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Alternative Oil Palm Fertilizer Sources and Management

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ABSTRACT

The euphoric sentiment of the oil palm industry in 2007 till first half of 2008, generated by the historic high prices of crude palm oil (CPO) as influenced by the price escalation of fossil fuel and biofuel, has very quickly vaporized and been replaced by an awakening call for prudence. Inorganic fertilizer prices soared concurrently to historic high levels as well. Notwithstanding the problem of uncertainty that led to non-timely supply and delivery, the cost of fertilizer inputs in oil palm plantations has doubled to 50%-60% of the cost of fresh fruit bunch (FFB) production. Profitability of the oil palm plantation business is consequently squeezed as the business remains as a price taker for its produce and the purchase of inorganic fertilizers. The Malaysian oil palm industry's dependence on inorganic fertilizer imports can only be partially mitigated by the use of organic fertilizers produced within the country. Recycling of solid and liquid wastes from palm oil mills is the logical alternative, and accepted as a standard good agricultural practice in the industry. There are, however, some obvious limitations in their utilization which must not be overlooked, particularly when the industry is moving toward sustainable development. The industry in Malaysia is poised to adopt a wholesome green technology approach with several options that can achieve multiple objectives. Co-composting of empty fruit bunches (EFB) and palm oil mill effluent (POME) has the highest attractiveness while at the same time the compost/organic fertilizer produced can be applied over a much bigger area, especially in those areas of poorer growing conditions, that can benefit significantly in growth/yield as compared to what may be expected from the current EFB mulching and irrigation with treated POME. Concurrently, biogas capture with and without generation of renewable energy enhances CO_2 emission reduction above the criterion of 35% as set by the EU Commission on Renewable Energy. Thus, palm oil will qualify as a feedstock for biofuel in the European market. The continuation of the clean development mechanism (CDM) beyond 2012 with the carbon credit incentive is critical for more ready adoption by the industry members. Composting systems and usage of compost for substitution of inorganic fertilizer, and the impact of compost on yield enhancement are described in the article. The 4 Rs approach to fertilizer management is also discussed in relation to compost usage. The oil palm industry is strongly urged to adopt the good agricultural practice of establishing leguminous cover crops for N fixation without fail in all new plantings/replantings. The choice of Mucuna bracteata *over other conventional leguminous cover crops is strongly emphasized for reasons discussed. The potential usage of bio-char, derivable from the oil palm biomass, is also highlighted as an area of research that can lead to its future exploitation for soil fertility improvement and long-term sequestration of CO_2 in the soil.*

ABSTRAK

Sentimen euforia industri sawit yang timbul pada tahun 2007 sehingga separuh pertama 2008, kerana peningkatan harga minyak sawit mentah (CPO) yang tertinggi dalam sejarah dan juga dipengaruhi oleh peningkatan harga bahan api fosil serta bio bahan api, lenyap dengan pantas dan diganti pula dengan kesedaran untuk berhati-hati. Harga baja bukan organik (kimia/mineral) melambung naik ke paras yang tertinggi dalam sejarah. Di samping itu, masalah ketidakpastian pembekalan dan penghantaran baja yang tidak tepat pada waktunya telah menyebabkan kos input baja di ladang sawit meningkat ke 50%-60% dari kos penghasilan tandan buah segar (FFB). Keuntungan dalam perniagaan perladangan sawit akibatnya menguncup lanjutan dari kekangan kawalan kos pengeluaran hasil dan pembelian baja kimia/mineral.

Kebergantungan industri sawit Malaysia pada baja kimia/mineral yang diimport hanya boleh dikurangkan sebahagiannya melalui penggunaan baja organik yang dihasilkan di dalam negara. Kitaran semula sisa-sisa cecair dan pejal dari kilang-kilang minyak sawit merupakan alternatif yang mu-

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nasabah dan diterima sebagai satu amalan pertanian piawai dalam industri. Walau bagaimanapun, terdapat kekangan yang jelas dalam penggunaannya, dan perlu diberi perhatian memandangkan industri sawit perlu bergerak untuk mencapai pembangunan mampan.

Industri sawit menghampiri kepada penggunaan kaedah teknologi hijau yang sihat dengan pelbagai pilihan untuk mencapai berbilang objektif. Tandan kosong buah (EFB) yang dikomposkan bersama efluen kilang minyak sawit (POME) merupakan pilihan utama. Kompos yang dihasilkan boleh digunakan untuk keluasan yang lebih besar, terutamanya dalam keadaan persekitaran pertumbuhan yang tidak subur di mana ia boleh memberi faedah dengan ketara dalam pertumbuhan/hasil berbanding dengan kaedah sungkupan EFB dan pengairan dengan POME yang dirawat. Dalam masa yang sama, pengumpulan biogas untuk atau tanpa penjanaan tenaga yang boleh dibaharui boleh mendorong penurunan pelepasan CO_2 *sebanyak 35% sepertimana yang telah ditetapkan oleh Suruhanjaya Kesatuan Eropah ke atas sumber tenaga boleh dibaharui. Oleh itu, minyak sawit layak sebagai bahan bekalan bio bahan api di pasaran Eropah. Perlanjutan mekanisme pembangunan bersih (CDM) selepas 2012 bersama insentif kredit karbon adalah kritikal bagi kegunaan industri. Sistem pengkomposan dan penggunaan kompos untuk menggantikan baja kimia dan kesannya ke atas pertambahan hasil dihuraikan dalam artikel ini. Pendekatan 4R merujuk kepada pengurusan baja dan berkaitan dengan penggunaan kompos turut dibincangkan.*

Industri sawit disarankan agar menggunakan amalan pertanian yang baik dalam penanaman kekacang tutup bumi untuk mengikat N dan menyuburkan tanah di semua kawasan tanaman baru/penanaman semula sawit. Pemilihan Mucuna bracteata *sebagai tanaman kekacang tutup bumi berbanding dengan tanaman kekacang konvensional yang lain dijelaskan dengan terperinci. Potensi penggunaan bio-char yang boleh didapati dari biojisim sawit juga ditekankan sebagai satu bidang penyelidikan yang boleh membawa pembaikan kesuburan tanah pada masa hadapan dan pensekuesteran* CO_2 *di dalam tanah untuk jangkamasa panjang.*

Keywords: fertilizer management, composting system, recycling of biomass, NuFes system, bio-char.

INTRODUCTION

The palm oil industry is one of the largest economic pillars of Malaysia. In 2008, the entire industry generated some RM 65.2 billion revenue for the nation, thanks to the historic high prices of palm oil during the year. The industry is just as important to our neighbouring country, Indonesia, the global leader in palm oil production. The issue of biofuel has inadvertently led to the coupling of crude palm oil (CPO) prices with fossil fuel prices temporarily during the same period. The run-up of petroleum prices to peak at USD 174 per barrel in July 2008 had caused the CPO prices to peak earlier at RM 4300 t^{-1} in March 2008. This had led the Malaysian government to reintroduce the policy of imposing additional cess (over and above the research cess of RM 11 + RM 4 t^{-1} of palm and kernel oil) to subsidize the price of cooking oil for the domestic market as well as the windfall tax. Along with this development, the prices of inorganic fertilizers, some of which are petroleum by-products, have skyrocketed. Prices of inorganic fertilizers remained exceedingly high unlike in the 1990s and earlier. Cost of manuring has doubled to 50%-60% of the cost of fresh fruit bunch (FFB) production. It became a wake-up call to all plantation owners.

Despite Malaysia being the biggest exporter of palm oil (15.41 million tonnes in 2008) in the world market, palm oil producers are unfortunately mere price takers for their produce. Just like for palm oil in international trade, Malaysia is a price taker for inorganic fertilizers as well. Apart from urea, Malaysia imports nearly all the fertilizers required in the country, although at the global level, Malaysia is just a tiny importer of inorganic fertilizers. According to FIAM (Fertilizer Industry Association of Malaysia) the total quantity of fertilizers imported (4.2 million tonnes) in 2007 was only 2.5% of the world inorganic fertilizer consumption. The oil palm industry consumed more than 75% of these imported fertilizers. As a commercial crop, oil palm cannot be grown profitably without fertilizer inputs, particularly in the tropical belt where Malaysia is located, because the soils are highly weathered and hence, have low inherent soil fertility.

While the world is actively researching into alternative energy and energy efficiency, it is timely too for the oil palm industry to seriously investigate alternative fertilizers and fertilizer efficiency. Unlike the energy sector where tremendous interest, effort and investment are placed on finding alternative energy and energy efficient technologies, the upstream activities of the palm oil industry have focused largely on the physical expansion of plantation area, and much less on the optimization of resources. The phenomenal escalation of fertilizer prices calls for investigation into alternative fertilizers and fertilizer efficiency by R&D personnel. This article discusses the current and potential options available to the industry players and their application in response to the awakening. Equally important is the sustainability of alternative fertilizers in the light of global warming/climate change, an issue which is at the heart of many environmental NGOs.

