WASTE TO HEALTH

# Organic Waste Management for Sustainable Soil Management & Crop Production

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## ABSTRACT

Organic waste management is essential not only in turning waste into wealth but more importantly in improving environmental quality and health, and contributing to sustainable crop production when it is recycled in the agricultural sector. The agricultural sector in Malaysia produces a tremendous amount of waste which has traditionally been burnt or simply dumped (a common practice till now) making it a source of greenhouse gas emissions and other environmental problems which affect human health. More recently, due to the prohibition of open burning of organic wastes, it has become a trend to convert wastes into wealth, i.e. value added products. Research has escalated to investigate various technologies with the aim of reducing waste through good waste management practices, i.e. recycling in agriculture or conversion into useful products for commercialization. However, returning organic wastes back to agricultural land simply by mulching (e.g. oil palm empty fruit bunches (EFB) applied fresh from the mill or as processed EFB mats to newly transplanted palms and mature palms) or incorporation of crop residues into soils after harvesting contributes to recycling of nutrients and organic matter back into soils, thus building up soil quality and health, prevents land degradation and increases soil productivity. Composting of organic wastes (not limited to agricultural wastes) reduces the bulk of the wastes and concentrates nutrient contents. This process not only converts the wastes into value-added products such as organic fertilizers, soil amendments and soilless potting media but also avoids wastes being exposed to the environment and vulnerable to greenhouse gas emissions (nitrous oxide and methane) and pollution of natural resources (leaching into groundwater and surface run-off into surface waters). The use of soilless potting media derived from organic wastes could partially or totally replace

the use of peat which is a slowly renewable resource. Apart from this, there has been an increase in interest, in the last decade, in transforming organic wastes into biological charcoal or biochar under controlled conditions, such as pyrolysis and gasification, with the main objective of using it as a soil amendment in agricultural land, particularly for naturally infertile or degraded soils. Biochar contains carbon that is potentially resistant to microbial degradation and has dual functions. Firstly, biochar improves soil quality and crop productivity due to its high porosity and sorption properties. Secondly, biochar increases carbon storage or sequestration in soil thus reducing carbon dioxide in the atmosphere and mitigating global warming and climate change.

Sustainable management and recycling of organic wastes in agriculture is a holistic approach which should be pursued not only with the sole objective of converting wastes into wealth but more seriously for its various benefits to crop production, the environment (clean water and air, and balanced carbon cycle) and, ultimately, human health.

## INTRODUCTION

In the 20th century, as the world population continues to grow and become more urbanised and affluent, the production of wastes has increased tremendously. It is predicted that by the year 2025, the world population will reach 7.65 billion, from the current 7.05 billion people, with waste production almost doubling from 3.53 million tons per day to 6.07 million tons per day (Hoornweg *et al.,* 2012). Many developing countries in the Asia-Pacific region already face critical problems with regard to waste management and the quality of the environment (Nadi *et al.*, 2011). Rapid urbanization and economic growth in the region has resulted in a corresponding increase in solid wastes that municipal governments are finding it difficult to dispose off because most of the existing dumpsites have or nearly reached their maximum capacity and finding land for new dumpsites is becoming increasingly difficult. Other problems include: insufficient government prioritisation and support, lack of finance, inadequate long-term planning, indiscriminate disposal of wastes, poor handling and disposal of hazardous and biomedical wastes, insufficient recycling and reuse, lack of skilled personnel, and poor monitoring and enforcement.

Solid waste generation in Malaysia recently reached a crucial stage, especially in terms of the amount and composition. With waste generation increments of 3% per annum due to urban migration, affluence and rapid development, Malaysia is left with no choice but to find ways to manage its waste disposal more efficiently and immediately if it wants to safeguard its environment from harmful effects (Syed, 2010).

Generally, solid wastes consist mainly of organic materials such as food waste (45%), followed by plastic (24%), paper (7%), iron (6%) and glass and other materials such as wood (3%) (Ninth Malaysia Plan, 2006; Fauziah *et al.*, 2007). Currently the per capita generation in Peninsular Malaysia is nearly 1.2 kg of municipal waste (MSW), amounting to 19,000 tonnes of waste per day, and it is set to rise to 30,000 tons daily by 2020 (Zamali *et al.*, 2009). Besides municipal solid waste, a large amount of waste is generated from agriculture, an important sector in Malaysia's economic development. More than 2 million tons of agricultural wastes is produced annually (Wan Azlina *et al.*, 2011). Major agricultural residues are generated from oil palm and rice cultivation (Figure 1).

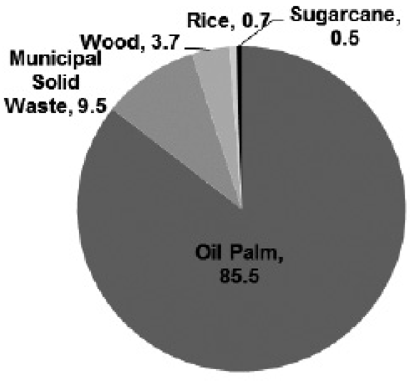



**Figure 1** Biomass residues produced from various industries in Malaysia.

(Source: Hasan and Shirai, 2003)

The oil palm sector is the largest agriculture sector and hence the major contributor to agricultural residue generation in Malaysia. In 2012, oil palm cultivation in Malaysia was estimated to cover around 5.08 million hectares, with an average production of 18.89 tons of fresh fruit bunch (FFB) per hectare (MPOB, 2013). The major by-products from palm oil extraction are empty fruit bunch (EFB), palm kernel shell, fibre and POME. Rice is the other main generator of agricultural waste, mainly in the form of rice straw and rice husk. In 2011, 2.578 million metric tonnes of paddy was harvested from 687,940 hectares of rice fields in Malaysia, producing 1.66 million metric tonnes of rice (DOA, 2012). Lim *et al,.* (2012) reported that for every kilogram of paddy harvested, 0.41-3.96 kg of rice straws and 0.20-0.33 kg of rice husks are produced.

