloping land without terracing will lead to soil loss and nutrient loss. Planting oil palm on peat swamps that require drainage will lead to large emissions of carbon dioxide and possibly also gaseous forms of nitrogen and sulfur. Finally, the size and location of oil palm plantings will determine the fate of species that depend on those habitats. Therefore, planning needs to balance many factors on a broad scale and consider long-term consequences through thorough consultation with all parties concerned.

Balances of materials and energy are landscape-scale processes that overlap with off-site environmental quality (particularly water quality and the atmosphere), with on-site sustainability in the field (e.g. soil fertility) and with mill operations (inputs and outputs of nutrients, water and energy). Materials can be categorised in various ways, but in an agricultural system the balances of water, nutrients, carbon and pesticides are of primary importance. For these budgeting issues, inputs and outputs need to be quantified. This can be done at different timescales and spatial scales, but the aim is to be as holistic as possible (landscape scale, over the whole oil palm cycle). The 'balance' issues include the concept of carbon footprints and the emission of greenhouse gases.

Health of aquatic ecosystems is a landscape-scale issue that cannot be measured by area. Values and trends can, however, be measured. Defining the points in space and time for monitoring schemes is difficult but critical if these schemes are to be useful. The difficulty arises because water exists everywhere in the environment, is continuous (e.g. boundaries between groundwater, stream water and seawater are not clearly defined in nature) and continuously moves and changes in composition. Furthermore, natural variations in quality are large, and anthropogenic perturbations must be measured against these variations.

Health or fertility of soil is the basis for agricultural sustainability. It depends on the interaction of many processes that occur at the land surface—the most biodiverse part of all ecosystems—where minerals, water, air and organisms have their maximum level of interaction and in which the crop is supported. Soil health is similar to health of aquatic ecosystems in that it can be quantified in terms of trends or rates. It can be assessed in many ways, generally focusing on parameters that integrate physical, chemical and biological processes. Many aspects of soil health are determined by soil type, whereas others are more sensitive to management. Soil loss by erosion or decomposition (in the case of peat) can be considered as a soil health issue or as a landscape-scale balance issue, but as the target is zero loss from the field, it is considered here as a field-scale soil health issue.

Another aspect of the health of agricultural land is the presence of pest species such as invasive weeds, pests and diseases. Pest species may be considered as an environmental sustainability issue, as poor control can lead to environmental damage. However, they are a distinctly different type of issue from the health of land, water and atmosphere and are not discussed further here.

# Aspects of environmental sustainability

## Planning and biodiversity

Most concern about the environmental impact of oil palm is about the conversion of forest into plantation. Once established, oil palm plantations can be managed in an environmentally sustainable way. Although planning for new developments is a critical issue for the oil palm industry in PNG, it is considered only very briefly in this report.

Most of the recent and potential future expansion of the worldwide area under oil palm is at the expense of forest (Germer and Sauerborn 2008), and this is also the case in PNG. However, further loss of forest is not necessarily a requirement for expansion of the oil palm industry; it would be possible to meet the demand for oil for edible purposes projected for 2050 from plantings on degraded areas such as anthropogenic grasslands (Corley 2009). The fragmentation, disturbance and destruction of natural habitats brought about by converting forest to plantations decrease biodiversity (Laidlaw 2000; Robertson and van Schaik 2001), primarily because oil palm plantations harbour less biodiversity than forests (Kessler et al. 2007; Fitzherbert et al. 2008). The future of lowland forest across PNG needs to be considered and, where necessary, protected. The objective of planning is a balance between potential productivity and conservation aims, with priority areas being defined. At a smaller scale, design can incorporate areas such as riparian buffer zones and wildlife corridors. Planning also needs to consider how to monitor and prevent encroachment of oil palm or other land uses such as gardening into those reserved areas.

In PNG, most of the original oil palm plantations were established on existing cropland, mainly previous plantations of cocoa or coconut. However, most areas available for future expansion are forests with high biodiversity, even though most of these are secondary forests that have been logged at least once. Little, if any, primary forest is available, and clearing of primary forest is precluded by the RSPO guidelines (Criterion 7.3; see Table 2). For biodiversity conservation, it would be preferable that new oil palm developments occur on existing cropland, anthropogenic grasslands or degraded habitats, rather than primary or secondary forests (Fitzherbert et al. 2008; Koh and Wilcove 2008). Although such cropped, degraded or grassland habitats exist in PNG, they are mostly not feasible areas for expansion as they would require 'greenfields' developments, with building of new infrastructure and mills. Greenfields developments are unlikely in the near future because of the level of investment required and the uncertainty of land tenure. Indeed, none have occurred in PNG since the 1980s, apart from Ramu. Land tenure uncertainty arises because, whereas all current mills and plantations are on alienated land, no more suitable alienated land is available. Although most future developments are likely to be on forested land, there are some notable exceptions. The current oil palm development at Ramu is exclusively on grasslands. In Oro province much of the most recent development has been on grasslands, and further expansion onto grasslands is feasible.

In addition to considering conservation values, planning must consider the impacts of developments on environmental sustainability once the plantations are established. For example, development on peat or acid sulfate soils inevitably leads to major problems for environmental sustainability. This is primarily due to the massive release of carbon dioxide and gaseous forms of nitrogen and sulfur in the case of peat soils (Imbushi et al. 2003; Macdonald et al. 2004, 2009) or sulfuric acid and metals at environmentally toxic concentrations in the case of acid sulfate soils (Gosavi et al. 2004; Burton et al. 2008). Neither peat nor acid sulfate soils have been developed or are being considered for development in PNG. However, oil palm is frequently planted on swampy mineral soils, which, when drained, can pose similar (but less pronounced) problems to developments on peat. The effects on greenhouse gas emissions of converting various types of vegetation to oil palm are discussed below (under 'Balances of carbon and energy'). Planting on steep terrain can cause soil erosion. The RSPO guidelines require topographic and soil mapping to be carried out in the planning stage and allow only limited planting on steep terrain or on marginal and fragile soils (Criterion 7.4; see Table 2).

Other issues should also be considered in planning for environmental sustainability. For example, climate change–induced sea level rise (0.1–0.2 m by 2050) and increased rainfall are predicted for PNG (IPCC 2007); both would increase environmental risks. The physical landscape of oil palm growing areas of PNG is also very dynamic; major ash falls, land slips in mountainous areas and fluvial changes on the plains can be expected due to active uplift and volcanic activity.

In addition to replacing previous vegetation and affecting land and water, oil palm developments impact on surrounding ecosystems through increased population pressure. Population pressure increases in oil palm areas primarily as a result of the large employed labour force of the plantation companies and their relatives, and immigration of people onto land settlement scheme smallholder blocks. More people means more pressure on resources such as fisheries, along with increased access to improved fishing methods and technology. Additionally, more land is required for gardens, and rotations with forest fallow inevitably become shorter, or forest fallow disappears altogether. The pressure to clear forest for gardens is particularly relevant to reserved land, such as riparian buffer zones, which are often cleared.

## Balance of water

Sustainability of agricultural systems is closely tied to the water balance. In many parts of the world, agriculture is not sustainable due to changed water balances. In drier areas, conversion from native vegetation to crops has increased recharge, raising watertables and causing salinisation of streams and soil. Salinisation due to increased recharge is also common in irrigated areas. Other irrigation schemes are not sustainable because water is extracted from aquifers faster than it is replenished. Disruption of the water balance by agriculture also impacts on downstream ecosystems.

The closer the water balance is to that under the original vegetation, the less likely are sustainability problems. Salinisation is not an issue for oil palm in PNG, due to the wet climate and net loss of salts from the landscape. However, soil erosion, nutrient loss, stream bank erosion and subsidence of peat are all potential problems for oil palm that are tied to the water balance. Mature oil palm has a similar water balance to the original forest, which underpins the sustainability of oil palm systems.

The water balance in oil palm plantations in PNG is characterised by high rainfall, high transpiration and high deep drainage (Figure 6). Average annual rainfall ranges from approximately 1,900 mm at Ramu in Morobe province to approximately 4,200 mm at Navo in West New Britain province. Annual evapotranspiration is approximately 1,300 mm (Banabas et al. 2008a). In most areas, there is no substantial period of water deficit (potential evapotranspiration higher than rainfall) during the year, except for Ramu, where there is a deficit, and hence water supply limitation to transpiration, for about 4 months of the year.

Due to relatively even distribution of rainfall throughout the year and permeable soils, most of the excess water (>1,300 mm/year in most places) is lost by deep drainage rather than surface run-off (Banabas et al. 2008a). The high values of deep drainage mean that the most likely loss of fertiliser-applied nutrients is via leaching rather than surface run-off. During the planting and replanting stages, interception and transpiration will be lower for some time, so deep drainage and run-off losses are likely to be higher.

Apart from transpiration, irrigation and drainage are the main perturbations of the water cycle in oil palm compared with natural vegetation. Irrigation is not currently practised in PNG, but is being considered at Ramu. Given the hydrology of that area, irrigation would not be expected to cause significant environmental concerns. Any decrease in flow to the Ramu River would be minimal, as the area of oil palm is small relative to the size of the catchment and the period of likely irrigation is short. Whether surface or groundwater is used, supplies are large, as rainfall in the adjacent mountains is high. Localised raising of the watertable is possible but unlikely under proper irrigation management, given the ubiquity of gravel beds in the underlying alluvial beds, and the proximity of the river.

In other parts of the country, drainage is carried out in many low-lying areas, with open drains around oil palm fields, up to about 1 m deep. Drainage serves to lower the watertable. This can influence the carbon cycle, accelerating decomposition of soil organic matter. It can also detrimentally influence nearby groundwater-dependent ecosystems, although such situations are not known in PNG.

## Balances of carbon and energy

Combustion of fossil fuels and land-use change affect greenhouse gas emissions and climate change, and the carbon balance of industries and products has come under increasing scrutiny. Agricultural production, including oil palm cultivation, is no exception. Carbon balance and energy balance are more-or-less interchangeable, since the main way in which energy is stored is in carbon compounds produced by photosynthesis, either in the past in the case of fossil fuels, or at present in the case of biofuels. Photosynthesis converts carbon from carbon dioxide into organic compounds, and converts solar energy into stored chemical energy. Combustion or respiration converts the organic carbon into carbon dioxide, and the stored energy into heat and motion.

Long-term sustainability relies on a positive energy balance—that is, more energy is fixed in photosynthesis than is consumed to produce the product. Most agricultural systems are inherently sustainable in this regard, although some current agricultural systems can be energy negative (the ratio of energy return to energy invested is less than 1). Oil palm appears to be the most energy positive of all crops, having a ratio of energy return to energy invested of more than 3 (Angarita et al 2009; Pleanjai and Gheewala 2009; Yee et al. 2009). The actual figure depends on whether or not initial clearing of forest is included, the length of the supply chain considered and various other factors.