OIL PALM PLANTATION DEVELOPMENT

The world is blessed with oil palm, a perennial crop that is capable of producing five to eight times more vegetable oil per unit area than any other known annual oilseed crop (*Figure 1*). The attractiveness of the palm oil business has led to the rapid conversion of less profitable rubber/cocoa plantings to oil palm plantations in Malaysia, and the clearing of degraded and logged-over forests in her neighbouring country, Indonesia. Oil palm plantation area in Malaysia has increased from 2.54 million hectares in 1995 to 4.49 million hectares in 2008. A very significant portion of the new oil palm plantings was from ex-rubber/cocoa areas. Physical area expansion was more phenomenal in Indonesia during the same period from 2.02 million hectares in 1995 to 7.01 million hectares in 2008. There is also oil palm plantation development in other countries such as Colombia, Brazil and Papua New Guinea, and those in Central America, tropical Africa and Indo-china. Total global oil palm area is less than 13 million hectares, a tiny fraction as compared to the combined oilseed areas cultivated annually. The combined palm oil exports of just Malaysia and Indonesia account for 60% of the global vegetable oil trade. It is obvious that the issue of sustainability, such as fertilizer usage, is crucial to all vegetable oil growers, and must be properly and adequately managed for a better world.

FERTILIZER CONSUMPTION

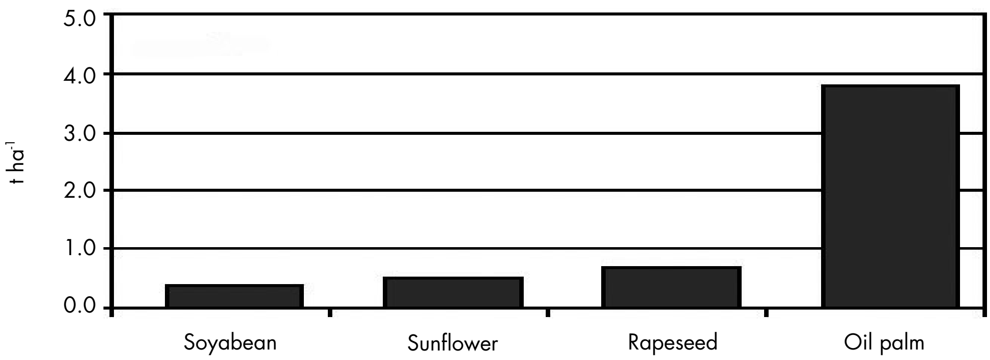
Global Scenario

Global fertilizer consumption is expected to increase as a result of increasing demand for food (as a direct outcome of population growth) and biofuel feedstocks (as the world continues to source for renewal energy). Based on the statistics available from the International Fertilizer Association, global fertilizer consumption in terms of N, P_2O_5 and K_2O will increase by 9.8%, 14.7% and 18.5%, respectively, by 2011/2012 as compared with the actual consumption statistics in 2006/2007 (*Table 1*). However, the forecast was made prior to the global economic crisis in 2008/2009. While the global supply and demand statistics (*Table 2*) continue to project a positive balance situation, there is a forecast of deficits in the supply of P and K fertilizers in the Asia region (*Table 3*). Such uncertainty is obviously of concern in Malaysia, especially in relation to the timely availability of the fertilizers and price escalation as had been experienced in the year 2008 and in early 2009. Malaysia, being a tiny consumer in the global fertilizer trade, is unfortunately not in the best position to negotiate for cheaper prices.

Malaysian Scenario

Apart from limited quantities of urea and ground magnesium limestone, Malaysia has to depend solely on imports to meet her fertilizer requirements. Based on the import statistics available from the Department of Statistics, Malaysia imported an average of 3.834 million tonnes of various fertilizers per year over the period 1998 till 2007, valued at RM 1.81 billion (*Table 4*). Total imports during this period were highest at 4.715 million tonnes in 2005. Since 2004, there has been significant increases in annual total imports of fertilizers as compared with the previous years. This was invariably due to the expansion of the area planted to oil palm in the country.

As may be expected, inorganic fertilizers form the bulk of the total fertilizer consumption in Malaysia. The usage of organic fertilizers has been negligible. Imported organic fertilizers have never exceeded 11 000 t yr^{-1} over the last decade. The quantity of organic fertilizers produced by the lo-



Source: Oil World (2008).

Figure 1. Comparing oil yields of oilseed crops.

TABLE 1. ACTUAL AND PROJECTED GLOBAL FERTILIZER CONSUMPTION (million tonnes nutrients)

Nutrient	2006/2007	2007/2008	2011/2012
N	97.9	100.1	107.5
P_2O_5	38.9	40.0	44.6
K_2O	27.1	28.4	32.1
Total	163.9	168.5	184.2

Source: International Fertilizer Association.

TABLE 2. GLOBAL SUPPLY AND DEMAND OF N, P AND K FERTILIZERS (million tonnes nutrients)

Nutrient	2007	2011
N supply	131.1	154.2
N demand	126.1	137.2
Global N balance	5.0	17.0
P_2O_5 supply	36.8	43.3
P_2O_5 demand	36.0	41.5
Global P_2O_5 balance	0.8	1.8
K_2O supply	38.3	43.2
K_2O demand	32.2	38.4
Global K_2O balance	6.0	6.8

Source: International Fertilizer Association.

TABLE 3. FORECAST ON DEMAND AND SUPPLY OF INORGANIC FERTILIZERS FOR ASIA

	2007/2008	2008/2009	2009/2010	2010/2011	2011/2012
			(thousand tonnes)*		
N supply	72 123	76 317	79 933	85 491	89 850
Total demand	75 255	76 111	77 961	80 413	82 476
Surplus (deficit)	(2 132)	206	1 972	5 078	7 374
P supply	13 882	14 744	15 484	16 185	17 964
Total demand	19 209	19 890	20 560	21 168	21 784
Surplus (deficit)	(5 327)	(5 146)	(5 076)	(4 983)	(3 820)
K supply	5 428	5 524	6 226	6 450	6 530
Total demand	14 485	15 138	15 794	16 464	17 073
Surplus (deficit)	(9 057)	(9 614)	(9 568)	(10 014)	(10 543)

Note: * difference between supply potential and consumption; bracket sign denotes deficit situation.

Source: Current World Fertilizer Trends and Outlook to 2011/2012
http://ftp.fao.org/agl/agll/docs/cwfto11.pdf

TABLE 4. QUANTITIES (x CO^3 t^{-1}) AND VALUES (x 10^6 RM) OF MALAYSIAN FERTILIZER IMPORTS, 1998-2006

Year	Organic		Nitrogenous		Phosphatic		Potassium		Others		Total	
	Quality	Value	Quality	Value	Quality	Value	Quality	Value	Quality	Value	Quality	Value
1998	6.2	5.7	1 115.1	442.9	755.6	230.1	1 168.1	579.5	221.0	169.1	3 266.0	1 427.4
1999	5.0	4.0	1 989.0	431.5	721.6	209.7	1 263.2	629.8	282.2	217.5	4 261.0	1 492.5
2000	2.2	2.5	1 298.5	489.7	717.4	160.4	1 241.0	617.6	304.5	198.5	3 563.4	1 468.6
2001	7.6	3.1	1 399.7	365.3	529.1	135.6	1 013.1	496.8	264.9	143.6	3 214.5	1 144.4
2002	3.7	4.9	1 251.1	491.2	485.0	132.8	1,056.0	513.4	296.7	190.8	3 092.4	1 333.1
2003	6.8	5.3	1 253.2	507.6	617.5	165.3	1 344.4	653.7	222.8	163.2	3 444.7	1 495.0
2004	8.8	9.1	1 645.7	975.9	896.0	274.2	1 637.0	1 114.9	393.1	297.6	4 580.6	2 671.7
2005	8.5	8.6	1 937.6	926.8	1 016.1	278.0	1 273.1	1 079.3	479.5	355.9	4 714.8	2 648.6
2006	11.8	11.1	1 544.1	749.1	802.5	273.5	1 597.3	1 274.0	415.1	343.5	4 370.8	2 651.1
2007e	8.1	17.3	815.0	1 069.6	617.3	361.4	883.3	1 636.9	272.0	491.6	2 595.8	3 576.9
Mean	6.7	6.0	1 492.7	597.8	726.8	206.6	1 288.1	773.2	320.0	231.1	3 834.2	1 814.7

Note: e = estimate (quantity: January - June; value: January - December).
Mean: excludes 2007e.
Others: fertilizers containing various formulations of N, P and K, *etc*.
Source: Department of Statistics, Malaysia

cal manufacturers has been rather limited as well. Moreover, these fertilizers are predominantly used for annual and horticultural crops.