**Table 1** Major biomass residue generation in Malaysia

| Industry | Type of Residue | Amount Generated ('000 tonnes) |
|---|---|---|
| Oil Palm | EFB | 15,701 |
| | Fiber | 9,447 |
| | Shell | 4,211 |
| | Others (POME) | 51,990 |
| Paddy | Rice Husk | 471 |
| | Paddy Straw | 856 |
| Sugar | Bagasse | 356 |
| Wood | Sawn Timber | 1,692,718 $m^3$ |
| | Plywood and Vencer | 121,000 $m^3$ |
| | Moulding | 75,600 $m^3$ |

Source: APEC, 2007

## PROBLEMS RELATED TO SOLID WASTES

Improper management of solid wastes, especially in landfills, can have negative impacts such as leachate contamination of surface and groundwater, pest infestation and health problems and emission of greenhouse gasses (Fauziah and Agamuthu, 2005). The contamination by leachates from landfills of water bodies can cause serious ***water and land pollution***. For example, in 2010, leachate contamination from a landfill in Semenyih caused the closure of the nearby water treatment plant due to high ammonia levels being found in the water supply leading to water supply disruption for a million consumers (The Star, 2010). The threat of contamination from landfills is very serious as only 12 out of over 300 MSW disposal sites in Malaysia are sanitary landfills with proper leachate collection and treatment facilities (Fauziah and Agamuthu, 2005). Agricultural activities and agro-based industries are also a major source of water pollution, from the processing of palm oil, rubber, pineapple, tapioca, sugar, sago and, to some extent, paper and pulp manufacturing.

***Greenhouse Gas*** (***GHG) Emissions*** originate in situations where biodegradable wastes deposited in landfills produce methane, a GHG which is 21 times more potent than carbon dioxide. Between 60 and 80 per cent of municipal solid waste in Asia's developing countries consists of organic material. This waste is currently sent to landfills and dumps where it contributes to a large amount of GHG emissions every year (Table 2).

**Table 2** Landfill Methane Emissions and Total GHG Emissions for Selected Countries

| Country | Methane Emissions from Post-Consumer Municipal Waste Disposal* ($MtCO_2e$) | Total Greenhouse Gas Emissions** ($CO_2$, $CH_4$, $N_2O$) ($MtCO_2e$) | Percent Methane from Disposal Sites Relative to Total GHG Emissions |
|---|---|---|---|
| Brazil | 16 | 659 | 2.4% |
| China | 45 | 3,650 | 1.2% |
| India | 14 | 1,210 | 1.1% |
| Mexico | 31 | 383 | 8.1% |
| South Africa | 16 | 380 | 4.3% |

(Source: Hoomweg et al., 2012)
*EPA 2006
** UNIFCCC 2005

## SOLID WASTE MANAGEMENT PRACTICES

There are several methods used for managing MSW, with the most popular being landfilling, recycling and waste to energy conversion (i.e. incineration) (Figure 2). For agricultural waste such as EFB and other oil palm by-products, it is conventionally recycled via incineration, mulching in oil palm estates and composting (Menon *et al.*, 2003; Sumathi *et al.*, 2008; Baharuddin *et al.*, 2009; Rosenani *et al.*, 2011).

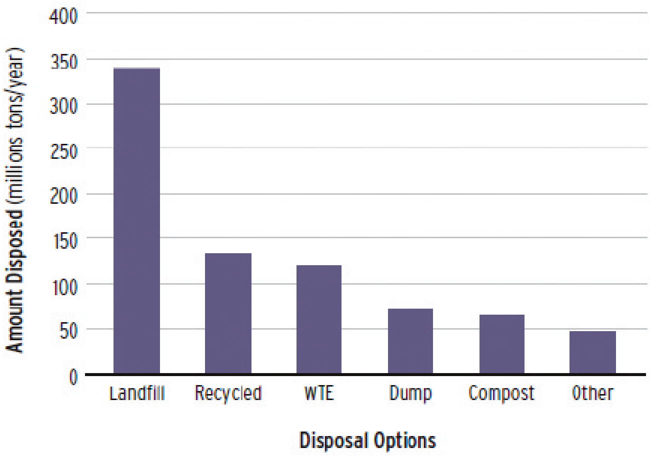



**Figure 2**: Disposal of total Global MSW according to disposal methods.

(Source: Hoomweg *et. al*, 2012)

***Landfilling*** of solid wastes remains the most widely used waste management method as it can handle bulk quantity. However, such operations are costly and increasingly questioned by communities concerned about the potential long term risks and aesthetics associated with having a landfill in their neighborhood. ***Incineration*** solves the bulk issue and long residence time of organic wastes with

2 beneficial outcomes, i.e. energy generation and mass reduction. Agricultural wastes such as EFB were traditionally incinerated in the mill as fiber fuel which caused severe air pollution problems. Consequently the introduction of the Malaysian Environmental Air Quality Regulation in 1978 prompted mills to look for alternative waste management methods.

***Nutrient recycling*** via mulching and composting is the current approach whereby organic wastes from agricultural activities, such as crop residues, etc., are recycled in various ways such as mulching, composting and charred. The advantage of recycling organic wastes includes positive replacement of chemical fertilizers with organic based fertilizers, less soil and water pollution, lower greenhouse gas emissions and improved soil sustainability.

The incorporation of agriculture wastes as useful by-products for agricultural activities has been carried out and studied in Universiti Putra Malaysia (UPM) over the past few decades. These research studies on amending organic matter into infertile or degraded tropical soils to enhance plant and soil productivity encompasses various crop residues, such as groundnut, oil palm and rice.

## INCORPORATION OF CROP RESIDUES INTO SOIL FOR NUTRIENT CYCLING AND SOIL AMENDMENT

Sustainability has been a major concern for agriculture in the last few decades. The dependency on inputs such as chemical fertilizers and pesticides have had a harmful impact on the environment and human health, leading to the introduction of agronomic practices aimed at reducing such chemical inputs while maintaining or enhancing crop yield and soil health. The incorporation of crop residues into soil not only promotes nutrient recycling, but also improves soil fertility by adding soil organic matter.

In a field experiment under a crop rotation system of maize (*Zea mays* L.) and groundnut (*Arachis hypogaea*), the incorporation of crop residues was shown to improve recovery of applied N in the soil and crop, in comparison to the treatment where crop residue was removed (Rosenani *et al.*, 2003; Mubarak *et al.*, 2003a; Mubarak *et al.*, 2003b**;** Dourado-Neto *et al.*, 2010). Significant positive effect of crop residues on N retention was observed at 15- to 30-cm soil depth in subsequent crop cycles (Figure 3). The study also showed that the gradual beneficial effects of crop residue incorporation can be observed in the  long term, where after two years, there was significant increase in soil exchangeable K and available P, and cation exchange capacity (CEC) (Mubarak *et al.*, 2003d).