The main energy inputs into oil palm production systems are fossil fuels for fuel and nitrogen fertiliser (Yusoff and Hansen 2007). The high net energy yield of oil palm is due to its high productivity, and is beneficial to environmental sustainability in terms of carbon and energy balance. However, it is also an important driver for use of palm oil as biofuel. The use of palm oil as a substantial substitute for mineral oil fuel is frightening to contemplate, given the enormous energy demands of people globally. Less than 5% of palm oil is currently used as fuel, and any

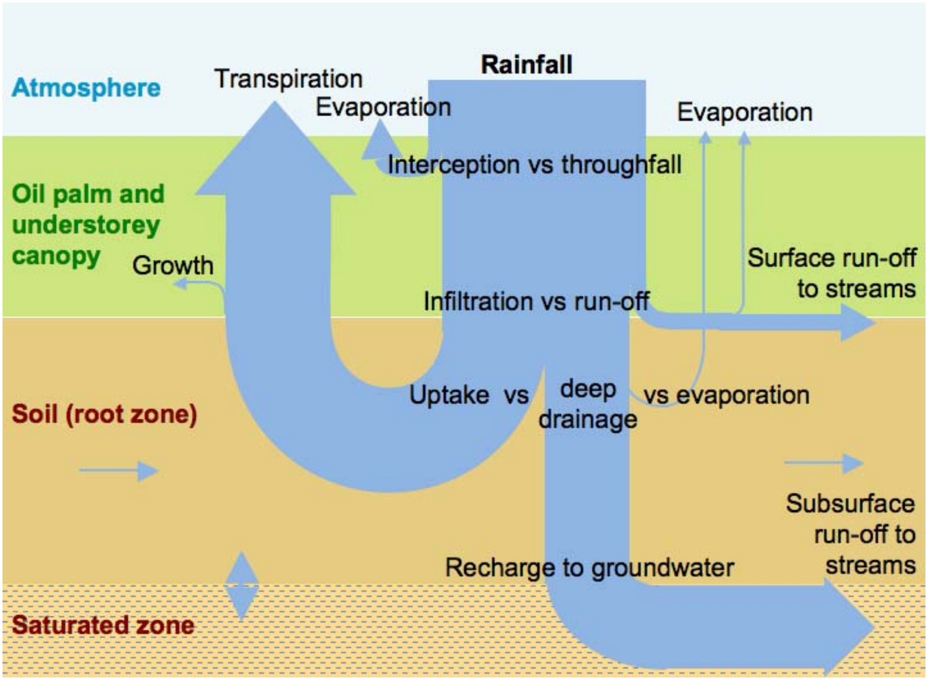



**Figure 6.** Water balance in typical oil palm blocks in Papua New Guinea; the blue arrows represent water fluxes, with their width approximating the relative quantities

significant increase in use as fuel is likely to have disastrous effects on the conservation of remaining lowland tropical forests (Danielsen et al. 2009). Furthermore, if land is converted from forest, the carbon/energy gain of producing palm oil compensates for the carbon/energy loss from forest conversion only after 75–93 years (Fargione et al. 2008; Danielsen et al. 2009). For conversion from grassland (Figure 7) or peat, the corresponding period is approximately 10 or 600 years, respectively (Danielsen et al. 2009).

Approaches such as 'carbon footprinting' and 'life cycle analysis' use similar concepts to quantify the carbon or energy budgets of the production chain, although life cycle analysis usually also considers environmental issues other than carbon/energy balance (Mattson et al. 2000; Yusoff and Hansen 2007). Carbon footprinting is becoming more rigorous as standards for calculation are devised and accepted (e.g. standard PAS2050, BSI 2008a, b), based on the outputs of the Intergovernmental Panel on Climate Change (IPCC 2007). There is only sketchy information for oil palm production systems and no systematic studies of the complete greenhouse gas balance.

The greenhouse gas implications of the carbon cycle are considered below under 'Balances of greenhouse gases'.

Oil palm is among the most effective of crops in sequestering carbon because of its high rates of net primary productivity and biomass growth. However, much of the carbon sequestered in biomass during a crop cycle is returned to the atmosphere when the palms are felled. The only long-term (over multiple crop cycles) change in carbon storage in an oil palm system will be the change in soil carbon, but there have been no long-term studies to quantify these changes. Total annual dry-matter production of oil palm—including leaves, trunk, roots, male flowers and fruit bunches—is approximately 30–37 t/ha, equivalent to a total annual carbon fixation of approximately 13.5–16.6 t/ha (Hartley 1977; Lamade and Bouillet 2005); this may be higher than forests (Lamade and Bouillet 2005).

**Figure 7.** Oil palm recently planted on grassland in the Ramu Valley. Conversion from grassland to oil palm causes a net sequestration of carbon. (Photo: Paul Nelson)

The net flux of carbon into or out of the soil/crop system is the difference between primary productivity or photosynthesis (palms and understorey) and respiration (plant and soil). Although easy to define, this is difficult to measure. The main approaches are:

- measuring changes in carbon stocks (plant and soil) over time
- measuring photosynthesis and respiration over small areas and scaling up
- directly, by gas flux measurements above the canopy.

All these approaches have many assumptions and difficulties, exacerbated by the spatial and temporal variability in oil palm plantations. Gas flux measurements by eddy covariance show the most promise for quantifying net fluxes, and several projects are planned or underway in other countries to measure fluxes in oil palm plantations by this method.

The most significant part of the oil palm production cycle for carbon cycling is the initial conversion to oil palm (Germer and Sauerborn 2008; Wicke et al. 2008). Conversion from forest results in a net loss of carbon to the atmosphere, whereas conversion from grassland results in net sequestration of carbon. In environments suitable for oil palm, forests have a total biomass of about 342 t of dry matter/ha and grasslands about 27 t/ha (Germer and Sauerborn 2008). When that biomass decomposes, it releases approximately 627 t of carbon dioxide/ha for forest and 42 t/ha for grassland (Germer and Sauerborn 2008). The RSPO guidelines prescribe avoidance of burning; in any case, burning releases approximately the same amount of carbon dioxide as decomposition. Soil organic carbon content decreases upon conversion from forest to oil palm, but increases upon conversion from grassland to oil palm (Germer and Sauerborn 2008; Dewi et al. 2009).

Although little or no peat is being developed for oil palm in PNG, this is an important issue in South-East Asia. Total carbon content of peat soils depends primarily on the depth of peat, which can be up to several metres. Drainage accelerates decomposition and emission of carbon dioxide (Imbushi et al. 2003). Release of carbon after conversion to oil palm is approximately 8.6 t/ha per year, translating to carbon dioxide emissions of 31 t/ha per year (Germer and Sauerborn 2008). The effects on methane and nitrous oxide emissions are more complex (Germer and Sauerborn 2008). Subsidence of drained peatlands also poses problems.

Development of a new oil palm plantation in West New Britain (Photo: Richard Dellman)

# Balances of nutrients

## Maintaining the balance

Oil palm, like all other plants, requires mineral nutrients (nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, zinc, manganese, copper, boron, molybdenum, chlorine, nickel and possibly silicon) in order to grow and reproduce. It also requires carbon, hydrogen and oxygen, but these are generally not thought of as nutrients as they are obtained from the atmosphere (as carbon dioxide and oxygen) and water, and they are not considered further in this section.

For terrestrial plants, the repository of mineral nutrients is the soil and the plant itself. To maintain healthy plants, it is important to maintain this repository, and in undisturbed systems, it is maintained by efficient cycling of nutrients within the ecosystem. In contrast, in agricultural production systems, nutrients are removed from the ecosystem in the product. In order to maintain a productive and healthy soil, an understanding of nutrient pathways is required.

Nutrients may be exported from a site:

- in the agricultural product—in this case, the fruit bunches
- through leaching
- through overland flow, dissolved or attached to sediments
- through conversion to gases (nitrogen as ammonia, nitrous oxide or dinitrogen; and sulfur as hydrogen sulfide or sulfur dioxide)
- through fire—as smoke, ash or volatilised gas.

Nutrients may be imported to a site:

- in returned by-products from the mill
- in fertiliser
- through overland flow, dissolved or attached to sediments
- in ash, dust and rainfall
- via biological nitrogen fixation.

Weathering of primary minerals releases mineral nutrients in plant-available forms, which may also be regarded as an import as it increases the repository of nutrients available to plants. This is probably an important source of nutrients in PNG, in the young and rapidly weathering soils on which oil palm is predominantly grown. Because of the high and frequent rainfall, these minerals are also likely to be an important source of leached nutrients, especially potassium, calcium and magnesium.

To maintain the repository of nutrients available for palm growth, the imports must balance the exports. If there are insufficient inputs, the repository of nutrients will decline, leading to suboptimal yields and consequently poor values of sustainability when measured on a per oil yield basis.

The simplest way to maintain the repository of nutrients is by adding inorganic fertilisers and encouraging biological nitrogen fixation through healthy leguminous cover crops. The most commonly used leguminous cover crops, which are planted at the same time as the oil palms, are *Pueraria phaseoloides* and *Calopogonium* species (Giller and Fairhurst 2003). However, excessive nutrient inputs can:

- exacerbate losses and subsequent environmental damage (particularly water quality)
- reduce energy efficiency (fertilisers cost energy to produce)
- reduce the ratio between economic benefit and cost of production—in particular, excessive nitrogen inputs can accelerate soil acidification (see 'Health of soil') and production of greenhouse gases (see 'Balances of greenhouse gases').

The magnitude of the pathways of export, loss and import therefore need to be considered, as well as the balance of nutrients. By minimising exports and losses, imports of fertilisers—which are expensive (cash, energy and environment)—can also be reduced. Import and export pathways are discussed further below.

## Nutrient import, export and loss pathways

Nutrient import and export pathways are very much dependent on scale. At the scale of the whole estate, including a smallholder area, the main exported product is oil, which contains virtually only carbon, hydrogen and oxygen. Thus, there is almost no export of mineral nutrients in the product. However, apart from oil, sometimes whole palm kernels or palm kernel meal are exported, both of which have high contents of nitrogen and potassium. In addition, there will be losses associated with the mill:

- Mesocarp, and sometimes shell, is used to fuel the mills, which will result in gaseous and particulate losses of nutrients.
- Because of the anaerobic conditions in the effluent ponds, there is likely to be a substantial loss of nitrogen as nitrous oxide, which is an important greenhouse gas (see 'Balances of greenhouse gases'), and dinitrogen.

At the scale of the division or smallholder project, nutrients are exported in the fruit bunches. While some of these may come back as EFB or palm oil mill effluent, this is usually only to plantation fields close to the mill, and rarely to smallholder blocks. In any case, it usually only reduces the fertiliser inputs, rather than eliminating them. There is a case for increasing EFB inputs to smallholder blocks, but piles of EFB can become fly breeding sites if they are not spread quickly, which poses health problems close to habitations. Also, many smallholder blocks are far from the mill.

At the scale of the individual palm, as well as the export of the fruit, nutrients are redistributed, especially in pruned fronds. The frond pile, being stacked with green fronds, represents a large amount of nutrients, especially nitrogen and potassium. As the fronds decompose and release nutrients to the soil directly below, these nutrients are vulnerable to loss by leaching in the high rainfall environment. Fertiliser application is another highly concentrated source of nutrients that is vulnerable to loss. Loss may occur through overland flow, leaching (due to a limited capacity of the palms to take up the nutrient relative to the supply of that nutrient) or conversion to gases.

For nitrogen, leaching of nitrate appears to be the main loss pathway in PNG, and annual losses of nitrogen have been estimated at about 37–103 kg/ha from mature plantations, based on water balance and soil solution concentrations (Banabas et al. 2008a). Where fertilisers are applied, application rates of nitrogen are generally in the range of 80–150 kg/ha. However, it is possible that nitrate leaching is slowed to some extent in the subsoil, from where it could be taken up. Many tropical soils have anion retention or exchange capacity due to their variable charge, low pH and low organic matter content. The anion exchange capacity of soils in oil palm growing areas of PNG is generally <5 $mmol_c$/kg at soil pH, but can reach 28 $mmol_c$/kg in acidic subsoils (Nelson and Su 2010). An anion exchange capacity of 2.5 $mmol_c$/kg is sufficient to retard nitrate leaching (Wong and Wittwer 2009). Losses of nitrogen in surface run-off are low (<1.5% of additions in fertiliser), mainly because there is little surface run-off of water (Banabas et al. 2008a).

In some situations, gaseous losses of nitrogen are also possible due to the loss of ammonia volatilised during the conversion of urea to ammonium, nitrous oxide produced during denitrification or nitrification, or dinitrogen produced during denitrification. Volatilisation is known from other studies to be significant when urea application is followed by a moist period (e.g. dew) but rainfall is insufficient to leach urea into the soil, and atmospheric conditions are windy with low humidity. Once the urea is leached a few centimetres below the soil surface, and providing soil pH is not high, then losses of ammonia are minimal. In PNG, environmental conditions and results of fertiliser experiments (urea versus other forms of nitrogen fertiliser) indicate that volatilisation to ammonia is not significant. Where soil has high concentrations of nitrate and organic matter, and conditions are anaerobic (waterlogged), losses of nitrogen as nitrous oxide and nitrogen gas, produced by denitrification may be high. These conditions are common after the application of fertiliser in wet conditions, especially in low-lying areas or on clayey soils. Very few measurements of denitrification have been carried out in oil palm. However, measurements in Indonesia (Ishizuka et al. 2005) and on well-drained soils in PNG (Banabas 2007) have shown low emissions of nitrous oxide, equivalent to less than 1 kg/ha per year (of nitrogen) and less than 1% of fertiliser nitrogen applied. Losses of nitrogen as dinitrogen are much more difficult to quantify and have not been reported for oil palm.