Price Scenario

Prices of petroleum impact both directly and indirectly on the prices of fertilizers. Some nitrogenous fertilizers like urea are by-products of the petroleum industry. In the case of fertilizers which are mined materials like phosphatic rocks, potash and kieserite/magnesite, the cost of fuel influences the mining and processing costs, as well as transport and shipping costs of these fertilizers in the global market. The dramatic increase in fertilizer prices in 2007/2008/2009 was invariably the outcome of the recent escalation of oil and gas prices with the price of petroleum peaking at USD 174 per barrel in July 2008.

As both petroleum and fertilizers from mined materials are non-renewable and exhaustible, one can expect prices of chemical fertilizers to fluctuate violently in years to come. This is an issue of concern that warrants attention. Optimization and efficient usage of fertilizers is undoubtedly a major factor that can have a great impact on the sustainability of agricultural production.

Figure 2 indicates the rising trend of the actual fertilizer prices paid by a plantation group in Malaysia over the last 20 years. Should fertilizer prices continue to rise, the profitability of palm oil will be increasingly squeezed, and the business may even become non-profitable in the following situations when CPO prices are low:

- new plantation development;
- old plantings and young replants; and
- marginal lands with poor site yield potential.

ORGANIC FERTILIZERS AS AN ALTERNATIVE NUTRIENT SOURCE

Organic fertilizers are not something new in the market-place. They have been in use all these years even before oil palm was planted in this country. Unlike inorganic fertilizers which are either mining ores (*e.g.* muriate of potash or MOP, rock phosphate, kieserite) or petroleum by-products (*e.g.* urea), organic fertilizers are mainly animal dungs and composts derived from plant materials/biomass. Essentially both inorganic and organic fertilizers contain plant nutrients (macro- and micro-nutrients) required by plants. The latter are generally 'bulky' due to the presence of organic matter, and contain both macro- and micro-nutrients but in lower content. Conversely, inorganic or chemical fertilizers can neither add to the humus content of soil nor replace it.

Fertilizers are a key cost input in commercial agriculture. Oil palm is no exception. The cost of manuring has increased from 30% in the past to the current level of 50% of the total cost of production which itself has increased very significantly in recent years as given in *Table 5* (Basri *et al*., 2009).

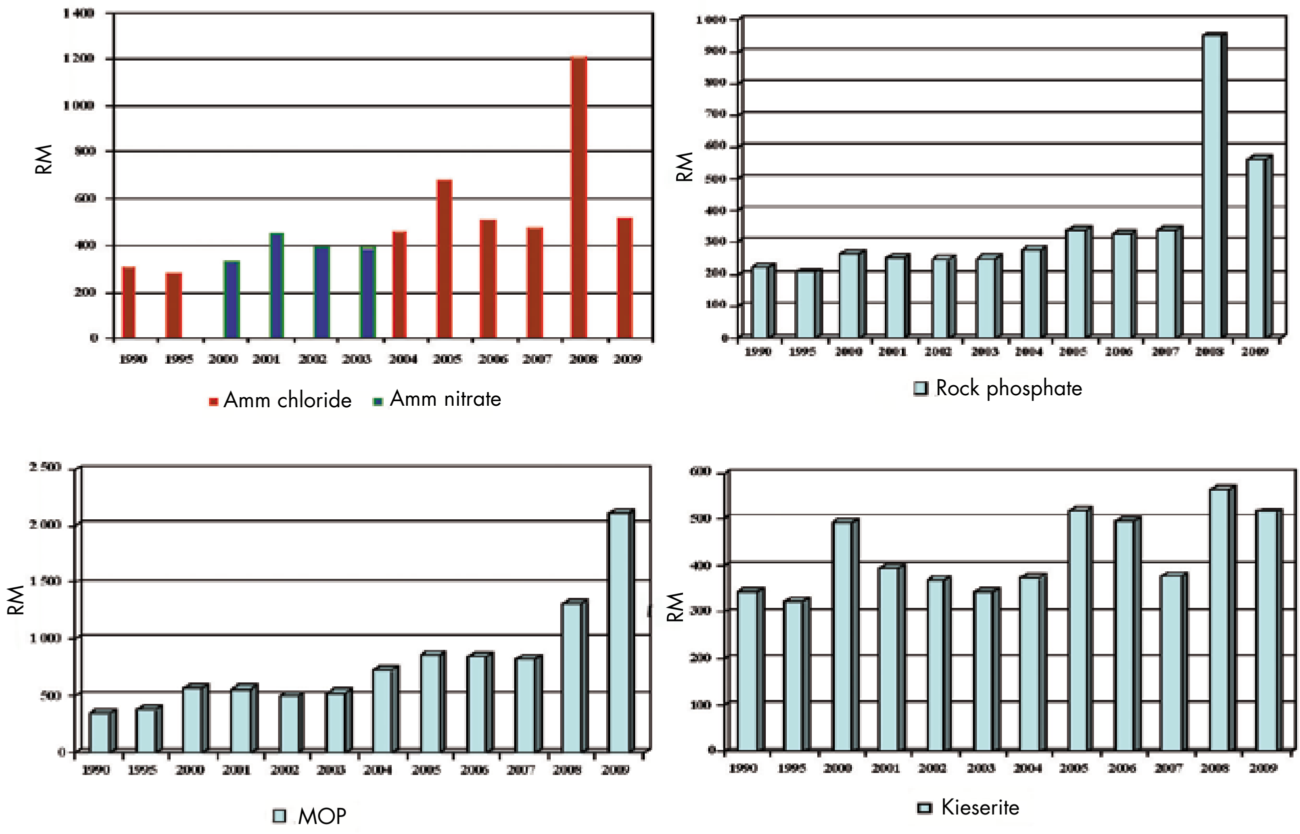


Figure 2. Actual prices (RM t^{-1}) of straight fertilizers as paid by a plantation group.

There are some 400 palm oil mills located throughout the country. Most of these palm oil mills are located within oil palm plantations. The combined quantity of crop processed in 2008 was 90 million tonnes of FFB, giving a total of 17.73 million tonnes CPO. Based on the total CPO production in 2008, some 20 million tonnes of empty fruit bunches (EFB) were available for composting to produce organic fertilizers that can be potentially applied over 1.5 million hectares per year. Until recent years, EFB were either incinerated to produce bunch ash (having about 30% K_2O and trace amounts of micronutrients, and suitable for use as a fertilizer with liming property), or applied as mulch in oil palm fields for nutrient recycling. Due to the environmental concern over air pollution from EFB incineration, bunch ash production is not allowed in the newer mills and is restricted to a limited number of the older mills by the Department of Environment. While mulching with EFB is considered a good agricultural practice, the oil palm industry can in fact derive a far larger benefit both economically and environmentally by co-composting EFB and palm oil mill effluent (POME).

OPTIMIZING THE USE OF OIL PALM BIOMASS

Palm oil contains very little plant nutrients. Almost all the nutrients absorbed or immobilized by the oil palm are retained in its biomass. The various components of the oil palm biomass that are available in the country for the recycling of plant nutrients are given in *Table 6*. Plant and animal matter can be processed to yield power in the form of heat, steam and fuel through burning, pyrolysis, fermentation or extraction. Gasification or/and anaerobic digestion of palm oil mill solid and liquid 'wastes' are possible solutions in generating green energy. This approach is preferred in situations where the energy can be utilized *in situ* (in-house), or conveniently fit into the national grid system. In a situation where palm oil mills are mostly sited away from the national grid system, coupled with the current low fit-in tariff (for SREP), composting of EFB with POME is a logical and sensible option for the industry where the end-product can be utilized to substitute inorganic fertilizers. Biogas capture for energy can still be carried out for use

TABLE 5. FRESH FRUIT BUNCH (FFB) YIELD, COST OF PRODUCTION AND COST OF FERTILIZER APPLICATION IN MALAYSIA

Peninsular Malaysia	2007	2008
Average FFB yield (t ha^{-1})	19.44	19.63
FFB cost of production (RM t^{-1})	160.53	214.04
Fertilizer cost per ha (RM)	852.90	1 989.12
Fertilizer cost per t (RM)	43.87	101.33
% of cost of production	27.33	47.34
Sabah		
Average FFB yield (t ha^{-1})	23.17	23.02
FFB cost of production (RM t^{-1})	136.13	192.51
Fertilizer cost per ha (RM)	1 050.00	2 285.12
Fertilizer cost per tonnes (RM)	45.32	99.27
% of cost of production	33.29	51.56
Sarawak		
Average FFB yield (t ha^{-1})	15.93	16.22
FFB cost of production (RM t^{-1})	172.09	265.31
Fertilizer cost per ha (RM)	948.74	2 470.40
Fertilizer cost per tonnes (RM)	59.56	152.31
% of cost of production	34.61	57.41
Malaysia		
Average FFB yield (t ha^{-1})	19.86	20.21
FFB cost of production (RM t^{-1})	149.14	213.68
Fertilizer cost per ha (RM)	993.94	2 248.21
Fertilizer cost per tonnes (RM)	50.05	111.24
% of cost of production	33.56	52.06

Note: adapted from Basri *et al.* (2009).