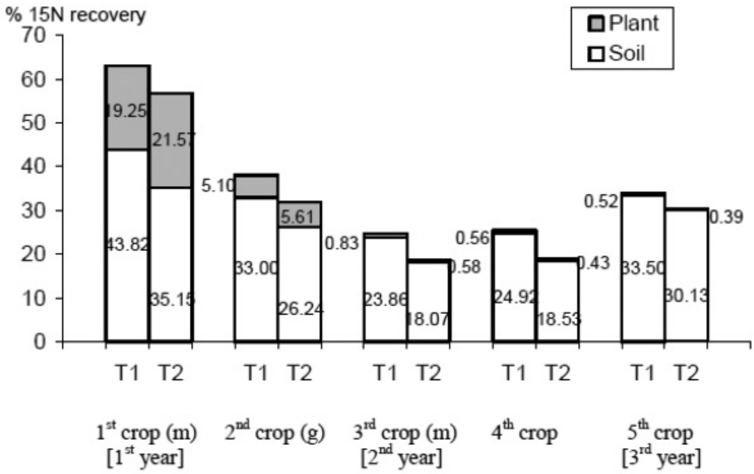



**Figure 3**: Recovery of $^{15}N$ in the soil and plant over five cropping cycles. The treatments recommended are inorganic fertilizer with crop residues (T1), and recommended inorganic fertilizer without crop residues (T2).

(Source: Rosenani *et. al*, 2003)

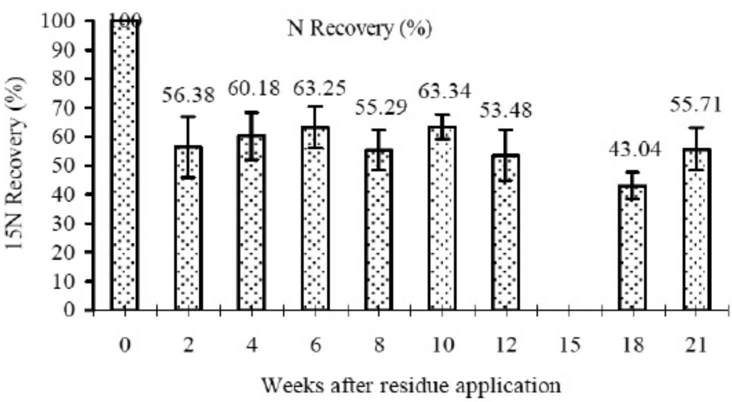



**Figure 4**: Maize residue $^{15}N$ recovery (%) in the soil during decomposition.

(Source: Source: Rosenani *et. al*, 2003)

This study also found that there must be good synchrony between crop residue incorporation and the next planting cycle to ensure optimum uptake, as otherwise nutrients released from the crop residue would be lost through leaching with no significiant effect on subsequent crop yields (Rosenani *et al.*, 2003; Mubarak *et al.*, 2003c). Nitrogen mineralization from maize residues was found to be quite rapid, from 4 to 8 weeks after incorporation due to the hot, humid conditions (Figure 4). In the humid tropics, unless the fallow period is short (i.e. 4 to 6 weeks), incorporation of crop residues after harvest would not benefit the subsequent crop significantly due to rapid decomposition and release, and loss of nutrients through leaching. However, in a rain-fed area it is sometimes inevitable that fallow periods are long (i.e. more than 6 weeks depending on the rainfall), thus affecting the availability of nutrients released from the incorporated residues of the previous crop. However, addition of organic materials into the soil, in the form of crop residue or animal manure, may have positive effects on emission of nitrous oxide, a greenhouse gas (Khalil *et al.*, 2001; Khalil *et al.*, 2002).

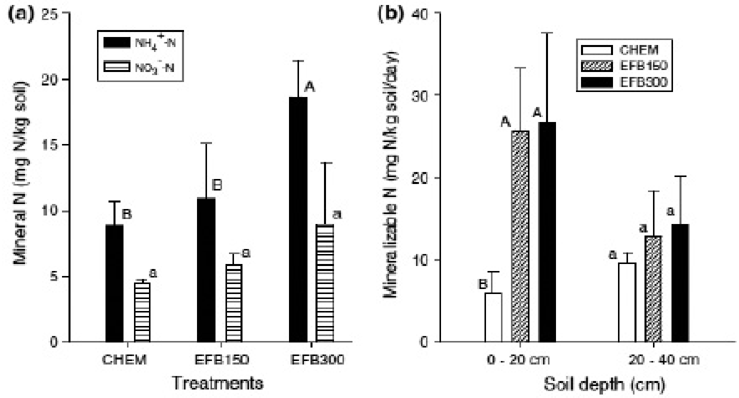
## APPLICATION OF OIL PALM EMPTY FRUIT BUNCH AS MULCH

Mulching is an important agronomic practice that can help in retaining moisture, protection of soil surface from erosion, regulating soil surface temperature, reducing nutrients leaching from fertilizers and weed control. Besides adding organic matter to the soil and improving soil fertility, it reduces chemical fertilizer costs and aids in waste management. EFB has been recycled as mulch and a source of nutrients in oil palm fields and also other crops, such as in orchards. However, documented information of the effects of such practice on soil properties, especially in the long term, is rare. Field trials carried out earlier in plantations, mainly focused on plant growth parameters and yields. Thus, a long-term field trial was established in an estate under Golden Hope Plantations Sdn. Bhd. to investigate the long-term effects of 3 rates of EFB application, from 1982 to 1993 (Rosenani *et al.*, 2011a). In this trial the EFB was applied in a heap in the middle of four palms (Plate 1), as most of the palm roots grow out radially for quite a distance. A study by Zaharah *et al.*, (1989) showed that oil palm roots grow out radially and laterally by up to 36m and may absorb nutrients from the entire soil area between the palms. The feeder roots of the palm also tend to concentrate in areas of high organic matter and moisture. The recommended treatments were chemical fertilization and zero EFB application rate (CHEM), 150 kg EFB palm-1 year-1 (EFB150) and 300 kg EFB palm-1 year-1 (EFB300) applications. The treatments with EFB application were not accompanied by application of chemical fertilizers. The cumulative addition of EFB significantly increased soil pH, organic C, total N, CEC and exchangeable bases while reducing exchangeable Al content (Figure 5). The overall yield response during the 10 year-period showed that EFB150 treatment was comparable to CHEM while the FFB yield of the EFB300 treatment was significantly higher than that of the EFB150 and CHEM treatments. The EFB application improved soil fertility and sustained crop production in the long term. This study also showed that the application of EFB improved soil chemical properties (organic C, soil pH, CEC and exchangeable bases) over the ten year period. Application of EFB over the 10 year-period also significantly increased total N content in the 0–40 cm soil layer in the EFB300 plots while no significant difference was observed between the CHEM and EFB150 plots. Rosenani and Hoe (1996) also reported an increase in soil pH and availability of K, Ca and Mg in soils applied with EFB mulch, even after a short period of 15 weeks of decomposition. EFB naturally decomposes rapidly and loses up to 50% dry matter weight within 15 weeks after application with rapid release of K, particularly when accompanied by chemical fertilizer application (Rosenani and Hoe, 1996; Rosenani and Wingkis, 1999).