The timescale of nutrient balances also needs to be considered. In immature plantations, inputs of nitrogen through biological nitrogen fixation are presumably high due to light reaching the leguminous cover crops through gaps in the oil palm canopy. In contrast, in mature plantations, inputs of nitrogen via biological nitrogen fixation are probably negligible. Also, as palms mature, the root system becomes more extensive and more capable of taking up nutrients before they are lost by leaching. As plantations mature, the stock of nutrients in the vegetation builds up considerably. However, when the palms are felled, the nutrients are mineralised and are highly susceptible to loss, as there is limited plant growth and nutrient uptake at this time.

## Concepts for target setting

From the discussion above, it is clear that a number of concepts need to be considered:

- The nutrient repository should be maintained at an appropriate level by balancing exports, losses and imports.

- Exports and losses should be minimised so that imports can be minimised. This will minimise all the other effects of applying fertilisers, such as acidification of soil, eutrophication of water bodies, and energy costs in producing and transporting fertiliser.
- As undisturbed ecological systems have a natural rate of nutrient loss, especially those on young soils, this provides a target to either achieve or improve on. Alternatively, since it is unlikely that this target could be achieved in an agricultural production system, undisturbed systems could be a benchmark for assessing the performance of the oil palm industry, and comparing it with other industries (e.g. logging) operating in the same agroecological region.
- Of the nutrients, nitrogen balance is the most important for environmental sustainability in PNG. Optimising biological nitrogen fixation is likely to be important for improving sustainability in the long term. Loss by leaching is the most important export of nitrogen, and leaching losses can be managed by the timing and placement of fertiliser (Banabas et al. 2008b). Losses of gaseous forms of nitrogen are largely unstudied in oil palm.

## Nutrient balance measurements in PNG

Agricultural crops are amenable to the study of 'partial nutrient balances': the difference between the amount of nutrients imported and the amount exported. This simple analysis can be undertaken at the scale of a field, block or plantation estate, or even on a larger scale, such as a district, province or even the whole country. This simple approach is useful if one is interested in a broad picture of what nutrients are being applied and what is exported.

A more detailed analysis of a nutrient balance requires examination of what is actually available to the crop (nutrients supplied by the soil and applied nutrients), what is exported in product and what remains behind in plant tissue—either relatively quickly recycled (the pruned fronds) or stored for a longer time (in the trunk of the palm). Several detailed studies of nutrient balances have been undertaken in PNG. Nitrogen balance studies (Banabas 2007; Banabas et al. 2008a, b) were referred to above. Cycling of magnesium and potassium has also been studied in some depth (Webb et al. 2009). In addition, nutrient balances were studied in one of PNGOPRA's fertiliser trial sites in Milne Bay province in 2007. Details of the trial design and results are in the Appendix.

In the nutrient balance study in Milne Bay, uptake and export of nitrogen, potassium and phosphorus were measured. Nutrients in leaflets, rachis and core are stored within the palm and become available when the fronds are pruned or after felling, when the fronds and trunk decompose. However, nutrients in bunches are exported from the plantation. Table 4 lists the amount of nutrients exported from the field as a percentage of total nutrient uptake. Table 5 shows the nutrient recovery efficiency for nitrogen and potassium applied in fertiliser.

Recovery efficiency of the applied nitrogen and potassium was high at low application rates and decreased as more fertiliser was applied (Table 5). In addition, recovery efficiency of nitrogen was influenced by potassium, and vice versa.

At normal plantation rates of fertiliser application (equivalent to 4 kg sulfate of ammonia/palm plus 2.5 kg muriate of potash/palm), there was a high uptake of applied nutrients at this site; uptake by the palms

**Table 4.** Nutrients exported in oil palm fruit (PNGOPRA trial 504, 2007)

| Treatment (kg fertiliser/palm) | Nutrients exported (as % of total uptake) | | |
|---|---|---|---|
| | Nitrogen | Potassium | Phosphorus |
| SOA: 0; MOP: 0.0 | 39 | 52 | 46 |
| SOA: 2; MOP: 2.5 | 39 | 42 | 47 |
| SOA: 4; MOP: 2.5 | 40 | 38 | 41 |
| SOA: 6; MOP: 2.5 | 43 | 40 | 39 |
| SOA: 6; MOP: 5.0 | 36 | 38 | 38 |
| SOA: 6; MOP: 7.5 | 39 | 40 | 42 |

kg = kilogram; MOP = muriate of potash (potassium chloride); PNGOPRA = Papua New Guinea Oil Palm Research Association; SOA = sulfate of ammonia (ammonium sulfate) was equivalent to 80% of applied nitrogen and more than 90% of the applied potassium. Other studies showed that the inefficiencies in potassium uptake at this site were not due to losses of potassium from the system; all potassium applied as fertiliser was either taken up by the palms or retained in the top 0.4 m of soil (Webb et al. 2009).

**Table 5.** Nutrient recovery efficiency for nitrogen and potassium applied in fertiliser (PNGOPRA trial 504, 2007)

| Treatment (kg fertiliser/palm) | Nutrient recovery efficiency (uptake as % of applied) | |
|---|---|---|
| | Nitrogen | Potassium |
| SOA: 2; MOP: 2.5 | 96 | 72 |
| SOA: 4; MOP: 2.5 | 81 | 95 |
| SOA: 6; MOP: 2.5 | 56 | 112 |
| SOA: 6; MOP: 5.0 | 59 | 60 |
| SOA: 6; MOP: 7.5 | 70 | 42 |

kg = kilogram; MOP = muriate of potash (potassium chloride); PNGOPRA = Papua New Guinea Oil Palm Research Association; SOA = sulfate of ammonia (ammonium sulfate)

# Balances of greenhouse gases

All the main greenhouse gases—carbon dioxide, nitrous oxide and methane—are produced and consumed in oil palm plantations. Of the three gases, carbon dioxide is produced and consumed in the largest quantities. Although produced in smaller quantities, methane and nitrous oxide have global warming potentials 25 and 298 times that of carbon dioxide, respectively (IPCC 2007). Greenhouse gas emissions are calculated as 'carbon dioxide equivalents' using these factors. Concepts and quantification of carbon dioxide and methane emissions are discussed under 'Balances of carbon and energy', and emissions of nitrous oxide are covered under 'Balances of nutrients' (above).

Moves are currently underway in PNG to capture and use the methane produced in mill effluent ponds as a fuel. Those initiatives are registered as clean development mechanisms under the United Nations Climate Change Programme.

The RSPO Greenhouse Gas Working Group has reviewed and synthesised information on greenhouse gas emissions throughout the production chain, identified options for mitigation of emissions, and provided recommendations for modifying the existing principles and criteria (GHG-WG 2009).

# Balance of soil (erosion)

Movement of soil through erosion and subsequent deposition is usually considered detrimental for two main reasons:

- Erosion removes fertile topsoil and can even remove the physical support of palms.
- Deposition may occur where it causes environmental or other problems (e.g. in waterways).

## Erosion

Erosion of soil is a natural consequence of the actions of weather in all environments, even so-called pristine environments. It results from the actions of wind, ice and water, resulting in, for example, sand dunes, moraines and floodplains. In some respects, especially in floodplains, upstream erosion is beneficial to downstream communities in that it provides a new layer of soil and associated nutrients.

However, in many agricultural situations, the rate of erosion is increased from its natural level. This can result in substantial amounts of sediment travelling in streams, being deposited along the way, and reaching the marine environment. As discussed in a previous section, the scale of the process is important.

In mature oil palm plantations with good canopy and groundcover and on flat or low-sloping land, especially on soils with high infiltration rates, long-distance movement of surface water and associated sediments is not common. Although there may be evidence of surface erosion in some areas (e.g. weeded circle, harvest paths), the detached soil often accumulates where run-off water velocity slows or ceases, such as frond stacks. The result is a 'terraced' effect from short-distance transport of material; this is of little or no concern to the plantation itself or the surrounding environment.

On the other hand, many situations can exacerbate erosion. Erosion is influenced by both site-dependent factors and management-dependent factors.

### *Site-dependent factors influencing erosion*

High duration and intensity of rainfall, high soil erodibility, and high slope length and gradient all result in high susceptibility of an oil palm block to erosion. Although site-specific management cannot change this susceptibility, the original selection of an oil palm block or plantation is under the control of the oil palm industry.

*Management-dependent factors influencing erosion*

Vegetation cover can be managed at a number of scales. At the palm scale, maintenance of ground-cover and efficient placement of frond stacks can reduce erosion from the site by reducing the energy of rainfall, or trapping or slowing water and dislodged soil particles. At the block scale, both vegetation management and landscape management affect erosion—for example, oil palm canopy cover (vegetation management), and harvest path, road alignment and drainage design (landscape management). At the smallholder division or plantation scale, vegetated buffer zones along watercourses and engineering solutions, such as contour terraces, are important.

### Deposition

Depending on the movement pathway, eroded soil may be deposited elsewhere in the landscape (e.g. lower slopes or flats) or delivered to the river system. Large quantities of eroded soil delivered to river systems are generally detrimental to the river itself and the receiving marine environment. On the other hand, eroded soil redistributed within the landscape may or may not be detrimental to the receiving landscape, although it is generally detrimental to the source landscape.

The choice of whether or not to develop a particular area and the design of the development will have a profound consequence on erosion and possible off-site impacts. Thus, many issues need to be considered in order to minimise erosion or its impacts.

## Health of soil

Soil health is difficult to define precisely and even more difficult to quantify. It is usually understood to reflect a soil's ability to maintain healthy plant growth by providing the plant with adequate resources. The resources are physical support, water, oxygen, a balanced supply of nutrients, high activity of beneficial organisms and low activity of patho-

Examining the volcanic ash soil profile in a smallholder oil palm block in West New Britain (Photo: Paul Nelson) gens, and absence of toxins. Soil health also refers to the resilience of soil, which is its ability to continue to provide resources in the future, even in the face of stresses. Soil health is influenced by inherent properties such as mineralogy, and by management factors.

Processes that damage soil health include:

- compaction—affects availability of water and oxygen
- acidification—affects nutrient availability and retention, and concentration of toxins
- depletion of nutrients—reduces accessibility to nutrients
- accumulation of nutrients—can have toxic effects
- depletion of organic matter—affects nutrient availability and retention, availability of water and oxygen, and the activity of soil fauna and microorganisms
- contamination—by pesticides, herbicides and heavy metals.

## Compaction

Compaction of soil is generally the result of 'traffic' across a soil surface, most commonly by humans, animals or machinery. In some cases, compaction is desirable—for example, in the construction of roads—but it is undesirable where plants are grown for agriculture. Within oil palm blocks, compaction is usually caused by machinery and field workers. Harvest paths, the most compacted part of the block, are compacted because of human and wheelbarrow traffic, or by in-field collection tractors. They generally occupy only a small area (6%), but this can be as high as 14% when in-field collection tractors are used (Nelson et al. 2006). The weeded circle is compacted by human activity (harvesting, pruning and weeding), but the degree of compaction is generally much lower than the harvest path; however, the weeded circle represents about 14% of the block area. Root activity is high under the weeded circle, despite compaction, because of close proximity to the palm stem.

## Acidification

Acidification of soil is a natural result of weathering and biological activity in most environments. In landscapes undisturbed by human activity, acidification is largely the result of inefficiencies of nitrogen recycling, which result in leaching losses, atmospheric inputs and mineral weathering. However, these rates of acidification are usually very small compared with rates in agricultural systems. The difference is mostly due to fertiliser input and product export.

In any system, the rate of acidification depends on the balance of acid and alkali additions, commonly referred to as the net acid addition rate (NAAR). Soil pH decline depends on NAAR and the ability of the soil to buffer its pH against this acid addition (commonly referred to as the pH buffering capacity).