TABLE 6. OIL PALM BIOMASS AVAILABLE IN MALAYSIA FOR NUTRIENT RECYCLING BASED ON 2008 STATISTICS FROM MPOB

A	Biomass in plantations*	Dry weight (t ha^{-1})	Total (x 10^6 t yr^{-1})
i)	Trunks @ felling	79.7	14.3
ii)	Fronds @ felling	15.3	2.7
	Total trunks and fronds @ felling	95.0	17.1
iii)	Annual pruning of fronds**	10.7	38.4
B	Biomass @ mills	Dry weight (x 10^6 t)	Fresh weight (x 10^6 t)
i)	EFB @ 22% FFB	6.8	19.3
ii)	Fibre @ 13.5% FFB	7.1	11.8
iii)	Shell @ 5.5% FFB	4.8	4.8
	a) Sterilizer condensate @12% FFB	0.5	10.5
	b) Hydrocyclone sludge @ 50% FFB	2.2	43.9
	c) Hydrocyclone washing @ 5% FFB	0.2	4.4
iv)	Total POME	3.0	58.8

Note: based on: (i) 4.488 million hectares; (ii) replanting @ 4%/year; and (iii) total FFB @ 87.751 million tonnes in 2008.
*Based on the mean of figures reported by Chan *et al*. (1980) and Mohd Husin *et al*. (1986).
**Based on 80% of total area.

in drying the mature compost. Composting itself is a green technology that can lead to zero discharge (Teo, 2003). Incidentally, the environmental regulations of Sabah and Sarawak prohibit the discharge of treated POME into the river course unless biological oxygen demand (BOD) of the treated POME is below 20 ppm, a rather difficult target to achieve indeed. Even for land application, POME with BOD of less than 1000 ppm (that implies a very low nutrient value) is only allowed in Sabah. This is a rather futile irrigation exercise for a state experiencing heavy rainfall for the most part of the year.

Currently, mulching with EFB and land application of treated POME are considered good agricultural practices. Notwithstanding the advantages of the current usage as have been reported (Lim, 1987; Loong *et al.*, 1987; Singh *et al.*, 2009), there are practical drawbacks and limitations in the implementation as listed below compared to compost production and utilization.

Limitations in mulching with EFB:

1. High rising cost of evacuation, transportation and application as a result of rising fuel price.
2. High rates (25-75 t ha yr^{-1}) of application limit the area of coverage.
3. Application restricted to areas which are easily accessible or have good terrain in the vicinity of the palm oil mill.
4. Problem of evacuation during the rainy season and peak crop season.
5. Untimely and poor standards of application (uneven spread in thick layers) leading to:
   a. Very significant losses of soluble nutrients, particularly K (*Table 7*).
   b. Inadvertently creating breeding grounds for *Oryctes rhinoceros*. Chemical control is required in case of severe infestation by this pest that can lead to yield decline (Chung *et al.*, 1991; Wan Zaki *et al*., 2009).
   c. High C/N ratio that leads to immobilization of N in the vicinity of application before the eventual release of nutrients from the biomass. It takes six to nine months for the normal process of decomposition.
   d. Methane emission when applied in flood-prone and high rainfall areas, particularly on clayey soil. Mulching contributes to an insignificant offset in carbon emission.

Equally important is the issue of fulfilling the EU Directive on Renewable Energy (RE) for palm oil to qualify as a feedstock for biofuel. By adopting biogas capture coupled with composting technology, the reduction in CO_2 emission would far exceed the 35% requirement set by the EU Commission on Renewable Energy to qualify palm oil as a feedstock for biofuel. As reported by Choo *et al.* (2002), biodiesel derived from palm oil produces 78% less CO_2 as compared to diesel. In the global effort to limit greenhouse (GHG) emission, the palm oil industry can play an important role by integrating biogas capture from POME and composting of EFB to serve the purpose of GHG reduction while exploiting a fuller benefit of using the resultant organic fertilizer as an alternative to inorganic fertilizer. At the 2009 International Conference on Oil Palm and the Environment, there was a definite urging by the Malaysian Palm Oil Board to adopt these green technologies (Choo *et al*., 2009).

Based on the sustainability development criteria in the host country, Buron *et al.* (2007) have computed the overall utilities (or attractiveness) of CDM projects which utilize palm oil mill by-products in order to reduce GHG emission (*Table 8*). It is clear from *Table 8* that composting and flaring of biogas are, respectively, the most and least feasible projects in terms of sustainability.

To date, most of the CDM projects from Malaysia as approved by UNFCC of the United Nations are based on methane capture and composting as highlighted by Khandhar (2009). The feasibilities of these projects are invariably enhanced with certified emission reduction (CER) revenue. The wait-and-see situation is supposedly over, and it is now time for the industry to act on the basis of economic viability and environmental sustainability. The Malaysian government is also strongly urged to introduce the RE Fund in support of speedier adoption of these green technologies.

COMPOSTING SYSTEMS

There are several commercial composting systems that can be adopted to convert EFB and POME into compost or organic fertilizer (*Appendix 1*). Different systems differ in the degree of usage of EFB and POME, and the maturity period of the compost produced. The principle involved in these different systems is essentially the same as illustrated in *Figure 3*. In the composting process, all the nutrients from EFB and POME are concentrated in the end-product with simultaneous evaporation of moisture from POME. Apart from EFB and POME, inclusion of decanter cake, boiler ash and mesocarp fibre are optional in any composting system. There are both the open system and closed system under a roofing structure. The former requires a bigger land area while the latter is more capital-intensive. For mills that are located in areas having high and frequent rainfall, it is more practical and convenient to adopt a closed system.

TABLE 7. NUTRIENT LOSSES (%) FROM EMPTY FRUIT BUNCHES (EFB) IN FIELD APPLICATION AND STORAGE

Nutrient	Scenario 1	Scenario 2
N	9	24
P	10	22
K	18	42
Mg	8	20
B	ND	28

Note: scenario 1: one week after field application and 33 mm rainfall.
Scenario 2: 15 days of field storage and 129 mm rainfall.
Source: Caliman *et al.* (2001); Saletes *et al.* (2004).

TABLE 8. OVERALL UTILITY OF CLEAN DEVELOPMENT MECHANISM (CDM) PROJECTS IN THE PALM OIL INDUSTRY OF MALAYSIA

CDM project	Overall utility (%)
Compost	46.07
Biogas to electricity	34.23
Biogas to energy	30.64
Biogas to heat	22.82
Biogas to flaring	14.85

Source: Buron *et al.* (2007).