**P** il
palm trees in an EFB treatment plot

(Source: Rosenani et. al, 2011a)

Applying EFB as a mulch and nutrient source in the oil palm field near the palm oil mill is a good and practical alternative method for the disposal and management of palm oil wastes. The application of EFB improves soil fertility and sustains crop production in the long-term. In practice, the planter may apply the lower rate of EFB over a bigger palm area and reduce fertilizer costs while maintaining the FFB yield or apply a higher rate over a smaller area nearer to the mill to reduce transportation costs and produce a slightly higher yield.




mineralizable nitrogen in the 0–20 and 0–40 cm soil layers, (b) as influenced by 10 years application of chemical fertilizers (CHEM), 150 kg EFB palm-1 year-1 (EFB150) and 300 kg EFB palm-1 year-1 (EFB300). Horizontal bars indicate standard deviation. Means followed by the same letter are not significantly different at 5% level by Duncan's Multiple Range Test.

(Source: Rosenani *et. al*, 2011a)

Returning unprocessed EFB to the field as a mulch and source of nutrients in oil palm fields is currently a common practice. However, the EFB in its natural form is heavy, thorny and bulky and cannot be stored. Hence, for logistic reasons, the EFB needs to be transformed into a form that is convenient and economical for mulching of oil palms and possibly, other crops. The conversion of EFB into a mulch mat was studied to determine its potential use for nutrient retention on sandy tin tailing soils during transplanting of timber plants (Wan Asma, 2006; Wan Asma *et al.*, 2011). Sand tailings from past tin mining activities represent one of the main problem soils in Malaysia for agricultural and forestry activities due to its porous nature. Results of the study showed that laboratory and commercially produced EFB mulch with a combination of chemical fertilizers were able to reduce nutrient leaching, although it did not improve the soil nutrient concentration of the sand tailings. The cumulative volumes of leachate collected were significantly lower for treatments with mat application compared with the control treatments. The organic mulch layer on top of mineral soils helped retain a major part of soil moisture for plant uptake by reducing water loss through flowing down through the sandy soil. The study also showed that incorporating fertilizers inside the mulch mat could be the best way to reduce fertilizer nutrients loss in such soils (Table 3). The EFB mat was slow in decomposing and was able to function as a mulch and remain intact for the four month duration of the study.

**Table 3** Percentage of total N leached corresponding to total N input in all treatments

| Treatment | Source of N input (mg N) | | | Total N input (mg N) | Amount of total N in leachate (mg N) | Total N leached of total N input (%) |
|---|---|---|---|---|---|---|
| | Fertilizer | Mat | Soil | | | |
| S | 0 | 0 | 11.7 | 11.7 | 0.0 | 0.0 b |
| Sf | 7500 | 0 | 11.7 | 7511.7 | 2295.2 | 30.60 a |
| M | 0 | 9240 | 11.7 | 9251.7 | 153.7 | 1.66 b |
| Mt | 7500 | 9240 | 11.7 | 16751.7 | 1473.4 | 8.80 ab |
| Mc | 7500 | 9240 | 11.7 | 16751.7 | 463.9 | 2.77 b |
| Mb | 7500 | 9240 | 11.7 | 16751.7 | 1847.3 | 11.00 ab |
| CM | 0 | 1000 | 11.7 | 1011.7 | 67.6 | 6.68 ab |
| CMt | 7500 | 1000 | 11.7 | 8511.7 | 2286.3 | 26.90 a |
| CMb | 7500 | 1000 | 11.7 | 8511.7 | 1581.1 | 18.60 ab |

(Source: Wan Asma *et al*, 2011)

n = 4; values in same column with the same letter are not significantly different ($p < 0.05$); S = control, Sf = compound fertilizer broadcasted, M = laboratory-produced mat, Mt = mat M with fertilizer broadcasted on mat, MC = mat M with fertilizer incorporated inside, MB = mat M with fertilizer broadcasted underneath mat, CM = commercial mat, CMT = mat CM with fertilizer broadcasted on mat, CMB = mat CM with fertilizer broadcasted underneath the mat. (Source: Wan Asma, 2006)

## COMPOSTING OF ORGANIC WASTES FOR USE AS SOIL AMENDMENT, FERTILIZER AND POTTING MEDIA

Composting is a very popular process in the management of organic solid wastes because: (a) it reduces the volume; (b) microorganisms are destroyed during composting; and (c) the end product is rich in nutrients content (Kulhman *et al.* 1989). Compost can be used as fertilizer, organic soil additive and crop substrate due to its high nutrient composition which is essential for plant growth (Muhammad, 2000). Application of compost as fertilizer to the soil has shown improvement in soil chemical and physical properties and crop performance. (Hussein *et al.*, 2006). Currently, very limited choices of potting media are available in the market, i.e. mainly peat, coconut coirdust (CCD) and red clay soils. Peat is one of the traditional organic materials used extensively in ornamental horticultural industries to prepare potting planting media. However, peat is a finite resource and large scale peat extraction causes environmental damage (Barber, 1993; Buckland, 1993). Compost can be a partial or complete substitute for peat in horticulture.

### Compost as Potting Media

Co-composting of oil palm wastes, particularly the empty fruit bunch (EFB), frond and trunk, with sewage sludge could potentially be converted into a value added product. Kala et al. (2009) conducted a study on co-composting of different oil palm wastes with sewage sludge for use as potting media for ornamental plants. They found oil palm trunk with sewage sludge at 4:1 ratio to be the most optimum compost for potting media for ornamental plants because of its texture that is similar to peat and its high nutrient content (2.05 % N, 0.64 % P, 1.39 % K, 0.71 % Ca, 0.23% Mg, pH 6.2 and low C/N ratio, 19) (Table 4). The nutrients were within the recommended levels of the Council of European Communities (CEC, 1986). The oil palm trunk-sewage sludge compost (OPTSC) was tested for potted chrysanthemum production where it was found that the OPTSC could be used as a soilless potting medium with Agroblend (a slow release fertilizer), as a complete or partial substitute for peat with reduced fertilizer costs (Kala et al., 2012). This finding could contribute to converting oil palm waste and sewage sludge into a value-added product and reduce dependency on peat, which is a finite resource, as a potting media. Another study was carried out by Zikri (2005) to investigate the use of oil palm waste compost as soil amendment in Serdang series soil polybag media for oil palm seedling growth in the first stage nursery. Seedlings in a medium with 60% compost (lowest bulk density, highest water retention and pH value 6.7 – 7.4) with full and half recommended rate of compound fertilizer showed good growth performance.