### *Net acid addition rate*

The amount of acid added to (or removed from) a system depends on the:

- accumulation (in situ), addition, and export of organic anions, bicarbonate ions, ammonium ions and nitrate ions
- addition of liming materials
- addition and export of hydrogen ions.

Generally in agricultural systems, the contribution of bicarbonate ions and hydrogen ions (except in acid rain) to NAAR is small. The contribution of added liming materials depends on the agricultural system and farm practice. If lime is not applied, the major contributors to NAAR are the balance of nitrogen in the system and the balance of organic anions. In a stable system such as a mature plantation, accumulation of organic matter (in situ) is usually small. Thus, the major influence of organic anions on NAAR is the export of organic materials (FFB) and import of organic materials (EFB, decanter cake, expeller). However, at times of clearing or replanting and early growth in immature plantations, the accumulation (or degradation) of organic acids will have a substantial influence on NAAR.

### *Nitrogen cycle*

The type and amount of nitrogen fertiliser applied, the amount of nitrogen fixed biologically, and the fate of nitrogen derived from these sources have major influences on NAAR. Because many of the processes in the transformation of nitrogen forms in the biological nitrogen cycle involve the production or consumption of hydrogen ions, any changes to nitrogen cycling will influence NAAR (Figure 8).

If we start with 'organic matter' (which includes nitrogen in plant material, soil organisms, soil organic matter and urea fertiliser), its mineralisation to ammonium consumes one hydrogen ion ($H^+$), its subsequent nitrification to nitrate produces two $H^+$, and the uptake of that nitrate into the palm consumes one $H^+$, making the whole process acid neutral (i.e. $-1 + 2 - 1 = 0$). However, if some of

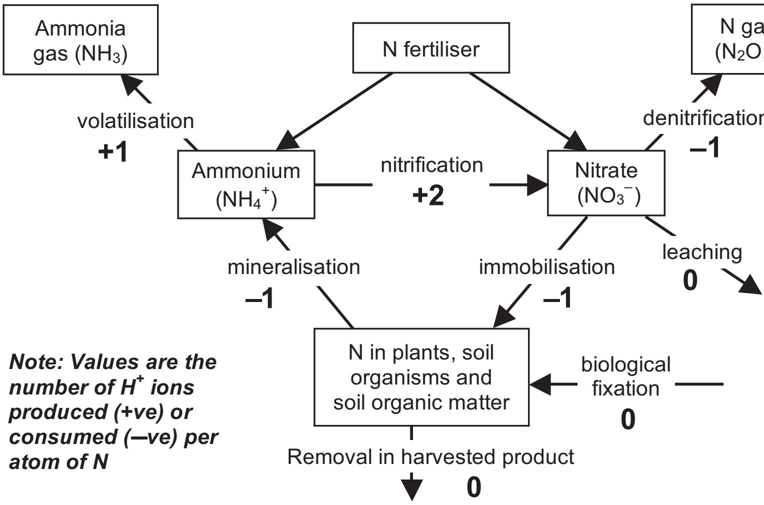



**Figure 8.** Effect of the nitrogen (N) cycle on acid generation

the nitrate is lost through leaching or run-off (a neutral process), this reduces the $H^+$ consumption in the uptake process. For example, if all of the nitrate is lost by leaching, one $H^+$ is produced (i.e. –1 + 2). Similarly, if an ammonium-based fertiliser (e.g. sulfate of ammonia) is used, one $H^+$ is produced, even if there is no loss of nitrate by leaching. Thus, irrespective of the efficiency of nitrate uptake, sulfate of ammonia is always an acidifying fertiliser. Therefore, the choice of nitrogen fertiliser and its application rate has an immediate potential impact on acidification, with the magnitude of that impact dependent on the efficiency of uptake (Table 6).

*Carbon cycle*

Production of soil organic matter is an acidifying process, and its decomposition is an alkalising process. Thus, a closed cycle of production and decomposition of organic matter in situ is a neutral process. If the cycle is interrupted by off-take of product (acidifying) or import of organic residues (e.g. EFB, alkalising), the acidification rate will be affected. The magnitude of that effect will depend on the inorganic cation/anion balance of the organic matter. Since inorganic cations commonly exceed inorganic anions, electrical neutrality requires that the difference is made up of organic anions. The magnitude of organic anion content is often expressed in terms of ash alkalinity, an experimentally determined parameter. Thus, in practice, the contribution of product export to acidification, or organic waste import to alkalisation, is determined by the amount of organic matter and its ash alkalinity.

**Table 6.** Impact of fertiliser application on net acid addition rate at different uptake efficiencies of nitrogen (at 135 palms/ha and 100 kg of nitrogen/ha)

| Fertiliser | Fertiliser application rate (kg/palm) | Acid production if all nitrogen taken up by palms (kmol $H^+$/ha ) | Acid production if all nitrogen lost by leaching (kmol $H^+$/ha) |
|---|---|---|---|
| Ammonium sulfate | 3.5 | 7.1 | 14.3 |
| Ammonium chloride | 3.0 | 7.1 | 14.3 |
| Ammonium nitrate | 2.1 | 0.0 | 7.1 |
| Diammonium phosphate | 4.1 | 3.6 | 10.7 |
| Urea | 1.6 | 0.0 | 7.1 |

ha = hectare; kg = kilogram; kmol = kilomole

In most agricultural systems, the contribution of the nitrogen cycle (in particular, nitrate leaching) to NAAR is much greater than the contribution of product export. However, in oil palm, NAAR due to FFB export may be considerable. Given typical FFB yields (18–30 t/ha) and cation contents (potassium plus calcium plus magnesium contents of 0.15–0.30 $kmol_c$/t), the NAAR due to FFB export (assuming no return of EFB) can be estimated at approximately 3–9 kmol $H^+$/ha per year.

*pH buffering capacity*

The effect on soil pH of acid addition (NAAR) into a system depends on the soil's pH buffering capacity (pHBC). In an unbuffered solution (e.g. pure water), addition of a strong acid results in complete dissociation to $H^+$ and the associated anion. Thus, all of the acid added has an effect on pH (the concentration of $H^+$ ions in solution). However, in the complex environment of a soil, there are many potential reactions, such that the amount of added acid does not linearly affect the $H^+$ concentration of the soil solution. In other words, some of the added $H^+$ ions are 'mopped up' by other reactions and therefore do not contribute to pH change. A simple example is that of dissolution of calcium carbonate by acid. If acid is added to a solution saturated with calcium carbonate and a solid phase of excess calcium carbonate, the $H^+$ ions are completely consumed by the reaction; thus, they do not contribute to the $H^+$ of the solution and do not result in reduced pH.

Although most of the soils of concern in PNG do not contain free carbonates, many other reactions consume $H^+$ ions added to the system (Nelson and Su 2010). For example, $H^+$ ions might replace calcium ions ($Ca^{2+}$) on a cation exchange site on clay or organic matter, or react with the weak organic acids in organic matter. As suggested by these examples, pHBC is often related to the magnitude of cation exchange capacity (CEC) and organic matter content in a soil. Indeed, these two parameters, once calibrated, are often used to estimate pHBC in the absence of direct measurements. At very low pH (around 4), addition of $H^+$ may result in the dissolution of clay minerals. Although this dissolution buffers pH effectively, it is irreversible; any amelioration to increase pH (e.g. liming) will not restore the dissolved clay.

A strong buffering capacity is generally regarded as a good feature of a soil, as it makes the soil resilient to pH change and its consequences, such as reduced availability of many nutrients. However, this resilience works in both directions—the higher the pHBC of soil, the more effort will be required to raise its pH, which is a disadvantage if the soil's pH is too low. In general, a high pHBC allows greater flexibility and tolerance in management, but is not a substitute for long-term good agronomic practices that minimise NAAR.

*Consequences of pH change, especially decline*

Many soil reactions and root processes, including nutrient availability and uptake by plant roots, are pH dependent. Most plant species grow well in environments between pH 5.5 and 7.0. Outside this range, adverse conditions can inhibit productivity. At low pH (below 5.5), aluminium ions ($Al^{3+}$) from clay begin to come into solution. Aluminium is not required by plants, and $Al^{3+}$ can have many detrimental effects on plants for a number of related reasons—for example, it can affect the uptake of calcium ions and other nutrients. However, oil palm and commonly used leguminous cover crops are relatively tolerant of acidic conditions, growing well down to soil pH values of approximately 4.5 (Auxtero and Shamshuddin 1991; von Uexküll and Mutert 1995; Fageria et al. 2009).

Low pH also reduces the CEC of variably charged soils, which are common in the tropics. A reduction in CEC results in lowered cation nutrient holding capacity. The $H^+$ and $Al^{3+}$ ions also displace the nutrient cations (e.g. calcium, potassium, magnesium, zinc, copper) from the cation exchange sites. Both of these actions make the cations vulnerable to leaching loss. While it might be possible to restore pH and CEC though interventions such as liming with materials such as calcium carbonate, this will not return those nutrients to previous levels, except for the calcium. Indeed, the increased concentrations of exchangeable calcium, with now diminished levels of other cations, may exacerbate the situation. Low pH may also increase retention of phosphorus by soil surfaces, thus restricting phosphorus availability to palms and increasing the cost of any remedial activity. One potentially positive effect of lowered pH in some soils is the potential increase in anion exchange capacity and hence reduced leaching of nitrate (Wong et al. 1990).

All of these consequences may result in decreased primary productivity, both above and below ground. This decrease in productivity will ultimately affect soil organic matter contents, which will further exacerbate nutrient cycling and retention.

Thus, in oil palm, as in other agricultural systems, it is better to maintain a healthy pH through well-managed strategies than to rely on remediation after degradation.

### Organic matter

Soil organic matter has many roles in soil health, and soil organic matter content is one of the main determinants of soil fertility in the tropics. It is sensitive to management and is closely linked to balances of water, carbon and nutrients. The presence of organic matter in soils improves water infiltration and aeration through its support of soil biological activity, especially macrofauna, and also through its direct effects on soil structure and structural stability.

Organic matter also has a number of roles in soil chemistry. It is a good source of nutrients and the main reservoir of nitrogen, sulfur and phosphorus. This is particularly important for nitrogen and sulfur, as the mineral forms of these elements are usually anions, and most soils, including those in oil palm growing areas of PNG, have a very low anion exchange capacity. For nitrogen, a soil organic matter content of 1–5% in the 0–10 cm layer (which covers the range of most oil palm growing soils in PNG) is equivalent to about 1,000–5,000 kg of nitrogen/ha. This nitrogen is released as the organic matter decomposes, providing a slow release form of nitrogen, which is important in soils with a high infiltration rate and high rainfall.

Organic matter, through its organic acids, also has a high CEC and is thus important in the retention and supply of macronutrient cations (such as calcium, magnesium and potassium), as well as many of the micronutrient cations. Also, through its organic acids, organic matter contributes to the pHBC of the soil. Indeed, on a weight-for-weight basis, it contributes far more than clay.

A well-maintained mature plantation will have a stable (but constantly cycling) soil organic matter content; sometimes as much as 5–10% by weight, depending on the management zone. However, at times of major disturbance such as replanting, the soil organic matter is highly vulnerable to rapid decomposition, with subsequent loss of its stored carbon, nutrients, CEC and pHBC. During such periods, strategies should be put in place to minimise organic matter decline.

## Health of aquatic ecosystems

Water quality (‘good’, ‘poor’ etc.) will have different interpretations for different users of that water. Changes to water quality can affect entire landscapes and the biological systems within them. These include effects on the health of humans, streams, estuaries and the ocean, as well as the health of the oil palm enterprise itself (including gardens and domestic animals).

During its pathway from atmosphere to ocean, water will pass through many ‘uses’ and affect those uses as well as being affected by them. As water moves along this pathway, many factors affect water quality.

One critical problem for large-scale land-based agriculture is how to minimise collateral impacts to adjacent ecosystems. Human-induced degradation of PNG’s coral reef ecosystems is emerging as a serious problem (Munday 2004). Unfortunately, it is impossible to determine the exact source of damage because of:

- the limitations of current technology and data
- spatial separation of the impacts from their specific terrestrial sources
- the difficulty of differentiating local-level impacts from the broad-scale effects of climate change (P. Munday, pers. comm.).