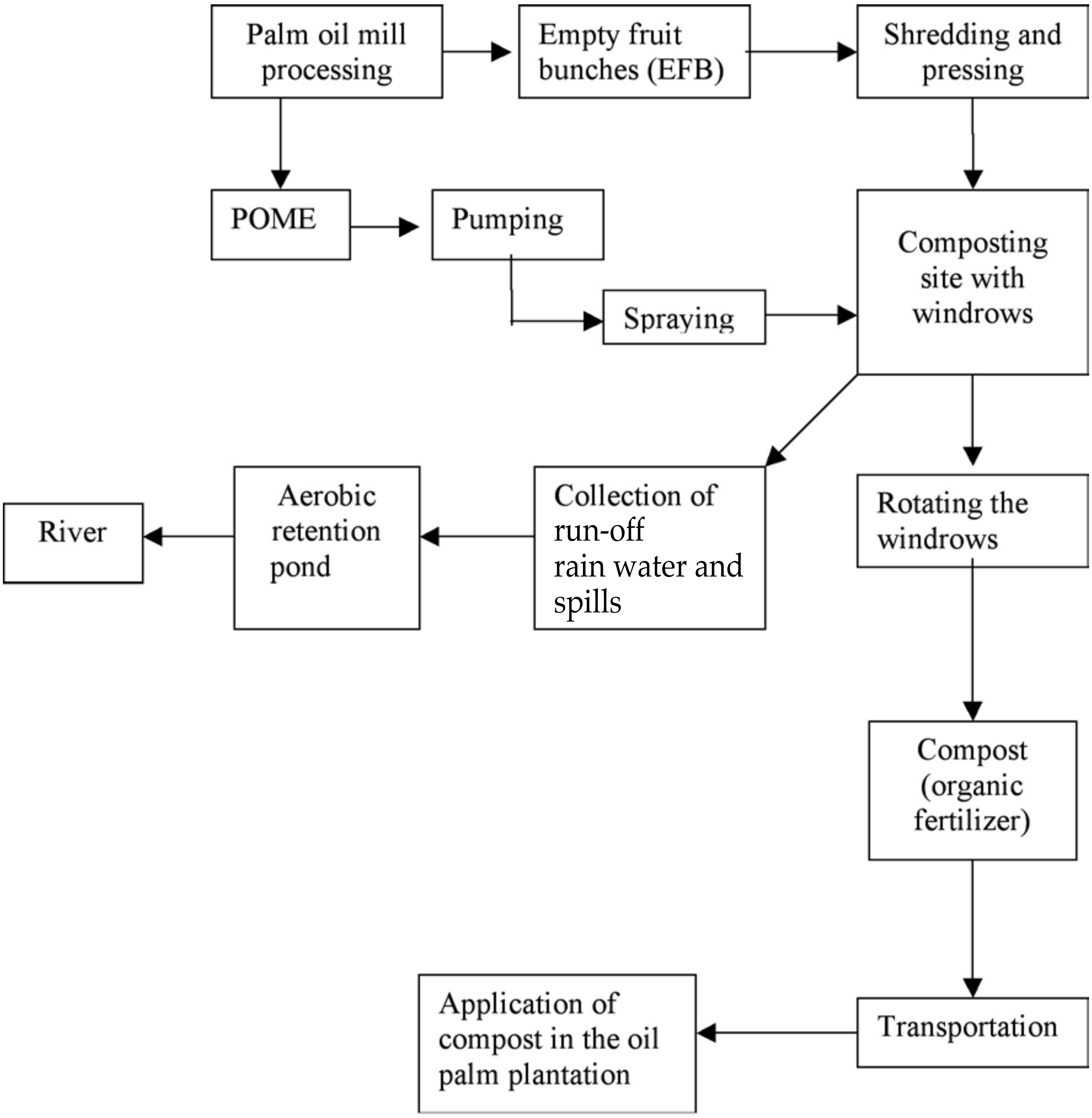


Figure 3. A typical co-composting process of empty fruit bunch (EFB) and palm oil mill effluent (POME).

Described below are two patented systems, open and closed (indoor), that have been adopted by the most number of mills in the country/region thus far. Biogas capture is optional in both systems. For the purpose of producing a better grade compost, vermiculture has been recently introduced as an add-on finishing process to the co-composting of EFB and POME in a similar system (Andrew Liew, pers. comm.)

MIWAMAS System of Composting

Mill Integrated Waste Management Solution (MIWAMAS) is a system for co-composting EFB and POME. It is a locally developed and patented technology exploiting the inherent capability of mesophilic microbes in breaking down the ligno-cellulosic material in EFB. The incorporation of solid and liquid wastes from the palm oil mill provides a good combination of carbon and nitrogen sources for the aerobic microbes to grow, multiply and ultimately transform the raw materials into a useful compost or organic fertilizer. The manufacturing process is potentially a zero waste technology, and offers an abatement of biogas emission from anaerobic treatment ponds.

The manufacturing process of MIWAMAS in the open air is as shown in the schematic *Appendix 1a*. Bulky EFB, instead of being normally transported to oil palm fields for recycling of nutrients in the form of a mulch, are shredded into smaller pieces using a hammer mill. The shredded EFB fibre are then transported to composting platforms, invariably constructed on a very gentle slope, where they are piled up in windrows of 3 m (w) x 1.5 m (h) x 50 m (l). POME is then pumped from anaerobic treatment ponds via an underground piping system and sprayed over the fibre at intermittent intervals. The POME-absorption capacity of the shredded fibre increases with increased size reduction as a result of a bigger surface area. Aerobic microbes are incorporated in the early stage of windrow formation to facilitate the biodegration of the ligno-cellulosic materials. To maintain an optimal composting environment, windrows of decomposing fibre are covered with a special cover that conserves heat yet allows gaseous exchange and evaporation of moisture, and protects against rain water. The composting windrows are thoroughly aerated regularly using a windrow turner which is manufactured locally. Water from POME is evaporated during the composting process while the inherent solids are retained. The amount of POME and the frequency of application over the decomposing fibre and of aeration by the windrow turner are determined by the desired duration of the composting cycle and the maturity of the compost. Temperature, oxygen and moisture content of the composting piles are monitored during the process to ensure a favourable environment for microbial degradation. A 8- to 10-week cycle is adequate to produce a compost grade suitable for application in the oil palm plantation. A longer duration is required should a mature grade of compost be needed for use directly or fortified with inorganic fertilizer.

Integrated Natural Fertilizer (INF) Plant

Unlike MIWAMAS, an INF plant, as the name implies, is a closed system having a roof structure over silos where shredded EFB undergo the aerobic composting process. The system is geared for the production of a higher grade compost for use with and without fortification by inorganic fertilizers based on a preferred formulation. In this system, the composting cycle is shorter (normally six weeks), and hence only 30%-40% of the available POME from conventional palm oil mills is utilized. Palm oil mills having advanced oil separation technologies with zero dilution water (*e.g.* 'ECO-D' system) and continuous sterilization of FFB that results in less water usage, and thus volume of POME which is smaller by some 30% to 60% (Schuchardt *et al.*, 2008), would have an advantage to integrate with an INF fertilizer plant.

Typically EFB from the mill are transferred by a conveyor belt to the shredding station (*Appendix 1b*). Daily loads of shredded materials are loaded onto the front end of a silo where the composting process takes place. A specially designed 'Komp-Max" turner hoisted on a crane is used to move the composting materials forward along the silo. The composting materials are thus aerated in the process while at the same time POME is sprayed onto them. Mature compost can then be harvested at the end of silo for subsequent drying, sieving and bagging. In this system, all nutrients are captured in the final product as there is no leaching.

Nutrient Composition of Compost

The nutrient content of compost varies with the quality of POME and the composting cycle. Generally, the nutrient content of compost is affected by its moisture content at the time of harvest. Typical results from the analyses of 'estate grade' composts from the MIWAMAS system and the INF plant are given in *Table 9*. In an open air system, the resulting more mature compost tends to have a lower nutrient content, and hence a closed system is more suitable for producing a higher grade organic fertilizer. There is a very little or no loss of nutrients in an indoor system.

TABLE 9. TYPICAL NUTRIENT CONTENTS (%) OF COMPOSTS PRODUCED BY MILL INTEGRATED WASTE MANAGEMENT SOLUTION (MIWAMAS) SYSTEM AND INTEGRATED NATURAL FERTILIZER (INF) PLANT WITHOUT FORTIFICATION WITH INORGANIC FERTILIZER

Nutrient	MIWAMAS system	INF plant
N	1.8	2.0
P_2O_5	1.2	1.2
K_2O	2.3	5.1
MgO	0.9	1.2

Fortification of compost or organic fertilizer with inorganic fertilizer is preferred in the closed system because there is no potential loss of nutrients. Incorporation of relatively insoluble fertilizers such as rock phosphate, GML and magnesite during the composting process can help to solubilize these fertilizers.

Critical Management Factors for Success

There are several management factors that are critical for the successful implementation of the composting system. Firstly, there should be a synchronization of operations between the palm oil mill, the composting plant and the plantation management while being under separate management teams due to different priorities. This implies a need for good co-ordination in the shredding operation and the evacuation of the shredded fibre to the composting platforms/silos. Timely monitoring of temperature, moisture and oxygen contents is essential to ensure a continuous aerobic process of biodegradation. Thus, it is important to have an adequate number of well-maintained turners at all times. There must be efforts on the part of the mill to minimize any unnecessary increase in water usage, while the composting team must ensure timely coverage of the compost piles against rain in the open system. It is also important for the plantation management to organize the logistics of compost application onto the field to ensure that all mature compost is evacuated in a timely manner from the composting platform for field application. Any stockpile or congestion at the composting platform or silo (in the case of the indoor system) would result in a slowdown in the off take of mill wastes with obvious consequences.

IMPACT OF COMPOST ON YIELD AND SOIL FERTILITY

The utilization of compost in agriculture is an ancient practice. The use of compost in this country is not uncommon albeit in smaller quantity, due to limited availability and less convenience in application, as compared to inorganic fertilizer. Nevertheless, the goodness of compost in improving the soil fertility of tropical soils in particular, and crop yield is a well-established fact. The benefits of EFB, even before the process of microbial degradation into compost, have been well-documented when used as a mulch in oil palm plantations (Lim, 1987; Loong *et al.*, 1987; Singh *et al.*, 2009). It is reasonable to expect that similar benefits can also be derived when one applies compost produced from EFB and POME.

The results of a three-year study on the effect of compost application on the fertility of Rengam series soil planted with oil palm are summarized in *Figure 4.* It is clearly evident that all major plant nutrients in the form of soil nitrogen, phosphorus and exchangeable bases increased dramatically at the application sites. Equally important are the confirmation of three other expected findings, as follows:

- elevation of soil pH to above 5.5 at which point ph nutrient uptake by plants is generally most efficient;
- cation exchange capacity is increased by several folds in the top 30-60 cm of the soil. Losses of soluble plant nutrients can thus be minimized; and
- the significant increase in soil carbon encourages soil microbial activities and aeration in the root zone.