**Table 4**: Chemical characteristics of the oil palm wastes (E=EFB, F=frond and T=trunk) and sewage sludge at different ratios (1:0, 3:1 and 4:1) after 12 weeks of composting (n=5)

| Parameters | E1:0 | E3:1 | E4:1 | F1:0 | F3:1 | F4:1 | T1:0 | T3:1 | T4:1 |
|---|---|---|---|---|---|---|---|---|---|
| pH | 6.9 a | 6.7 a | 6.9 a | 6.1 b | 5.8 c | 6.0 bc | 6.3 b | 6.1 b | 6.2 b |
| Vol. red.* | 19.7 b | 44.9 a | 47.0 a | 12.6 c | 18.2 b | 18.8 b | 10.6 d | 15.6 b | 14.8 bc |
| N % | 1.48 e | 1.78 c | 1.93 b | 1.22 f | 1.63 d | 1.45 e | 1.18 f | 2.04 a | 2.05 a |
| C/N | 32.6 b | 21.83 cd | 22.16 cd | 41.5 a | 29.67 b | 24.6 c | 41.24 a | 19.0 d | 18.98 d |
| Ca % | 0.320 g | 0.440 e | 0.420 e | 0.350 f | 0.520 c | 0.489 d | 0.287 h | 0.645 b | 0.702 a |
| Mg % | 0.260 c | 0.40 a | 0.330 b | 0.180 f | 0.220 e | 0.180 f | 0.160 f | 0.250 d | 0.230 d |
| K % | 2.11 bc | 4.03 a | 2.36 b | 1.89 cd | 2 21 bc | 2.05 bc | 1.32 f | 1.66 de | 1.39 ef |
| P % | 0.428 e | 0.585 d | 0.469 e | 0.444 e | 1.025 a | 0.808 c | 0.330 f | 0.885 b | 0.64 d |
| Pb (mg.kg-1) | 9.35 h | 62 a | 34.73 b | 9.97 h | 29.0 d | 26.35 f | 15.33 g | 33.19 c | 26.35 e |
| Cd (mg.kg-1) | 1.53 e | 3.9 a | 3.43 b | 2.0 d | 3.32 b | 2.97 c | 0.96 f | 2.78 c | 1.63 e |
| Mn (mg.kg-1) | 46.1 c | 108 a | 99.43 ab | 52.8 c | 98.46 ab | 84.85 b | 46.88 c | 87.97 b | 92.64 b |
| Zn (mg.kg-1) | 112 g | 881 a | 723 c | 66 h | 675 d | 495 e | 188 f | 829 b | 671 d |
| Fe ($mg.kg^{-1}$) | 3163 cd | 7335 a | 5322 ab | 1201 d | 5239 ab | 4692 bc | 1205 d | 6794 ab | 6310 ab |
| Cu ($mg.kg^{-1}$) | 17.88 d | 68.31 b | 67.63 b | 9.5 f | 53.33 b | 52.33 b | 14.67 | 78.6 a | 68.83 b |

(Source: Kala *et al.* 2009 )

*Vol. red = volume reduction.

* Means with different letters within the row indicate significant differences ($p<0.05$) using Duncan's multiple range test.

## Compost as Organic Fertilizer

Organic and sustainable farming systems require organic fertilizers as an input to sustain soil fertility. As organic fertilizers (OF) are complex and variable appropriate selection is important as they have a direct influence on the organic produce. A study was initiated to investigate the properties of a range of commercially available organic fertilizers in Malaysia (Kala, *et al.*, 2011). Thirty five commercially available OFs were obtained from Klang Valley, Selangor and Seremban. The OFs were grouped into oil-palm waste based (OP), plant based (P), manure based (M), plant and manure based (P+M), vermicompost (VC) based on the method of composting, and unknown (UKN) when the source of material was not known (either from the labels or the suppliers). Table 5 shows that there was vast variability in the chemical characteristics and nutrient contents of the fertilizers. It is recommended that the Department of Agriculture (DOA) have proper guidelines on the quality of OFs used in the organic farming systems in Malaysia, especially in standardizing the term 'organic' and information on the labels.

Another form of composting is vermicomposting, which is the production of compost using earthworms to break down organic wastes (feedstock) and turn them into vermicast. The vermicomposting production process is much faster as compared to composting,, ranging from 2 weeks to 1 month (depending on the type of feedstock), Vermicomposting also uses up less space as the bins can be stacked and it requires no heavy machinery. Vermicomposting can be carried out to dispose and convert agricultural waste into a useful substance. A study was conducted to study the potential of vermicomposting sago waste (Rosenani *et al.,*2011). Production of sago starch in Malaysia is 40 000 – 50,000 metric tonnes/year from an area of 33,000 ha of sago palms. Sago wastes include palm fronds, tree bark and sago pith waste. The palm fronds are commonly used as animal feed, the tree bark as fire starters while the sago pith waste is disposed off in the river. So, converting sago pith waste (SPW) into vermicompost can be one of the solutions to sustainable management of sago waste. The study showed that vermicompost produced from sago pith wastes can have high nutrient contents (Table 6). Selected SPW vermicomposts when used as a fertilizer for maize (as a test plant) showed improved plant growth performance and nutrient uptake when compared with chemical fertilizers.