Impacts on PNG’s other coastal aquatic ecosystems (estuaries and freshwater streams) are also reported regularly, but these reports are generally anecdotal rather than being based on hard data. Definitive studies of coastal ecosystems are urgently needed, and would provide multiple benefits in the context of sustainability of the oil palm industry. The proximity of coastal streams and oil palm plantations allows direct evaluation of impacts and confers the ability to attribute impacts to specific sources. As well, these coastal streams are the primary conduits through which stressors likely to affect coastal reefs are transported. Consequently, studying estuaries and freshwater streams provides the joint benefits of safeguarding these systems and contributing to an evaluation of the impacts of specific terrestrial sources on offshore habitats. This would provide a sound basis for monitoring, management and mitigation.

### Nutrients

Most nutrients of interest are water soluble and can be supplied in many ways (e.g. soil weathering, fertiliser application, nitrogen fixation, decomposition of organic matter). For a healthy and productive palm field, adequate supply of nutrients is essential. The supply of nutrients to palm roots is via water, either passively along with water uptake, or actively through generation of diffusion gradients. In either case, the soil water must contain dissolved nutrients. If the dissolved nutrients are not taken up by palms or other vegetation, they may be vulnerable to loss from the oil palm block and may become a source of contamination, thus lowering water quality, for other systems that use the water.

The two main pathways by which nutrients are lost from the oil palm ecosystem are through leaching and overland flow (Domagalski et al. 2006, 2008); both of these pathways eventually contribute to stream water or directly to the ocean (depending on soil properties and proximity to the coast). Water that leaches nutrients by percolating through the soil to groundwater may also affect groundwater-dependent ecosystems (some wetlands) and drinking water from village wells.

In PNG, many nutrients are retained strongly by the soil. Most added nutrient phosphorus, potassium and magnesium is strongly fixed by the soil under palms and not lost to the surrounding environment. The exception is nitrogen. There can be a substantial loss of nitrogen through leaching of nitrate, which may enter groundwater and thus streams and the ocean. However, because of the high rainfall and the size of the catchments above the oil palm blocks, there would be substantial dilution of the nitrogen reaching large streams or the ocean. Additionally, the retention of nitrate in subsoils, mentioned earlier, may limit the movement of fertiliser-derived nitrogen to water bodies. For smaller streams with slow water flow within plantations, nitrogen concentrations are likely to be of concern at times.

## Herbicides

Herbicides that have little residual effect once they come in contact with soil are now the most commonly used herbicides. However, it is still necessary to consider the effect of herbicide application and pathways of movement. Herbicides are usually used only to keep the weeded circle and harvest path clear of vegetation, and selectively on hard weeds growing in the inter-rows. If they are inappropriately applied, they may damage wanted groundcover or the palms themselves. This is particularly relevant to young palms with low-hanging fronds. If handled inappropriately, they may also be hazardous to oil palm workers. Similar to nutrients, herbicides may end up in streams or the ocean via

Health of aquatic and marine habitats, including those downstream of oil palm plantations, is critical for local people (Photo: Tibor Dombovári) groundwater and overland flow (Scribner et al. 2007; Borggard and Gimsing 2008). If the compounds are still active and in sufficient concentration, they may damage the freshwater and marine vegetation, thus affecting food chains. They may also affect groundwater-dependent ecosystems (some wetlands) and drinking water from village wells.

In PNG, herbicides are unlikely to move into water bodies in significant quantities. Most of the herbicides used decompose rapidly on contact with soil. The main herbicide used in PNG is glyphosate. Also used, in lesser amounts, are metsulfuron, 2,4D amine, and some Basta® (active ingredient glufosinate-ammonium) and Garlon® (active ingredient triclopyr) on trees. These products are applied along with sticking and wetting agents.

Herbicide use is less common on smallholder blocks than on plantations as the cost of herbicide is generally prohibitive for smallholders, and weed control by slashing can be sufficient. Also, because it is difficult to ensure adequate training in herbicide handling, storage, disposal and personal protection, neither plantation companies nor OPIC supply herbicide to smallholders.

## Insecticides and fungicides

Similar to herbicides, insecticides may have a direct effect on (untargeted) terrestrial organisms or follow the pathway of water into streams and the ocean via groundwater or overland flow (Schottler et al. 1994), or via atmospheric transport by rain and wind (Rawn 1999). In this case, however, the chemical may also have direct impacts on aquatic and marine fauna. There are potential effects on human health through drinking water or consumption of exposed animals.

In PNG, insecticides are unlikely to move from fields into water bodies in significant quantities, but movement from nurseries is more likely. There is minimal use of insecticides in the field because of the resistance of oil palm to many pests, and an active and successful strategy of integrated pest management. Most of the insecticide that is used is injected into the truck and thus is unlikely to escape to the environment. Methamidaphos is the chemical used for trunk injection, but it is likely to be banned in the near future, so alternatives are being sought by PNGOPRA. A chemical being used in Indonesia for the same purpose is dimehypo (also called bisultap). For bad outbreaks of *Oryctes* beetles in young palms, granular carbofuran is used occasionally, applied to the axil. For general caterpillars, *Bacillus thuringiensis* may be used in the Dipel® formulation, or homemade viral/fungal suspensions.

Significant use of insecticides occurs only in the nurseries. The main insecticide used there is Orthene® (active ingredient acephate), as a general broad-spectrum insecticide, or synthetic pyrethroids. A few fungicides are also used in the nurseries, mostly thiram (protectant) and thiabendazole (systemic). Rat bait (warfarin) is used in some plantations. There are reports of pesticides being stolen from plantations and being used instead of natural poisons to poison streams for fishing. This sort of problem can only be dealt with by improved security.

## Other water-soluble contaminants

Other water-soluble contaminants include chemicals (e.g. arsenic, lead and other toxic elements, organic compounds) that are not regarded as nutrients essential for biological growth. They can travel by the same mechanisms as nutrients and thus cause their own specific environmental damage or health problems in the same places in the landscape as nutrients. These chemicals may be a result of agricultural industries (e.g. mill wastes for oil palm) or extractive industries such as forest logging or mining.

## Sediment

Sediment derived from soil erosion influences aquatic ecosystems. Two types of sediment need to be considered separately:

- sediments that contribute to bedload—that is, the heavier particles such as sand and gravel that are moved by water but not at the same speed as the water travels
- suspended sediments, which generally travel at the same speed as the water and only settle out of the water column when the velocity of the water falls considerably (usually in estuaries or the ocean), or precipitate out when the chemical composition of the water body changes (again, usually in estuaries or the ocean).

### *Bedload*

The contribution to bedload is usually from eroding stream banks and gully formation, or from catastrophic events such as landslips. The likelihood of such events can be linked to the management of the surrounding landscapes, including changes to hydrology, and the management of soil cover, slope and riparian zones. It could be argued that bedload is not a water quality issue per se, as some may not consider it part of the water column in the same way as suspended sediments and dissolved chemicals. However, movement of bedload by water can result in changes to the stream bed (e.g. filling in of pools and holes) and thus affect habitat, especially for macro-fauna. Indeed, severe events such as landslips can result in a complete infilling of streams and creation of new stream courses. Even if the bedload is not affected by the planting of oil palm, extraction of gravel for road material associated with oil palm cultivation can change stream habitats and generate sediment.

*Suspended sediment*

Finer sediments are maintained in the water column by turbulent flow and travel at almost the same velocity as the water. They can be generated by the same mechanisms as bedload, and by erosion caused by overland flow. Unlike soluble chemicals (nutrients, herbicides, pesticides and other soluble contaminants), suspended sediments are not an issue for groundwater because of the filtering and trapping properties of soil. Thus, they do not pose an issue for drinking water from wells or delivery to streams or the ocean via groundwater. However, when the sediments settle or precipitate, they can cover vegetation (seaweed, seagrass) or fauna (corals etc.), reducing light penetration and thus primary productivity. Some sediments may also carry nutrients, which can be released and have the same effects as soluble nutrients.

*Supply of sediment in oil palm growing areas of PNG*

Because of high soil permeability in most oil palm growing areas of PNG, there is little surface run-off and thus little erosion from blocks. Erosion has the potential to be a problem at certain times, such as at planting or replanting and road construction. It can also occur in mature plantings with dense canopy and poor groundcover, and on steeper slopes without terracing, especially if there is poor orientation of harvest paths and frond piles. In some areas, particularly Navo, erosion from roads is considerable due to high soil erodibility and inappropriate road design and construction.

## Other stream health issues

Environmental factors such as connectivity of water bodies, depth and persistence of pools, water temperatures and microhabitats are often affected by agricultural practices. For example, management of

Stream bank erosion in an oil palm plantation in West New Britain (Photo: Paul Nelson) riparian vegetation affects shading of streams and thus water temperature. Removal of riparian trees will reduce the accumulated debris (logs, branches, leaves), which will affect microhabitats and nutrient inputs (Campbell and Doeg 1989). Similarly, management of vegetation and the soil surface can affect infiltration and run-off and thus the 'peakiness' and base-flow of streams.

Management of the landscape, under oil palm or other uses, has the potential to affect the health of the landscape, the resources in it, the health of those who depend on it and the health of landscapes nearby. However, although it is possible to identify sources of poor water quality, perceived or otherwise, it is not so easy to determine the biological outcomes of a particular environmental stressor. Stressors, as indicated by the intensity and/or duration of impact, may produce very different outcomes depending on the stressor in question and the indicator being measured—for example, water quality, number of species or environmental process (Figure 9). A stressor at a particular level could have no effect, a proportionate effect, a threshold effect or many other patterns of effect, depending on the environment, climate, species, habitat or other factors.

Many of these processes and the effects of stressors have been studied in other environments. Such knowledge cannot easily be translated directly to the tropics because of the generally greater level of biological diversity and thus complexity and responses in tropical systems (Sheaves et al. 2007). Although some of the guiding principles will prove valuable, research is needed to underpin candidate indicators of issues such as water quality, and its impact on stream and estuary health.

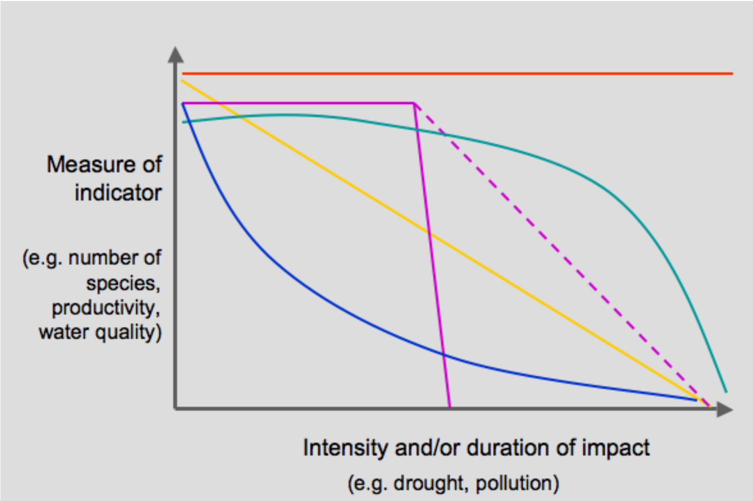



**Figure 9.** Theoretical responses of environmental indicators to stressors in an aquatic environment; responses will vary in pattern, trajectory and outcome depending on the stressor in question and the indicator being measured. Different line colours indicate different responses. (Source: R.G. Pearson, James Cook University)

# Indicators of environmental sustainability, and research needs

## Indicator purpose and qualities

In order to assess sustainability, we need measurable indicators. However, the world is awash with sustainability indicators that are not being used in practice. So it is worthwhile to revisit the purpose and requirements of indicators. The primary purpose is twofold:

- to guide management by growers—the indicator must provide evidence that the resource is being maintained, that there will be a sustainable income from oil palm, and that there will be flexibility for future activities (such as other crops, conservation, tourism)
- to provide evidence of sustainability to non-growers—the indicator must provide satisfactory evidence that production is not harming the environment.