The positive impact of compost on oil palm yield was earlier reported by Chua *et al*. (2006) and Ong *et al*. (2008) in a trial on palms planted on terraces on a steep terrain. Further results on FFB yield have been updated and summarized in *Table 10*. The conclusions of the trial remain essentially the same, as follows:

- there was a positive yield response to compost application ranging from 13.9% to 33.8% without and with the full rate of inorganic fertilizer, respectively;
- with the full application rate of inorganic fertilizer there was no need to increase the compost rate beyond 50 kg palm^{-1} yr^{-1} for yield enhancement;

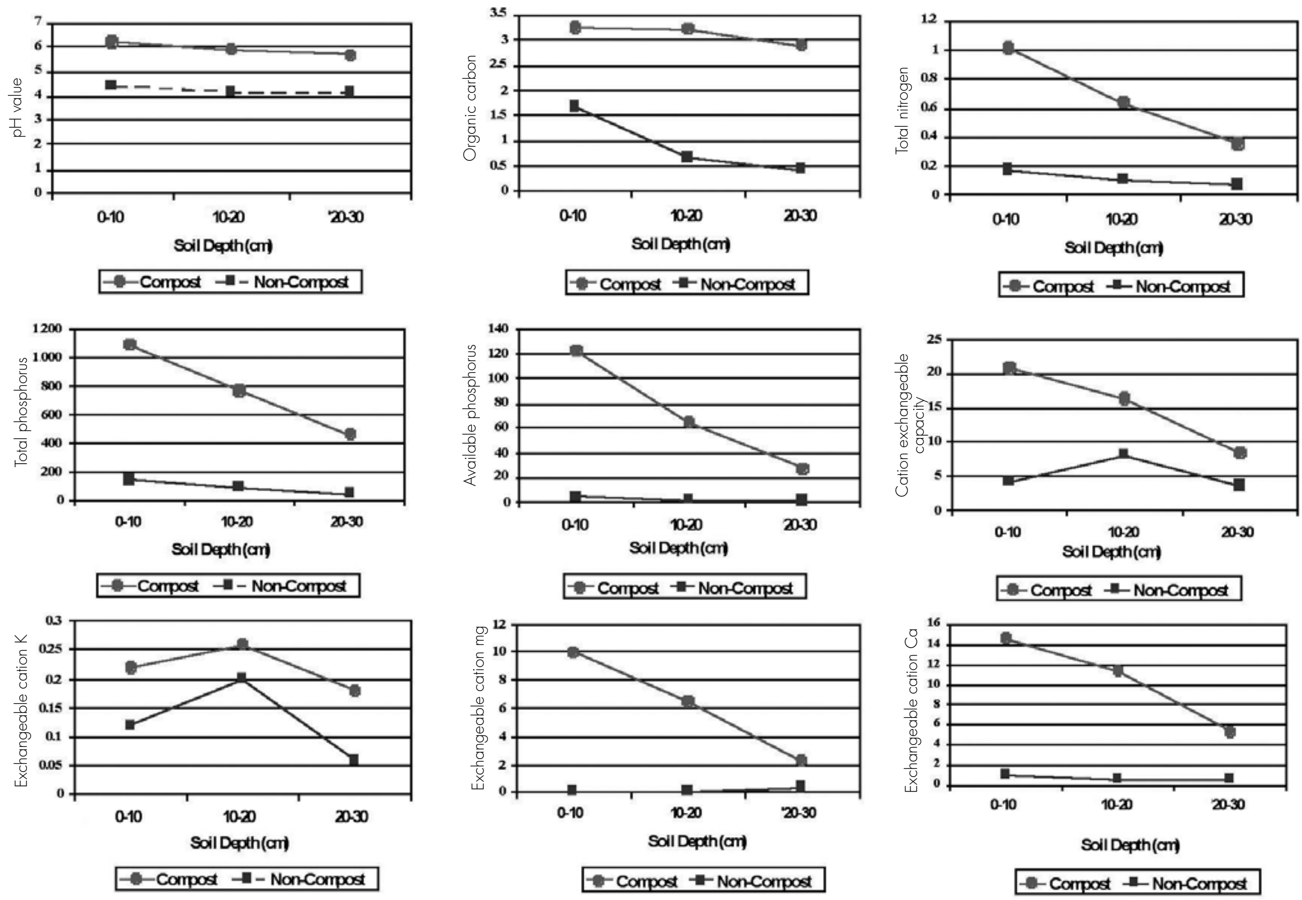


Figure 4. Effect of compost on soil fertility.

- compost at rates between 50 and 150 kg palm^{-1} yr^{-1} was adequate to compensate for a reduction of inorganic fertilizers by 25% to 50%. There were positive yield responses exceeding 20% when compared to the full rate of inorganic fertilizers applied without any compost; and
- compost application alone at 120 or 150 kg palm^{-1} yr^{-1} produced better yields than applying the full rate of inorganic fertilizers.

The results in *Table 10* are not unexpected in view of the past findings on the positive effect of EFB mulching on oil palm yield, more so in subsoil plantings on terraces. It is to be noted that compost was applied at the inter-palm area along the terraces while inorganic fertilizers were applied in palm circles. Based on experience, the incorporation of inorganic fertilizers with compost, whether applied on the soil surface or in shallow trenches (NuFes System), is preferred. For yield optimization on different soil types/terrains, more trials would be required to fine-tune the requirements of N, P, K and Mg for direct fortification during compost production, and/or integration over compost application sites in oil palm fields.

THE 4 Rs OF FERTILIZER BMP

Oil palm is extensively planted on different soil types, terrains and climatic conditions within the tropical belt. Optimization of nutrient efficiency and effectiveness is the key to minimizing the fertilizer cost per tonne of crop produced with due consideration to environmental health. In this regard, site-specific factors dictate the 4 Rs (Right source of application at the Right rate, Right time and Right place) of fertilizer management as reported by Roberts (2007), and described in a global framework for best management practices (BMP) in fertilizer use by Bruulsema *et al.* (2008).

Right Source

Organic fertilizer in the form of compost is undoubtedly a suitable source of nutrients for oil palm, a perennial crop. While the nutrient contents are generally lower than those in an inorganic fertilizer, they can be augmented by way of fortification with inorganic fertilizers to higher levels. In fact, the ability of compost to retain nutrients and moisture helps to minimize nutrient losses and encourages nutrient uptake by the palms through regulating the release of nutrients over time. Losses

TABLE 10. OIL PALM YIELD RESPONSES TO COMPOST APPLICATION AND TO THE WITHDRAWAL OF INORGANIC FERTILIZERS

Treatment		5-year mean	Relative increase (%)	
Inorganic fertilizer	Compost (kg palm^{-1})	FFB yield (t ha^{-1})		
Full rate (100%)	0	15.04	100.0	100.0
100	50	21.11	140.4	
100	100	20.51	136.4	133.8
100	150	18.76	124.7	
75	50	18.79	124.9	
75	100	17.26	114.8	123.1
75	150	19.46	129.5	
50	50	19.06	126.7	
50	100	16.71	111.1	120.5
50	150	18.61	123.7	
Nil	100	16.23	107.9	113.9
0	150	18.03	119.9	

TABLE 11. NUTRIENT LOSSES FROM GENTLY UNDULATING TERRAIN OF OIL PALM PLANTING

Nutrient loss pathway	Nutrient loss (%)			
	N	P	K	Mg
Erosion and surface run-off (1)	8.0	1.6	15.3	7.6
Leaching (2)	3.0	1.5	2.9	15.5
Expected total losses	11.0	3.1	18.2	23.1

Source: (1) Kee and Chew (1996).
(2) Foong (1993).

of nutrients from inorganic fertilizers applied on gently undulating terrain can be very significant indeed (*Table 11*). One can expect such losses to be even higher in plantations having rolling to hilly terrain.

Right Rate

The right rate of usage is dependent upon the requirement of oil palm. This has been an area of voluminous research over the years based on inorganic fertilizers (Goh *et al.*, 2009). Research information on the use of EFB and POME is also available, but similar information on the use of compost/organic fertilizer is rather limited. Some of the commercial practices as recommended by Lim *et al.* (2009) are briefly described below:

- compost usage in the nursery. As a nursery medium, compost is mixed thoroughly with top soil at a ratio of 1:4. More mature compost is preferred (Lord and Betitis, 2007). Irrigation rate is reduced due to the higher moisture-holding capacity of the medium;
- compost usage in the planting holes during field planting. Compost at 15 kg and 25 kg per hole is recommended for normal and lateritic soils, respectively. Thorough mixing of compost with the soil in the planting hole is essential; and
- compost usage in mature oil palm fields. In a plantation group where there are four composting plants (using the MIWAMAS system) in operation, 'estate grade' (at the end of a 10-week composting cycle) compost is applied in spots between palms at the rate of 6-7 t ha^{-1} (equivalent to about 50 kg palm^{-1}). Supplementary application of inorganic fertilizers is carried out based on leaf analysis results of the manuring blocks/fields. It must be categorically stated here spot placement of

compost on the soil surface is convenient but is not the best approach in the utilization of compost. Incorporation of compost into the top soil would have a more lasting positive effect on soil fertility.