**Table 5** Physico-chemical properties of commercial organic fertilizers according to source of materials

| | OP (n=10) | VC (n=9) | P (n=6) | P+M (n=3) | M (n=4) | UKN (n=3) |
|---|---|---|---|---|---|---|
| pH (1:5) | 7.3ab** | 6.1b | 6.6ab | 7.5ab | 6.9ab | 8.2a |
| EC (dS $m^{-1}$) | 1.1a | 1.4a | 4.1a | 2.4a | 2.2a | 3.1a |
| C/N | 11.6ab | 9.8b | 20.9a | 13.3ab | 10.5b | 14.1ab |
| O.M (%) | 40bc | 31c | 63a | 47ab | 57a | 58a |
| TOC (%) | 15a | 18a | 26a | 16a | 23a | 19a |
| Lignin (%) | 15a | 19a | 23a | 13a | 14a | 11a |
| TN (%) | 1.4b | 1.9ab | 1.8ab | 1.2b | 2.6a | 1.6ab |
| Cellulose (%) | 19.9a | 18.2a | 17.8a | 16.4a | 20.2a | 23.1a |
| P (%) | 0.8b | 3.9a | 0.9b | 0.8b | 1.3b | 1.1b |
| K (%) | 1.32a | 3.30a | 2.99a | 1.76a | 1.30a | 3.15a |
| Ca (%) | 1.01a | 0.90 a | 3.06a | 2.55a | 2.61a | 6.94a |
| Mg (%) | 0.34 a | 1.3 a | 0.5 a | 0.6 a | 0.9 a | 1.0 a |
| Zn (mg $kg^{-1}$) | 97b | 107b | 129b | 170b | 165b | 268a |
| Cu (mg $kg^{-1}$) | 56a | 38ab | 48ab | 56a | 31b | 48ab |
| Mn (mg $kg^{-1}$) | 240a | 318a | 265a | 525a | 443a | 275a |
| Fe (mg $kg^{-1}$) | 10960 a | 8548 b | 7606 b | 11030 a | 5268 b | 4912 b |
| Pb (mg $kg^{-1}$) | nd* | nd | nd | nd | nd | nd |
| Co (mg $kg^{-1}$) | nd | nd | nd | nd | nd | nd |
| Cd (mg $kg^{-1}$) | nd | nd | nd | nd | nd | nd |

(Source: Kala, *et al.*, 2011)

* nd- not detectable. Means with different letters within the row indicate significant difference ($p<0.05$) using Duncan's Multiple Range Test. (Source)

**Table 6** The chemical characteristics of selected vermicompost

| **Treatments** | **pH** | **C:N ratio** | **Total N (%)** | **P* (%)** | **K (%)** | **Ca (%)** | **Mg (%)** | **Humic acid (%)** | **Lignin (%)** |
|---|---|---|---|---|---|---|---|---|---|
| Autralian Std AS 4454 | 5.0-7.5 | < 20 | > 0.8 | < 0.1 | - | - | - | - | - |
| Malaysia Vermicompost range | 4.5 – 6.5 | 6.2 – 18.3 | 1.5 – 2.2 | 0.5 – 1.8 | 0.4 – 1.7 | 0.5 – 1.8 | 0.3 – 0.5 | 16.7 – 24.0 | 9.8 – 30.5 |
| SW+CM DM30 (2:1) | 6.3 c | 15.3 a | 3.1 ab | 1.3 a | 0.9 a | 1.1 a | 0.3 b | 19.3 a | 19.0 b |
| SW+CM DM60 (2:1) | 6.5 b | 12.3 ab | 3.5 a | 1.4 a | 0.9a | 0.8 a | 0.5 a | 23.0 a | 9.3 c |
| SW+GM DM30 (2:1) | 6.3 c | 15.8 a | 2.6 c | 1.3 a | 0.8 a | 1.0 a | 0.4 ab | 20.0 a | 27.1 a |

(Source: Rosenani *et al.,*2011)

Derived from Different Waste Materials in Selangor on Crop Performance and Nutrient Uptake of Maize and Soil Chemical Properties. Means with same letter within a column are not significantly different using LSD at $P<0.05$. SW =Sago waste; CM = Cow manure; GM = goat manure

*Only applicable to phosphorus sensitive plants. To investigate the feasibility of converting sago waste through vermicomposting into value added organic fertilizer.

## BIODEGRADABLE PACKAGING MATERIAL (BDPM) AS PLANTING MEDIUM

Polystyrene is one of the most widely used food packaging materials in the form of disposable plates and containers, with global production and consumption of polystyrene (all grades) in 2009 estimated to be approximately 14.4 to 14.9 million metric tons (World Petrochemical Report, 2010). The usage of polystyrene is not environmentally friendly as it is made from non renewable sources and takes hundreds of years to degrade. The styrene compound in polystyrene is carcinogenic and can cause cancer in the long term. Currently, there is great demand for biodegradable packaging materials which is more environmentally friendly to replace polystyrene. Biodegradable packaging materials (BDPM) are packaging materials which can degrade within a period of six months. In Malaysia, initiatives have been taken to produce plant-derived biodegradable packaging materials especially from EFB, tapioca starch and sugar cane bagasse. So far, only EFB derived packaging materials are commercially available in the market. Since these materials are plant-based and rich in nutrients, they can be allowed to decompose in soil and the nutrients may be recycled into the soil to be used as a planting media instead of being sent to a landfill. During the composting process, a genuine biodegradable plastic will be converted into carbon dioxide, water and compost, without leaving behind any persistent or toxic residue (Unmar *et al.*, 2008). However, such products are still a novelty, with no prior research available to study its feasibility. A trial was initiated to study the chemical composition of the locally produced BDPM and determine the rate of decomposition and effects on soil properties of the BDPM in soil, with the objective of using it as a medium for potted plants (Palani *et al.*, 2011 ; Palani *et al.*, 2013).

In the first study, the micronutrient concentrations in all of the BDPMs were found to be below the permitted concentrations, according to Korean standards, for compost. Tables 7 and 8 show the results of the characterization of the macro and micronutrients of the BDPMs used in this study. The second study which was the observation during the degradation period shows that there were significant changes in the appearance of the BDPMs. These changes include the texture of the plates which became soft and soggy, appearance of mold and porous surface. The observation done through SEM shows that the fibers that made up the BDPMs became porous at the end of the allowed degradation period. All the BDPMs showed an increase in temperature where the treatment with 5 whole plates showed a maximum increase of 30.6°C in the 16th week of degradation in soil. This pattern was followed by $CO_2$ efflux from the soil where it showed an increasing trend to a maximum of 512 mg $CO_2$ $m^{-2}h^{-1}$due to microbial activity in the soil .The efflux rate subsided to average value higher than the ambient level of 398 mg $CO^2$ $m^{-2}h^{-1}$ showing that degradation is still going on in the soil.