It is useful to differentiate environmental sustainability 'indicators' and 'data inputs'. Lack of clear separation between these terms has been at least part of the reason for the difficulty in defining sustainability indices (not discounting the many other major challenges). 'Indicators' are defined here as the quantities that are reported, and that can be derived from one or more 'data inputs'. Indicators must relate clearly to environmental issues, whereas the data inputs are preferably simple to measure (Table 7). It is best if the data inputs used are already available, such as records of yield or fertiliser use. The links between data inputs and indicators need to be scientifically valid, and as simple and transparent as possible. In some cases, crop or environment models may be useful, particularly where there are complex interactions, such as in nutrient balances.

A considerable amount of data is already available or being collected that is useful for assessing environmental sustainability. In some cases, the data are already used for that purpose, whereas in others they could be used for that purpose. Data are available:

- in static form, such as maps of soil types, topography and oil palm locations

**Table 7.** Desirable qualities for data inputs, indicators and the links between them (calculations)

| Data inputs | Links | Indicators |
|---|---|---|
| • Simple and cheap to measure<br>• Preferably already recorded<br>• Require no equipment, or little and robust equipment | • Scientifically valid<br>• Transparent and easy to explain | • Relate clearly to environmental issues<br>• Directly applicable to Roundtable on Sustainable Palm Oil auditing<br>• Detect trends over time<br>• Identify good vs bad areas<br>• Enable assessment of environmental and economic costs and benefits of changes in management<br>• Easily communicated to and understood by different stakeholders, especially smallholder growers, extension officers and plantation managers, being comprised of simple, easy-to-understand numbers, or being easy to interpret visually<br>• Integrate with existing tools (e.g. databases, accounting software) |

- in monitoring programs and records, such as yield records; climate records; leaf and soil analyses; water analyses (normally carried out upstream and downstream from plantations as a legislative requirement for the Department of Environment and Conservation); purchase records of fuel, fertiliser and pesticides; and visual inspection records of cover crops, erosion scores etc., recorded in oil palm management databases
- in the results of research projects and field trials.

There are many opportunities and challenges with using the available data. For example, soil analysis data are potentially very useful for analysing trends, but they suffer from large variability in soil properties and nutrient contents between management zones (Banabas 2007; Webb et al. 2009). Properly accounting for this variability is a major challenge for soil monitoring programs.

Many environmental sustainability indicators have been developed for particular ecosystem properties and functions or for particular industries. One Australian example is the set of indicator protocols or guidelines for soil condition, aquatic habitats, and estuarine, coastal and marine habitats, derived from the National Land and Water Resources Audit (NLWRA 2008). Several systems are currently in use or being developed for oil palm, including the Unilever system (Pretty et al. 2008) and the INDIGO® system of the Institut National de la Recherche Agronomique (INRA), which is being developed for oil palm by PT SMART and other collaborators (Caliman et al. 2005, 2006; Girardin et al. 2007; Caliman 2008). The Unilever system consists of 10 indicators: soil fertility and health (soil organic matter and soil compaction), soil loss, nutrients, pest management, biodiversity, value chain, energy, water, social and human capital, and local economy. The INDIGO® method is based on a matrix that crosses agricultural practices and the components of the agroecosystem. Nitrogen and pesticide indicators have been developed for oil palm (Caliman et al. 2006). Both of the oil palm systems take various risks into account to assess various environmental impacts.

Indicators differ in complexity and degree of integration. At one extreme is a collection of single-issue indicators (e.g. the farm sustainability dashboard by Spherical Matrix 2007, Figure 10), and at the other is a combined indicator. In combined indicators, the component indicators are

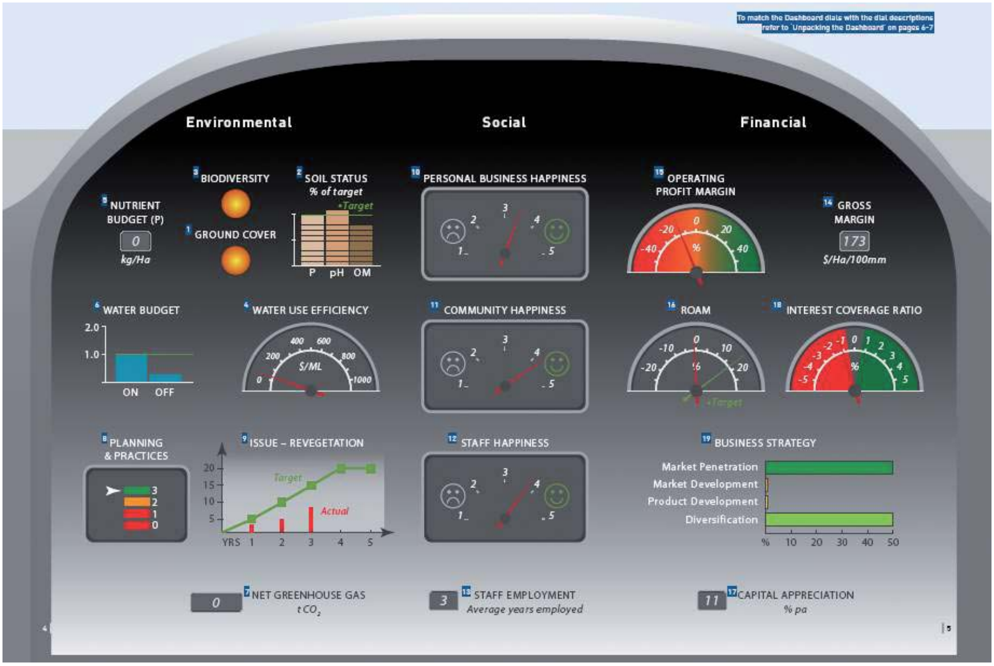



**Figure 10.** The 'farm sustainability dashboard' developed for southern Australian grain farms (Source: Spherical Matrix 2007)

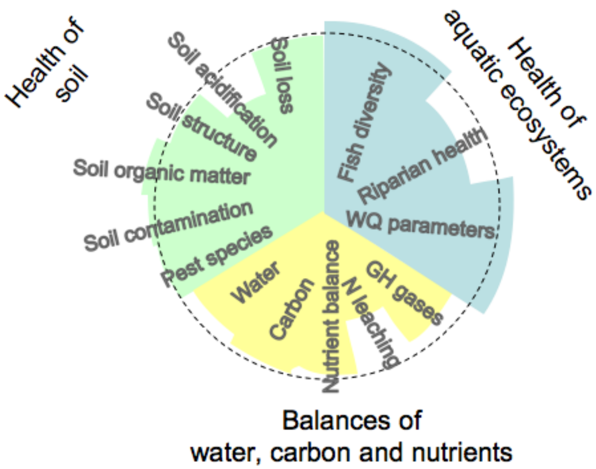
weighted in some way, either deliberately or by default, according to the number of indicators assigned to any particular issue. Having multiple single indicators can make it difficult to assess the whole picture, whereas combined indicators can be misleading or uninformative if it is not clear how they were calculated.

One way of combining indicators in a transparent way is to look at them all separately but at the same time. An example is the AMOEBA indicator concept developed for fisheries (Bell and Morse 2008). A hypothetical adaptation for oil palm is shown in Figure 11. The larger the coloured area, the higher the sustainability rating, which gives an immediate visual impression of overall sustainability. The dotted circle is a baseline or reference point, which can have different types of values for different types of indicators. Each wedge is an environmental sustainability issue. If a wedge reaches or passes the dotted line, it can be considered sustainable. The width of the wedges can be made proportional to the perceived importance of the issue. This allows a weighting scheme that is visual, unlike numerical weighting schemes. The indicator diagram could be produced at different temporal or spatial scales—for example, once a year for every smallholder division or plantation estate, or once for every stage of the crop cycle, and then one for the whole crop cycle, weighted for the length of time in each stage. This issue of scaling or aggregating is an important one. In some cases, it may be meaningful to aggregate using area-weighted means; in others, aggregation may obscure important issues; and in yet others, aggregation may not be necessary—for example, for aquatic ecosystem health, where indicators will already integrate upstream areas. Another issue is the expression of variability. It may be feasible to add a measure of variability to each indicator (i.e. each wedge of the diagram in Figure 11).

A further consideration for indicators is whether they are expressed as absolutes or relative to risk. For example, soil loss can be expressed in absolute terms or relative to the potential erosion in that particular environment. Either way, the risk component (e.g. soil erodibility, topography and rainfall erosivity) needs to be assessed together with the management component.

As discussed earlier, indicators can be expressed in environmental terms alone (direction and rate of change, or value/area) or relative to production. The former allows the manager to decide possible trade-offs between productivity and sustainability, and to decide what is the most appropriate measure of productivity to consider, so it is probably preferable.

When discussing indicators in relation to the RSPO, it is necessary to further define the term ‘indicator’. For the RSPO auditing process, management performance is already assessed against ‘indicators’. However, the definition of ‘indicator’ in the RSPO principles and criteria (RSPO 2007) is different from the definition used here. The RSPO



GH = greenhouse; N = nitrogen; WQ = water quality

**Figure 11.** A hypothetical integrated sustainability indicator for oil palm

indicators can be defined as 'plans, practices or monitoring programs to achieve a particular criterion'. The oil palm industry has identified a need to underpin the RSPO indicators, particularly those to do with soil and water, with indicators as defined in this report: a measurable value of a rate or quality used to define trend in or state of land/water/system properties.

Finally, a note about the validity of schemes for evaluating environmental sustainability. In a comparative study of five commonly used schemes, Galan et al. (2007) found that they sometimes produced completely different results. Following another review of methods, Payraudeau and van der Werf (2005) concluded that the method should be validated with respect to the:

- conception of the indicators
- consistency of the values of the indicators in relation to observed values
- suitability of the method and indicators to end users.

Potential environmental sustainability indicators for the PNG oil palm industry were discussed at a workshop in West New Britain in February 2009, and the outcomes of the workshop are summarised in the following sections. Some of the indicators could be developed using a 'desktop' study approach. Others will require different levels of research, both in the laboratory and in the field, in order to understand the underlying processes and to develop meaningful surrogates for difficult-to-measure parameters.

# Balances of carbon and energy

Carbon sequestration and carbon dioxide emissions are large and highly variable throughout the oil palm life cycle (clearing to planting to mature oil palm to replanting). The mill process is an integral component of any palm oil production system and contributes to emissions; it should therefore be included in a carbon balance study for oil palm production (Table 8).

## Relevance to smallholders

Carbon balance is relevant to environmental certification of smallholders in terms of carbon footprint and may affect a premium.

## Researchable topics

*Field carbon and energy balance*

- Validation of vegetative measurements for biomass estimation.
- Biomass production and carbon sequestration from seedling to mature phase (oil palm and understorey).
- Below-ground biomass studies.
- Carbon dioxide and greenhouse gas production under different phases, management, soil types.
- Develop model for field inputs and outputs applicable to PNG.
- Quantify energy inputs in fertilisers and fuel (and labour?).

**Table 8.** Research required to produce indicators of carbon balance

| Study | Reason | Potential stressor | Where |
|---|---|---|---|
| Net primary production and decomposition | Carbon sequestration and loss, greenhouse gas emissions (carbon dioxide and methane) | Phases of oil palm with low inputs and high loss of carbon (planting, immature, felling to replanting), limitations to yield such as nutrient deficiency | In blocks, during different phases |
| Mill carbon and energy balance | Loss of carbon in greenhouse gases (carbon dioxide and methane), contribution of by-products to in-field carbon balance | Fuel use, inefficient processes | Inputs to and outputs from the mill |
| Field carbon and energy balance | Is oil palm a net energy fixer or a net energy consumer? Input to life cycle analysis | High fertiliser use, high fuel use, limitations to oil yield such as nutrient deficiency | Inputs to and outputs from the field |

*Mill carbon and energy balance*

- How significant are these outputs and can they be reduced?

### Possible indicators

- Annual biomass increment.
- Modelling estimates of carbon balance, using climate, site and management factors.
- Audit of energy inputs in fertiliser and fuel.