Compared to the conventional EFB mulching at the rate of 25 to 75 t ha^{-1} the amount of compost derived from EFB can cover a plantation area larger by two to five times. This invariably offers an advantage to application on hilly terrain and poorer soils where better yield benefit can be expected.

Right Time

Timing of compost application is not a limitation except in extremely wet weather/season just like the application of inorganic fertilizers. In fact, nutrient losses from compost via surface runoff and leaching are likely to be very much less as compared to inorganic fertilizers when applied during the wet season on the ground surface. A case in point is the FELDA mulch (AAR mulch) used to cover inorganic fertilizer to reduce the frequency of application and fertilizer losses (Goh *et al*., 2009).

Right Place

The right place for application is where the root concentration is highest. In view of root-soil dynamics, the ideal place of application is to incorporate compost into the soil matrix by ploughing/rotortilling into the soil proper. However, it is often difficult for such an operation in oil palm fields once the crop is planted except at the time of land preparation. A trial on ploughing in compost at various rates along the planting rows (2.4 m or 8 feet wide) at replanting is being carried out. Normally, the application site is the palm circle where roots first develop during the period of immaturity. As palms mature, the root system can spread well beyond their palm circles. Whilst root density may differ from location to location depending on soil type, moisture, nutrients and organic matter, it can be generalized that the root system of mature palms is literally everywhere in the topsoil (but not true in the case of planting on terraces having heavy clayey soil and/or semi-weathered subsoil). However, nutrient uptake by the palm is by way of the feeder roots. It has been found that the feeder roots can be increased tremendously with the application of compost into soil pits/trenches and even at surface application sites. A trial carried out in an area where palms are planted on terraces (of Rengam series soil, a Typic Tropudult) showed that the biomass of roots at the application site increased by 2.1 times where compost was applied between palms along the terrace, and the feeder roots increased dramatically by 17.6 times as a result of compost application (*Table 12).* There was also proliferation of roots deeper into the soil. Thus, it would be highly beneficial to apply any supplementary inorganic fertilizers at the compost application sites. Ideally, compost can be fortified with the required chemical nutrients for ease of application. The concentration of the feeder roots coupled with ideal soil pH would undoubtedly enhance the efficiency in nutrient uptake. Similarly, Liew and Zaharah (2007) had earlier reported on the enhancement of root proliferation and better P uptake by oil palm as a result of EFB mulching.

To take advantage of the root dynamics in response to nutrients, moisture and aeration in the form of compost, a special application system called 'NuFes' (Nutrient Feeding Site) has been specially designed for the systematic application of compost in mature oil palm fields over time.

In flat to gently undulating areas where palms are planted in straight rows, a sloping trench of size 1 m x 2-3 m can be constructed between two palms along a palm row. The depth of the front portion of the trench should be limited to 30 cm, sloping deeper toward the other end of the trench (near to frond heap row) up to a depth of 75 cm. Compost (with or without inorganic fertilizer fortification) can then be applied to fill up the front end (shallow portion) of the trench. Future applications are then continued progressively from the front end of the trench until the entire trench is filled. This will take many years to achieve depending on the length of the trench. The idea of the initial application starting from the shallow end is to allow the proliferation of roots into the compost from both sides of the trench. It is advisable to apply half of the inorganic fertilizer in the year of commencement in the palm circles while waiting for root proliferation into the applied compost in the front end of the trench.

Compost can be applied yearly or half yearly, depending on requirement. Currently, it is recommended that 25-50 kg $palm^{-1}$ yr^{-1} be applied to the 'NuFes' trench. In the case where the compost is not pre-fortified during the manufacturing process, supplementary inorganic fertilizers can be applied over the compost in the 'NuFes' trench. This will lead to maximum nutrient uptake by the palms with the increasing buildup of feeder roots into the trench. Compared to the conventional application of inorganic fertilizers in palm circles, or general broadcast by mechanical means, losses of nutrients will be very minimal in the 'NuFes' system.

In the case of oil palm planted on terraces, the 'NuFes' system can be carried out by constructing shallow trenches (across part of the terrace) of not more than 30 cm deep in alternate inter-palm spac-

TABLE 12. EFFECT OF BIO-COMPOST ON ROOT BIOMASS OF OIL PALM PLANTED ON TERRACES

Depth of soil (cm)	Bio-compost site (A)			Non bio-compost site (B)		
	Small*	Large**	Total	Small*	Large**	Total
0-10	5.61	0.85	6.46	2.05	2.64	4.69
10-20	30.17	7.12	37.29	1.69	48.83	50.52
20-30	13.17	12.42	25.59	0.43	1.65	2.08
30-40	9.23	11.11	20.34	nil	nil	nil
40-50	7.71	8.32	16.03	nil	nil	nil
50-60	5.71	4.92	10.63	nil	nil	nil
60-70	1.98	2.77	4.75	nil	nil	nil
Grand total	73.58	47.51	121.09	4.17	53.12	57.29
A *vs.* B	17.6x	0.9x	2.1x	-	-	-

Note: *root diameter <3 mm.
**Root diameter >3 mm.
Source: Unpublished data.

es. Compost is applied at both ends of the shallow trench catering for the two adjacent palms. Similarly, the trench will be filled with compost over time.

'NuFes' trench construction can be carried out on year 3 plantings (before full interlocking of canopies between palms is achieved) on gentle terrain, and on year 5-6 in terraced areas. In this way, such trenches can be utilized for many years and also serve to minimize surface run-off of rain water. Based on our initial findings, the 'NuFes' trenches become an ideal site for root development, and hence optimize nutrient uptake by palms. One can even expect a significant reduction of fertilizer (nutrients) rate and/or a higher yield response as demonstrated in trials carried out by Chua *et al.* (2006) and Ong *et al.* (2008). More trials are to be carried out to fine-tune the 'NuFes' system of compost application.

NITROGEN FIXATION BY WAY OF LEGUMINOUS COVER CROPS

The benefits of leguminous cover crops for nitrogen fixation by soil microbes associated with the nodules of the leguminous root system is a well-known fact. A well-established cover crop during planting/replanting provides the following advantages:

- it facilitates the direct extraction of N from the atmosphere, and serves as a N source to oil palm;
- it enables the recycling of plant nutrients from the soil, particularly those in the subsoil, onto the soil surface in the form of plant litter;
- it minimizes soil erosion (and nutrient losses) during the immature phase of oil palm planting (Ling *et al.*, 1979); and
- it improves the general fertility of the top soil (enhancing aeration, bulk density, microbial activity, moisture and nutrient retention capacities).

Nutrients immobilized by a well-established leguminous cover crop (LCC) can be very significant (Han and Chew, 1982; Shaharudin and Jamalauddin, 2007). Hence, planting LCC can be viewed as providing an indirect source of plant nutrients coupled with a series of other benefits to oil palm.

In a commercial situation, comparing between the conventional LCC (comprising a typical mixture of *Pueraria phaseloides*, *Centrosema pubescens*, *Calapogonium mucunoides* and *Calapogonium caeruleum*) and *Mucuna bracteata* (a deep-rooted and more shade-tolerant creeping legume), the latter (once established) was able to withstand drought conditions, and benefitted the palms in terms of growth and initial FFB yield (*Table 13*). The higher yield was due to both an increase in average bunch weight and a higher number of bunches (or sex ratio) due mostly to a higher nutrient reserve and moisture retention. All details pertaining to the superiority of *Mucuna bracteata* over other LCC are documented in a book edited by Goh and Chiu (2007).

From the nutrient input, higher yield and environmental sustainability points of view, establishing LCC, *Mucuna bracteata* in particular, is a good

TABLE 13. COMPARISON BETWEEN YIELD PERFORMANCE OF OIL PALM PLANTED WITH CONVENTIONAL LEGUMINOUS OVER CROPS (LCC) AND WITH *Mucuna bracteata*

	Conventional LCC		*Mucuna bracteata*		Relative increase (%)	
Year	FFB yield ($t\ ha^{-1}$)	Av. bunch weight (kg)	FFB yield ($t\ ha^{-1}$)	Av. bunch weight (kg)	FFB yield ($t\ ha^{-1}$)	Av. bunch weight (kg)
1st	4.87	2.61	5.35	2.83	+ 9.9	+8.4
2nd	11.04	4.86	14.65	5.47	+32.7	+12.6
3rd	18.07	8.54	25.18	8.65	+34.7	+1.3
4th (6 m)	14.61	10.39	17.40	10.32	+19.1	-0.7
Total	48.59	-	62.58	-	+28.8	-

Source: Unpublished data.

agricultural practice that planters must not do without. Often such practice is curtailed in the case of large-scale planting/replanting, and/or with the excuse of having insufficient workers to manage the crops!