**Table 7** Characterization of macronutrients in Biodegradable disposable food and beverage packaging materials made from EFB, tapioca and paper. (n=3)

| Parameters | Paper | EFB | Tapioca |
|---|---|---|---|
| pH | 7.83a | 7.57a | 5.13 b |
| C (%) | 47.17c | 51.57a | 49.34b |
| N (%) | 0.18b | 0.33a | 0.16b |
| C/N | 257b | 158c | 307 a |
| Ca (%) | 2.15[a] | 1.38b | 0.85c |
| Mg(%) | 0.39[a] | 0.21b | 0.03c |
| K(%) | 0.18a | 0.18a | 0.13a |

(Source: Palani *et al*., 2013)

**Table 8** Characterization of micronutrients in biodegradable disposable food and beverage packaging materials made from EFB, tapioca and paper. (n=3)

| Parameters (mg kg-1) | Paper | EFB | Tapioca |
|---|---|---|---|
| Pb | 1.97c | 6.09a | 5.37b |
| Cd | 0.77a | 0.50a | 0.80a |
| Mn | 7.67b | 14.33a | 1.33c |
| Zn | 8.00b | 18.67a | 3.67c |
| Fe | 205b | 716a | 16c |
| Cu | 3.93ab | 5.33a | 2.37b |
| Cr | 0.28a | 0.08c | 0.11b |
| Al | 172b | 319a | 7.00c |
| Ni | 5.95a | 0.48c | 1.42b |

(Source: Palani *et al.,* 2013)

## CONVERSION OF AGRICULTURE WASTES INTO BIOCHAR

In the last decade, the idea of converting waste into biochar has been gaining popularity around the world. This carbon-rich material is made from biomass or plant material that undergoes thermal decomposition called pyrolysis, in little or absence of oxygen conditions. Biochar is very stable in soil for a very long time, helps sequestrate carbon and has numerous ways to improve soil conditions. The idea of producing and applying biochar came from the practice of *Terra preta de Índio* (Indian black earth in Portuguese) in the Amazon. The soil is dark and very fertile when compared to the soil surrounding the site, which is less fertile brown earth, called *terra mulata*. The high fertility is due to the high concentrations of recalcitrant (stable) charcoal produced from the remains of cooking and firing pots or middens (domestic wastes like animal bones, human excrements and kitchen wastes), Till today, *terra preta* soils are still fertile enough to be excavated and sold as potting media in Brazilian markets.

Biochar incorporated soil generally shows positive yield responses for a wide range of crops and plants. The positive response is due to both the direct and indirect nutrient properties of biochar (Lehmann and Joseph, 2009). Biochar with high mineral content provides additional nutrients to crops, while its nutrient retention properties reduce loss of nutrients provided by fertilizers, resulting in higher fertilizer efficiency. There are several different mechanisms associated with their proposed retention of nutrients and leaching behaviors. Amongst these are the negative surface charge on biochar that have direct electrostatic attraction toward positively charged ions, retaining cations and thus reducing leaching (Liang *et al*., 2006), increase in microbial activity and nutrient cycling (Steiner *et al*., 2008), or improved soil water holding capacity. *Biochar production and application in agriculture is currently being promoted worldwide and is a part of national policies in many developed countries as it is accepted scientifically to be the method with the highest potential for mitigation of climate change.*

Currently in UPM, there are various research studies being conducted to study various types of biochar and their potential as soil amendment for Malaysian soils to improve crop productivity. Several field trials are in progress.

### *Improvement of soil fertility and carbon sequestration in highly weathered acidic soils for sustainable production of vegetables using EFB biochar*

A study was carried out to investigate the potential of EFB biochar soil amendment in improving crop yield and soil chemical properties (Rosenani *et al*., 2011b; Rosenani *et al*., 2012; Tan *et al*., 2012**)**. The study was carried out in two phases: (i) a glasshouse container trial using sweet corn; and (ii) field trial with *Amaranthus viridis* (Plate 2). The objective of the study was to investigate the potential of locally produced EFB biochar in improving crop yield, nutrient uptake and soil properties. The treatments involved four different EFB biochar application rates: 0- ($BC_0$), 10- ($BC_{10}$), 20- ($BC_{20}$), and 30 ($BC_{30}$) t/ha. For the sweet corn container experiment, leachate was also collected to determine the effect of the EFB biochar amendment on fertilizer nutrient leaching. Application of EFB biochar was found to be able to significantly reduce the amount of nutrient (N, K, Ca, Mg) leached out by rainfall (Table 9). Fresh biomass of sweet corn in treatments with EFB biochar application was shown to be 18 – 24% higher as compared to treatment without EFB biochar. Meanwhile, the incorporation of empty fruit bunch biochar showed significant increase in fresh weight of *Amaranthus* *viridis* under organic production systems with poultry manure used as the organic fertilizer. However, the increase in biochar rate was not shown to significantly increase fresh weight of the crop.

**Table 9** Effects of EFB biochar soil amendment on total nutrients leached during the plant growth period of 56 days.

| Biochar | Mineral N | Soluble K | Soluble Ca | Soluble Mg |
|---|---|---|---|---|
| (t/ha) | (mg/container) | | | |
| 0 | 10076 ± 1460a | 4449 ± 175a | 4307 ± 64a | 4259 ± 285a |
| 10 | 6466 ± 581b | 2417 ± 211b | 2453 ± 236b | 2334 ± 434b |
| 20 | 4402 ± 460c | 1143 ± 113c | 1113 ± 105c | 1088 ± 116c |
| 30 | 3447 ± 193c | 508 ± 58 d | 495 ± 22d | 533 ± 60d |

(Source: Rosenani *et al.,* 2012)

*Means followed by the same letter within columns are not significantly different using LSD test, P= 0.05.

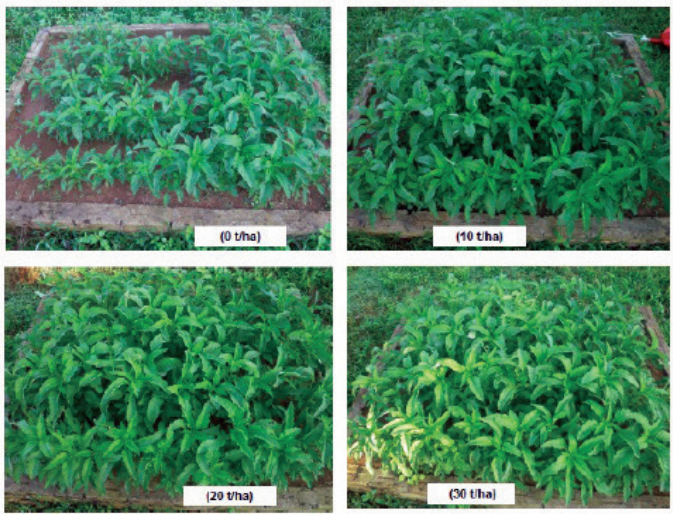



**Plate 2** Effect of EFB biochar application on the growth of *Amaranthus viridis* according to treatments

(Source: Tan *et al.*, 2012)