## Balances of nutrients

Nitrogen drives agricultural production systems (above and below ground). Generally, if nitrogen management is poor, then leaching losses, soil acidification and greenhouse gas emissions are high, and/or production may be low. Although much is known about the nitrogen cycle in agricultural production systems, in oil palm many of the nitrogen inputs (biological nitrogen fixation in particular) and outputs (gaseous emissions and leaching) are not well understood. Other nutrients (primarily phosphorus and potassium) are also applied as fertilisers in oil palm and need to be studied in relation to losses (Table 9).

### Relevance to smallholders

If nitrogen inputs from legume cover plants can be quantified and management practices that optimise nitrogen fixation can be developed, this will directly benefit smallholders through reduced nitrogen fertiliser inputs.

Fertiliser recovery efficiency is not directly measurable on smallholder blocks (requires large fertiliser trials), but partial nutrient balances (fertiliser in versus FFB out) are achievable at division scale and possibly at block scale. The limitation at block scale is the difficulty of obtaining accurate yields (and thus nutrient exports) due to shifting of crop between growers.

### Researchable topics

*Nitrogen fixation by legume cover crops*

- How much nitrogen is fixed? Relationship with shade (plantation age), season, soil nitrate, availability of other nutrients (especially phosphorus, magnesium, sulfur, cobalt, molybdenum and iron). Include below-ground component. Use appropriate methods from Unkovich et al. (2008).
- What is the fate of nitrogen fixed by legumes?
- Relationship between nitrogen fixed and more easily assessed indicators, such as legume dry-matter production, nodulation.

*Leaching of nitrate*

- Measure leaching of nitrate (and other nutrients).

**Table 9.** Research required to produce indicators of nutrient balances

| Study | Reason | Potential stressor | Where |
|---|---|---|---|
| Biological nitrogen fixation by legume cover crop | Cheap biological source of nitrogen (with particular reference to smallholders); unknown level of fixation | Poor sowing/planting or maintenance of cover crop, shade, fertiliser use | In block in different phases (planting, immature, mature, felling to replanting) |
| Leaching loss of nitrate | Leaching is loss (inefficient); contributes to soil acidification; potential to result in reduction in water quality | Soil type, fertiliser use, timing of application, soil conditions for acidification | In block |
| Greenhouse gas emissions | Losses as nitrous oxide, potential for volatilisation (inefficient use and wastage) | Soil type, poor drainage, nitrogen fertiliser types, timing of application, oversupply | In block |
| Fertiliser recovery efficiency | Integrated measure of efficient nutrient supply (fertiliser use) | Limitations to production, excessive fertiliser use, poor application practices | In block |
| Partial nutrient balances | Production may be mining nutrients or causing imbalances | Inadequate or excessive inputs of particular nutrients | Block or division scale |

- Link to timing of fertiliser application (huge industry interest in this).
- Nutrients in fronds (especially nitrogen, phosphorus, potassium), potential for leaching and losses.
- Root activity profile.

*Greenhouse gas emissions*

- Measure nitrous oxide production from using different nitrogen fertiliser types and other site and management factors.
- Assess total greenhouse gas emissions from nitrogen fertiliser use (including production costs in greenhouse gas emissions).

*Nutrient balance and fertiliser recovery efficiency*

- Assess nutrient balance by the nutrient use efficiency and fertiliser recovery efficiency approaches, using PNGOPRA trials on a range of soil types and management practices in PNG.
- Assess whether this approach is valid in relation to actual leaching of nutrients (i.e. quantify leaching of nutrients in key locations and compare with results from nutrient use efficiency and fertiliser recovery efficiency).
- Amounts and rates of returns and losses of nutrients in pruned fronds and felled palms (at the replanting phase).

### Possible indicators

- Partial nutrient balance or nutrient use efficiency calculation, using yield, biomass (from vegetative measurements) and fertiliser input data.
- Visual scoring of cover crop for biological nitrogen fixation estimate.
- Nutrient concentrations and discharge measurements in streams.
- Model leaching and gaseous losses, using climate and fertiliser input data.

## Health of soil and soil loss

Soil degradation (chemical, physical and biological) results in a reduction in the capacity of soils to produce plant products and clean water. Oil palm cultivation could cause soil degradation through inappropriate fertiliser use, mechanisation of some in-field practices and a reduction in cover, especially during development or replanting phases. Although biological health is critical, it is largely determined by organic matter, pH and physical properties (Table 10).

### Relevance to smallholders

- It is vital to keep production high and options open for productive use of land for subsequent crops. A 'healthy' soil is more likely to provide the nutrients required for profitable palm

**Table 10.** Research required to produce indicators of soil health and soil loss

| Study | Reason | Potential stressor | Where |
|---|---|---|---|
| Soil pH and acidification | Integrated measure of soil health (chemical and biological); directly affects capacity of soils to retain and supply nutrients | Fertiliser use, lack of cover (increased potential for leaching) | In block |
| Soil organic matter | Integrated measure of soil health (chemical and biological); carbon sequestration | Low inputs of organic matter (in some zones); lack of cover (increased potential for soil loss) | In block |
| Soil loss | Potential loss of nutrients and organic matter and source for stream sedimentation | Lack of cover and distribution of mill by-products and frond placement; impact of roads | In block, roads, streams |
| Porosity | Integrated measure of soil health (physical and biological) | Mechanisation | In block (harvest path) |
| Cover | Affects soil loss, organic matter input, nutrient recycling | Shade, excessive weeding | In block |

production. A degraded soil will require higher fertiliser inputs at a higher cost to produce and sustain oil palm production.
- Many of the individual components of soil health will be easily understood by smallholders (agrarian communities) and can be presented in written and spoken format at field days and other smallholder activities organised by OPIC.
- It may not be possible to measure on every block, but measurements on particular soil types and under particular management scenarios will probably be applicable to divisions.

### Researchable topics

*Soil pH*
- Soil pH spatial distribution (different zones and relevance to nutrient uptake), and effects of shifts (or not) in zones during replanting.
- Rate and process of acidification in different zones and management practices, especially fertiliser management, and possibly using a paired site approach.
- Assess potential prevention or amelioration options.

*Soil organic matter*
- Biomass production (phases in oil palm from seedling to mature); biomass loss (felling and replanting).
- Changes in soil organic matter content over oil palm life cycle.
- Verify published relationships between vegetative measurements and biomass.
- Impact on soil organic matter content from mill by-products and placement (e.g. EFB, decanter cake).
- Soil organic matter decomposition rates and factors affecting it.
- Modelling so that changes in soil organic matter can be predicted from environmental and management inputs.
- Possible indicators of soil fertility such as silicon cycling, leaf analyses.
- Strong link to 'carbon and energy balance indicator'.

*Soil erosion*
- Desktop study of suitability of USLE (universal soil loss equation) and to formulate minimum slope lengths and cover criteria.
- Assess effects of preventative measures (e.g. orientation of frond piles and harvest paths).
- Assess erosion score criteria (evidence of sheet erosion, rills etc., cover).

*Porosity*
- Effects of mechanisation on penetration resistance, hydraulic conductivity and water balance, aeration.

*Cover*
- Relate cover (relatively easily assessed) to processes such as soil loss, nitrogen input by legumes, organic matter input, nutrient recycling.

### Possible indicators

- See carbon balance indicators.
- See nutrient balance indicators.
- Scoring of canopy cover, groundcover, slope, soil infiltration, alignment of frond stack and harvest paths, road design (including drains, culverts, road material and road edging).
- Soil pH: routine, reproducible, simple and cheap, related to nutrient availability and retention, aluminium toxicity.
- Soil organic matter: very important, but difficult to measure simply, so high variability and sample numbers become an issue.

## Health of aquatic ecosystems

Contaminants (nutrients, sediments, pesticides) flowing from oil palm plantations (including smallholder blocks) could degrade water quality, which affects the biodiversity of freshwater streams, estuaries and coastal habitats, including reefs. Management of riparian vegetation is also likely to affect aquatic ecosystem health (Table 11).

### Relevance to smallholders

Local communities depend on freshwater streams and wells for their clean water supply. Fishing in estuaries and off coral reefs provides an important food source.

The scale of measurement can take in divisions.

### Researchable topics

*For all topics above*
- Assess meaningfulness in oil palm context.
- Consider targeted study to measure pesticides downstream (or down gradient in the case of groundwater) at time of herbicide, insecticide or rodenticide application.

### Possible indicators

- Turbidity and concentrations of nutrients, problematic micro-organisms and contaminants in water (passive or active sampling). For herbicides and insecticides, could use lowest detectable concentration as critical value.
- Isotopic signature of nutrient source in fish and invertebrates.
- Diversity of invertebrates and fish.
- Visual scoring of in-stream, estuarine and coastal habitats.
- See nutrient balance indicators.

## Modelling approaches for integration and prediction

Assessing the environmental sustainability of oil palm production systems requires quantification of the state of, and trends in, plant, soil, water and land attributes. On-site and off-site monitoring over time, using quantifiable indicators, is the basis of any sustainability assessment. Projection of long-term trends and prediction of likely system permutations are also essential, both for current management by smallholders and plantations and for the future viability and reputation of the industry. For example, climatic variability will affect the likelihood of adverse impacts on sustainability. Soil variability will result in different demands for plantation management. The combined impact of soil and climatic variability is likely to lead to uncertainty in recommendations garnered from short-term studies conducted at a small set of locations. Such a small sample may not be adequate to develop broad recommendations. Furthermore, where results are variable or difficult to interpret due to soil or climatic variability, it can be hard to inform management unless the underlying mechanisms are clearly understood.

For these reasons, process-based modelling approaches are regularly used to analyse production systems. Models developed and tested for these purposes allow decision-makers to explore uncertainty in their measurements, impacts of a wider range of climatic conditions, likely responses on differing soil types, and even a wider range of possible management options, including

**Table 11.** Research required to produce indicators of aquatic ecosystem health

| Study | Reason | Potential stressor | Where |
|---|---|---|---|
| Stream insect biodiversity (family/order level richness) | Integrated measure of stream health | Chemicals, sediments, riparian change | Upstream and downstream of plantation and mill |
| Freshwater fish biodiversity | Integrated measure of stream health | Chemicals, sediments, riparian change | Upstream and downstream of plantation and mill |
| Estuary fish biodiversity | Parallels work in freshwater and represents the downstream end of the potential impact sequence | Chemicals, sediments, riparian change | Upstream and downstream of plantation and mill |
| Stable isotope composition of tissues of aquatic fauna | Assess incorporation of fertiliser nitrogen into food webs, and screen for faecal nitrogen that could complicate detection of nitrogen eutrophication | Nitrogen fertiliser | Small samples of fish and invertebrates collected annually from diversity sampling sites |
| Microchemistry of bivalve shells and fish otolith | Screen for heavy metal contamination | Metal contaminants | Small samples of fish and invertebrates collected annually from diversity sampling sites |
| Habitat studies (visual/video and sonar—large streams only) | Evaluate extent of habitat for icon endemic fish (black bass, spot tail) | Reduction in provision of habitat provided by fallen timber due to loss of riparian forest | All accessible sites |

novel scenarios that are yet to be fully trialled in the field.

System modelling is now among the standard tools employed by agricultural industries worldwide to assess land-use assessments and performance. Crop system models such as APSIM (Keating et al. 2003) can potentially provide quantification of the production and environmental trade-offs (drainage, leaching, erosion and acidification) for specific areas where oil palm is grown. APSIM is well suited to yield gap analyses and could be employed in action learning activities with OPIC extension staff, smallholders and plantation managers. Other similar crop system models that have been developed for oil palm include OPRODSIM (Henson et al. 2007) and WaNuLCAS (van Noordwijk and Lusiana 1999; van Noordwijk et al. 2001).

Catchment-scale processes, such as effects of land management on erosion and water quality, are not simulated well by crop system models alone, but can be integrated and simulated using models such as Watercast (eWater CRC 2008), MIKE SHE (Hughes and Liu 2008) or the Water Erosion Prediction Project (Nearing et al. 1989).

# Conclusions and recommendations

## Conclusions

The oil palm industry in PNG has put a high priority on environmental sustainability, demonstrated by the participation of all PNG growers and millers in the RSPO, and the involvement of all the companies and smallholders (through OPIC) in the production of this report.