POTENTIAL USAGE OF BIO-CHAR AND ITS IMPLICATIONS

Soil fertility is a fundamental determinant of crop productivity. In recent years, bio-char or agri-char, a charcoal derived from pyrolysis of biomass, has received considerable attention in the area of improving soil fertility while concurrently serving as a long-term carbon sequester (Kimetu *et al.*, 2007). The benefits of incorporating bio-char in agricultural soils on annual crops have been established by some scientists (Downie *et al.*, 2007; Major *et al.*, 2007; van Zwieten *et al.*, 2007). Oil palm, a perennial crop that has an economic life-span of more than 25 years, will undoubtedly benefit from the incorporation of bio-char during land preparation. Some efforts should be made to investigate the best possible way to produce bio-char from oil palm biomass to recycle it for long-term soil fertility improvement and carbon sequestration, bearing in mind that some land in Peninsular Malaysia are undergoing the second to fourth replanting (rubber/oil palm). According to Jones (2006), every 1 t ha^{-1} increase in soil organic carbon represents 3.67 t of CO_2 sequestered from the atmosphere and removed from the GHG equation.

Incidentally, there could be a side monetary benefit in terms of carbon credits (at about USD 18 t^{-1} CO_2 at the end December 2008; http://www.point carbon.com/) from carbon sequestration (Gaunt and Lehmann, 2007). The recalcitrant carbon from bio-char is even more lasting than compost in the soil matrix. In any case, glomalin (a glycoprotein produced by arbuscular mycorrhizal fungi living on plant roots) and humic substances are relatively stable forms of soil carbon that have long-term implications in improving the soil environment and fertility (Jones, 2006). Key benefits of bio-char in acidic soils include raised pH, a significant increase in total soil carbon, reduced Al availability and improved cation exchange capacity (CEC) (Lukas *et al.*, 2007).

It is heartening to note that research has started in this country on the conversion of oil palm fronds, trunks, EFB and shell through pyrolysis to determine the ideal terminal temperature for optimization of fixed carbon content in bio-char, the energy content in the gasification process, and the eventual bio-oil content (Khor and Lim, 2006, 2008a, b; Khor *et al.*, 2008; 2009). It is envisaged that bio-char will be used during replanting in the not too distant future as an eco-friendly approach in improving soil fertility, and thus reducing the use of inorganic fertilizers.

CONCLUSION

Oil palm, like any other crops, cannot produce its yield economically without the adequate input of fertilizers. Inorganic fertilizer plays a critical role in the commercial cultivation of oil palm. It cannot be completely replaced by organic sources. However, organic nutrient sources should be utilized wherever available for recycling of nutrients and the protection of environment health. The use of compost derived from solid and liquid wastes from palm oil mills is an economical and responsible approach to waste management and yield enhancement. It is a green technology that minimizes water pollution and GHG emissions. This indirectly augers well for palm oil as a preferred feedstock for sustainable biofuel production. So long as fertilizer is to be used, irrespective of whether it is from inorganic or organic sources, and/or a combination of both, the 4 Rs approach of fertilizer stewardship must be adopted to ensure efficiency and effectiveness, which in turn leads to optimal productivity.

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Appendix 1

EMPTY FRUIT BUNCHES

PALM OIL MILL EFFLUENT

OTHER ORGANIC WASTES

- Bunch ash
- Boiler ash
- Decanter cake

PROCESS

Shred into fibre and heap

Daily spray (via sprinkler system)

Heap together with EFB fibre

WASTE MANAGEMENT PLANT

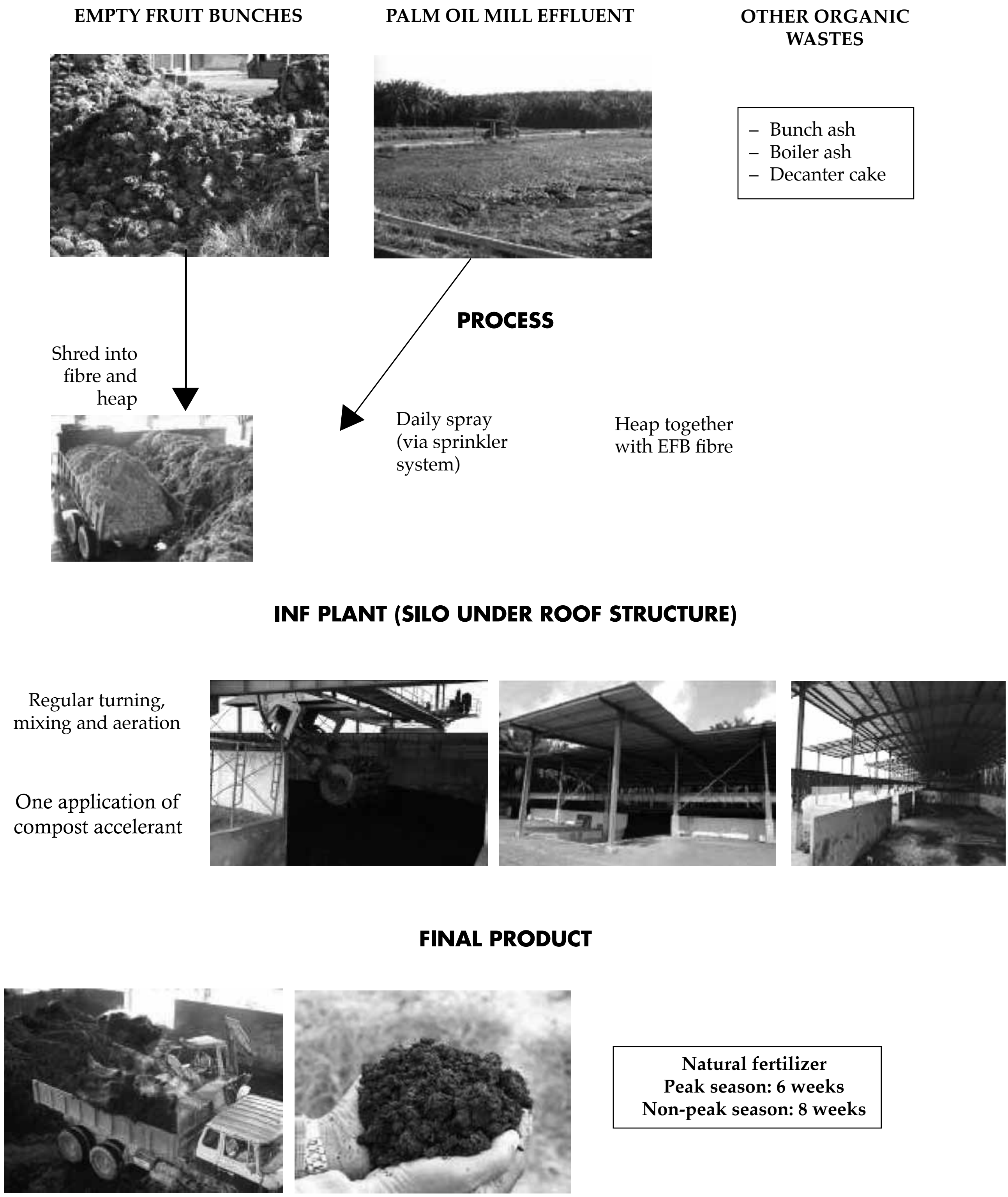
Regular turning, mixing and aeration

One application of compost accelerant

FINAL PRODUCT

Compost, 8-10 weeks per cycle

a. Compost manufacturing process by MIWAMAS system.



b. Compost/organic fertilizer manufacturing process by integrated natural fertilizer (INF) plant.

LIST OF TECHNOLOGY COMPANIES WITH EXPERTISE ON COMPOSTING SYSTEMS IN MALAYSIA

1. Asia Green Environmental Sdn Bhd (MIWAMAS system and INF fertilizer plant).
2. Boustead Biotherm Palmass Plant (BBPP) (Telok Sangat Palm Oil Mill, Johor).
3. CBIP System.
4. Hi-Tech Activated Carbon Sdn Bhd (Tee The Palm Oil Mill at Keratong, Pahang).
5. Aretae Limited – (Sankina Oil Mills Sdn Bhd; Takon Palm Oil Mill of J C Chang Group).
6. Brite-Tech Ventures Sdn Bhd; YTL – SV Carbon - (a) Banting Palm Oil Mill Sdn Bhd, Selangor, (b) Synn Palm Oil Mill Sdn Bhd, Taiping, Perak.
7. Prestige Central Management Sdn Bhd.
8. Senai Alam Sdn Bhd.
9. CH Compost Sdn Bhd.
10. Inno Integrasi Sdn Bhd.