Much of the contention about the environmental sustainability of oil palm centres around the destruction of forests, rather than the growing of oil palm per se. As a perennial adapted to the wet tropics, oil palm can be cultivated sustainably in the coastal lowlands of PNG, provided that attention is given to the issues discussed in this report. Good environmental management of oil palm cultivation is more readily achievable than for less vigorous or shorter lived crops.

Environmental sustainability issues can be categorised in many ways. This document suggests a categorisation scheme based on the spatial and temporal dimensions of environmental processes. The categories are planning and biodiversity; balances of water, carbon, energy, nutrients, greenhouse gases and soil; and health of soil and aquatic ecosystems.

The relationship between planning and biodiversity is a critical issue for PNG. The area of planted oil palm is small compared with Indonesia and Malaysia, and the rate of expansion is small compared with Indonesia. Although there are restrictions to the rate of expansion, including physical geography and land tenure, the future expansion of the industry in relation to the conservation of lowland forests and surrounding ecosystems must be considered at regional and national levels. However, planning issues were beyond the scope of this report; it focuses on the effects of oil palm cultivation on soil, water and the atmosphere.

Balances of water, carbon and energy in established oil palm are generally favourable (similar to forest), except for substantial losses of carbon to the atmosphere when forest is converted to oil palm. Throughout most of the growing cycle, oil palm has large rates of net primary productivity and carbon sequestration. The carbon balance during replanting is largely unknown.

Nutrient balances differ between oil palm and other vegetation cover, with high inputs and exports from oil palm. Fertilisers must be applied and/or legumes grown to sustain productivity. Ideally, these additions would exactly balance the uptake by biomass and the losses in product. However, losses of nutrients—particularly nitrogen—to the environment occur. Erosion losses appear to be small, but loss of nitrate via leaching is known to be significant in some situations. Gaseous losses of nitrogen may also be important, including the loss of nitrous oxide, a greenhouse gas. The amount of biological nitrogen fixation that occurs through the crop cycle, and the losses of nitrogen by leaching and as gas, are the least understood and potentially most environmentally sensitive nutrient balance issues.

Maintenance of soil health in oil palm blocks is critical for sustainability. Soil erosion, which is potentially the most destructive influence on soil health, is generally low in PNG oil palm blocks. It can be minimised by good planning, encouraging good groundcover and good design of roads. The main threat to soil health appears to be acidification, resulting from the removal of cations and loss by leaching of nitrate derived from ammonium-based fertilisers and biological nitrogen fixation.

The quality of water and the health of aquatic ecosystems are likely to be affected by losses of nutrients, particularly nitrogen, from oil palm cultivation. The magnitudes of the effects are unknown and are likely to be highly variable in space and time; they are also affected by dilution in flows from upstream of oil palm plantations. Losses of sediments from oil palm blocks appear to be small, but effects of enhanced stream bank erosion and sand extraction operations may be significant. Losses of pesticides are likely to be small, given their targeted use (weeded circle for herbicides and trunk injection for insecticides, and nurseries).

There is a need for practical and scientifically based indicators of environmental sustainability to underpin the RSPO certification and to guide improvements in management.

## Recommendations

In order to ensure and improve environmental sustainability of oil palm cultivation into the future, the PNG oil palm industry, together with scientific collaborators and funding providers, should have the following aims:

1. Identify the main risks and the options for managing risks to environmental sustainability in and around smallholder oil palm blocks and plantations, with particular reference to soil and water resources.
2. Develop environmental sustainability indicators (measurable values of a rate or quality used to define trend in or state of land/water/system properties) for oil palm in PNG. These indicators will underpin the RSPO indicators (plans, practices or monitoring programs to achieve particular criteria). The indicators should be meaningful, scientifically sound, practical, quantitative, appropriate, auditable, achievable, and easily communicated to, and understood by, different stakeholders (especially smallholder growers, extension officers and plantation managers). They should be aimed at assessing environmental sustainability and recommending best management practices. Where necessary, research should be carried out to produce the indicators.
3. Establish and implement management practices that ensure environmental sustainability while maximising productivity. This will include knowledge transfer to smallholders, OPIC extension staff and plantation managers.
4. Continuously assess and improve the procedures used to maximise environmental sustainability.

# Appendix

## Nutrient balance measurements in Milne Bay

A detailed analysis of nutrient balance in oil palm in PNG was undertaken on one of PNGOPRA's trial sites at Sagarai in Milne Bay province in 2007 (trial 504). The trial was a nitrogen × potassium fertiliser trial with four treatment rates of nitrogen and potassium. Each treatment was replicated four times, for a total of 64 plots. Each plot consisted of 16 monitored palms and was surrounded by a guard row (to separate treatments between plots and reduce nutrient poaching by palms between plots). Treatments were applied from 1995 to 2007.

Nutrient uptake and nutrient use efficiency (NUE) were calculated. NUE has several components, including yield or agronomic efficiency, which is the amount of extra yield per unit of fertiliser nutrient applied. It is the product of uptake or recovery efficiency (extra nutrient uptake per unit of fertiliser nutrient applied) and conversion or physiological efficiency (extra yield per unit of extra nutrient taken up).

To calculate nutrient uptake and NUE, the following were measured:

- Nutrient content of tissues produced (FFB, leaflet, rachis and trunk). For the FFB, bunches from each treatment were analysed, because it is highly likely that treatments will affect nutrient content of FFB. For the leaflet and rachis, samples of frond 17 were analysed (one frond from each palm, combined into one sample per plot). For the trunk, cores were taken and analysed.
- Annual biomass production (FFB, new fronds and trunk new growth). Biomass increment was calculated from vegetative measurements (e.g. number and dimensions of new fronds, change in trunk height) and previously established allometric relationships.

### Results for trial 504 in 2007

Six treatments were assessed, including the control plots (Table A1). Nutrient uptake is shown in Table A2. Nutrients in leaflets, rachis and core are stored within the palm and become available when the fronds are pruned or after felling, when the fronds and trunk decompose to organic matter. However, nutrients in bunches are exported from the plantation. In some areas on the plantation, a component of these nutrients is returned as EFB, but EFB are not used at the location of this trial. Table A3 shows the amount of nutrients exported from the field as a percentage of total nutrient uptake.

**Table A1.** Annual nutrient supply for each of the six treatments used for nutrient use efficiency calculations

| Treatment (kg fertiliser/palm) | Nutrients supplied per palm (kg/palm) | | | Nutrients supplied per hectare (kg/ha) | | |
|---|---|---|---|---|---|---|
| | N | K | P | N | K | P |
| SOA: 0; MOP: 0 | 0 | 0 | 0.11 | 0 | 0 | 13 |
| SOA: 2; MOP: 2.5 | 0.41 | 1.28 | 0.11 | 53 | 162 | 13 |
| SOA: 4; MOP: 2.5 | 0.84 | 1.28 | 0.11 | 107 | 162 | 13 |
| SOA: 6; MOP: 2.5 | 1.26 | 1.28 | 0.11 | 160 | 162 | 13 |
| SOA: 6; MOP: 5 | 1.89 | 2.56 | 0.11 | 160 | 324 | 13 |
| SOA: 6; MOP: 7.5 | 1.89 | 3.84 | 0.11 | 160 | 486 | 13 |

ha = hectare; K = potassium; kg = kilogram; MOP = muriate of potash (potassium chloride, 49% K); N = nitrogen; P = phosphorus; SOA = sulfate of ammonium (21% N)

**Table A2.** Mean nitrogen, potassium and phosphorus uptake in leaflets, rachis, fresh fruit bunches and trunk (growth increment over 2007) for six treatments in trial 504

| Treatment (kg fertiliser/palm) | Leaflets (kg/ha) | | | Rachis (kg/ha) | | | FFB (kg/ha) | | | Trunk (kg/ha) | | | Total (kg/ha) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | K | P | N | K | P | N | K | P | N | K | P | N | K | P |
| SOA: 0; MOP: 0 | 109 | 26 | 7 | 23 | 52 | 17 | 86 | 93 | 23 | 5 | 8 | 2 | 224 | 180 | 49 |
| SOA: 2; MOP: 2.5 | 131 | 32 | 9 | 28 | 125 | 19 | 109 | 124 | 27 | 7 | 15 | 2 | 275 | 296 | 57 |
| SOA: 4; MOP: 2.5 | 144 | 37 | 9 | 29 | 153 | 22 | 126 | 128 | 23 | 12 | 15 | 3 | 310 | 334 | 57 |
| SOA: 6; MOP: 2.5 | 139 | 36 | 9 | 28 | 165 | 24 | 134 | 146 | 23 | 13 | 14 | 2 | 313 | 361 | 58 |
| SOA: 6; MOP: 5 | 160 | 39 | 10 | 34 | 179 | 20 | 114 | 141 | 20 | 11 | 15 | 2 | 318 | 375 | 52 |
| SOA: 6; MOP: 7.5 | 158 | 39 | 10 | 34 | 171 | 19 | 133 | 154 | 22 | 12 | 19 | 2 | 337 | 382 | 53 |

FFB = fresh fruit bunches; ha = hectare; K = potassium; kg = kilogram; MOP = muriate of potash (potassium chloride, 49% K); N = nitrogen; P = phosphorus; SOA = sulfate of ammonium (21% N)

**Table A3.** Export of nutrients from the field in fresh fruit bunches

| Treatment (kg fertiliser/ palm) | Nutrients exported (as % of total uptake) | | |
|---|---|---|---|
| | N | K | P |
| SOA: 0; MOP: 0 | 39 | 52 | 46 |
| SOA: 2; MOP: 2.5 | 39 | 42 | 47 |
| SOA: 4; MOP: 2.5 | 40 | 38 | 41 |
| SOA: 6; MOP: 2.5 | 43 | 40 | 39 |
| SOA: 6; MOP: 5 | 36 | 38 | 38 |
| SOA: 6; MOP: 7.5 | 39 | 40 | 42 |

ha = hectare; K = potassium; kg = kilogram; MOP = muriate of potash (potassium chloride, 49% K); N = nitrogen; P = phosphorus; SOA = sulfate of ammonium (21% N)

**Table A4.** Nutrient recovery efficiency for fertiliser-applied nitrogen and potassium in trial 504, 2007

| Treatment (kg fertiliser/palm ) | Nutrient recovery efficiency (uptake as % of applied) | |
|---|---|---|
| | N | K |
| SOA: 2 MOP: 2.5 | 96 | 72 |
| SOA: 4; MOP: 2.5 | 81 | 95 |
| SOA: 6; MOP: 2.5 | 56 | 112 |
| SOA: 6; MOP: 5 | 59 | 60 |
| SOA: 6; MOP: 7.5 | 70 | 42 |

K = potassium; kg = kilogram; MOP = muriate of potash (potassium chloride, 49% K); N = nitrogen; SOA = sulfate of ammonium (21% N)

Recovery efficiency of the applied nitrogen and potassium was high at low application rates and decreased as more fertiliser was applied (Table A4). For example, nitrogen recovery was 96% at the lowest application rate, but 81% when the application rate was doubled. Recovery efficiency of nitrogen was influenced by potassium application, and vice versa. At high application rates of nitrogen (6 kg/palm as sulfate of ammonium), recovery efficiency of nitrogen was increased from 56% to 70% by the addition of potassium. Similarly, recovery efficiency of potassium was improved by the application of nitrogen. High yields (34 t/ha) were obtained at an sulfate of ammonium rate of 6 kg/palm and an muriate of potash rate of 2.5 kg/palm.

# Conclusions

At normal plantation rates of fertiliser application (equivalent to 4 kg sulfate of ammonium/palm plus 2.5 kg muriate of potash/palm), there was a high uptake of applied nutrients at this site (80% of applied nitrogen and more than 90% of the applied potassium was taken up by the palm).

Further work is required on the rate of cycling of nutrients returned to the field in pruned fronds. In addition, at felling, a potentially large store of applied nutrients (stored in the trunks and foliage) is released; the fate of this sudden burst of released nutrients has to be investigated.

To provide a realistic understanding of the fate of nutrients in oil palm, a nutrient balance study should be undertaken over the life of oil palm, not just as a snapshot in a mature plantation.

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