### *Use of biochar in rice cultivation on acid sulphate soil*

Problematic soils are found throughout the world. One of the best examples in our country is the acid sulphate soil. Acid sulphate soil is well-known for its extreme acidity (pH < 4), caused by the oxidation of the pyrite ($FeS_2$) mineral when the soil water is drained. High acidity not only creates a rather extreme condition for most industrial crops, the acidification process also brings forth the release of aluminium ions ($Al^{3+}$) from clay minerals, which later causes toxicity to most plants and other aquatic organisms. Amendment with biochar has shown the ability to elevate soil pH significantly, thus improving crop yields. A research on biochar soil amendment in an acid sulphate soil cultivated with rice showed that application of 10 t/ha of empty fruit bunch biochar resulted in significant increment of soil pH, and reduction of available aluminium in the acid sulphate soil (Rosenani *et al*., 2013). Biochar also shows interaction effects when incorporated with organic fertilizer, with increase in soil pH and carbon (Table 10). Rice yields showed a positive increment of up to 476%, together with overall plant height, number of tillers, percentage of filled grain, weight of 1000 grains and dry biomass, as compared with the control, at the application rate of up to 20 t/ha of biochar.

**Table 10** Effect of EFB Biochar Application on Soil pH and Organic Carbon Content

| Crop Cycle | Treatment | pH | C (%) |
|---|---|---|---|
| Second Crop | BC0 | 5.11 B* | 1.32 C |
| | BC10 | 5.63 B | 1.81 B |
| | BC20 | 6.21 A | 2.23 A |
| Third Crop | BC0 | 5.24 B | 1.58 B |
| | BC10 | 5.36 B | 1.60 B |
| | BC20 | 6.22 A | 1.90 AB |
| | Conventional | 4.92 B | 2.18 A |

(Source: Rosenani *et al*., 2013)

*Means sharing the same letters in a column for each crop cycle are not significantly different at $P<0.05$.

### *Sustainable biomass production of hempedu bumi (Andrographis paniculata) through enhancement of soil health with compost and biochar*

This study was initiated to investigate the potential of compost and biochar soil amendment in an organic production system of *Andrographis paniculata* or locally known as hempedu bumi. The study was carried out in a glasshouse pot trial using a combination of 3 EFB biochar rates (0, 15, 30 t/ha) and 4 organic fertilizer rates (0, 100, 200, 300 kg N/ha). The experiment showed significant interaction effects of biochar with organic fertilizers on plant height, number of branches, root biomass and photosynthesis rate (Nurulhasanah *et al*., 2013) (Figure 6). Plant growth parameters, soil pH and soil carbon were shown to increase with increasing rates of biochar and organic fertilizer applied. Both biochar and organic fertilizers promise an improvement of soil physical and chemical properties that enhance uptake of nutrients by crops due to improved soil nutrient availability (Husk and Major, 2011), thus increasing crop growth performance (Masulili *et al.*, 2010; Sarah *et al.*, 2013).

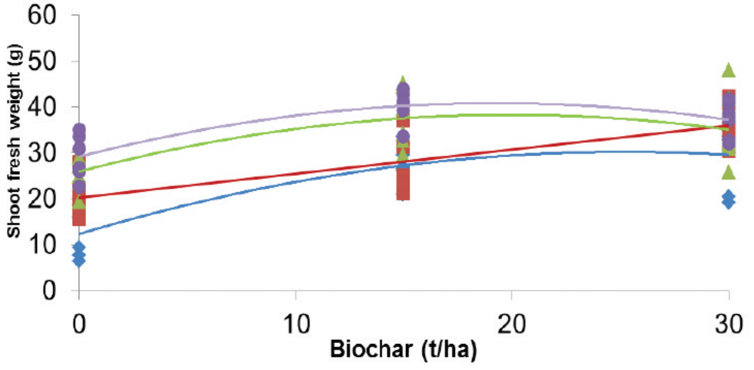



**Figure 6** Relationships between three rates of biochar application and shoot dry weight of *A. paniculata* when organic fertilizers were applied at 0 kg N/ha (◆), y = 12.34+ 1.42x – 0.03x$^2$, $R^2$ = 0.67; 100 kg N/ha (▮), y= 20.24+ 0.53x, $R^2$ =0.65; 200 kg N/ha (▲), y= 25.93 + 1.24x – 0.03x$^2$, $R^2$ =0.41; and 300 kg N/ha (●), y= 29.19+ 1.21x – 0.03x$^2$, $R^2$ = 0.72**.** Optimum rates = 20 t/ha biochar; 300 kgN/ha fertilizer**.**

### *Characterization of locally produced biochar for carbon sequestration in Malaysian agriculture soils*

The characteristics of biochar depend on the feedstock and pyrolysis process used during production. Different feedstocks and production processes will produce biochar with differing properties as shown by Spokas and Reicosky (2009) and Demirbas (2004). As such, each individual biochar has to be characterized differently. In Malaysia, potential feedstocks for biochar production are the abundant agriculture wastes such as rice husk in rice mills and oil palm empty fruit bunch (EFB) from palm oil mills. Being a recent novelty in Malaysia, the locally produced biochars have not been fully characterized as yet. A study was thus carried out to characterize the various biochars that are being produced commercially and also in the laboratory. The study is currently still in progress.

### *Reduction of greenhouse gases and nitrogen fertilizer loss from agriculture land using biological charcoal (biochar) as a soil amendment.*

There is limited information available on the mechanisms of EFB biochar in retaining nitrogen fertilizers or reducing N leaching, especially nitrate $NO_3^-$, since it is negatively charged. Further, there is also a great lack of information on its effect on $N_2O$ emissions in upland soils. Hence, a study is currently in progress to investigate the effects of EFB biochar on fertilizer–N recovery and $N_2O$ emissions, using maize as the test crop in an upland cropping system.

From the results obtained so far, locally produced biochars have shown promising results in improving soil fertility and crop growth performance. However, a lot of research is still required on locally produced biochars from organic wastes and their effects on Malaysian soils and crops, and their potential for soil carbon sequestration. Related research studies currently in progress include:

1. Alleviation of Al and Fe toxicity and improved cation exchange capacity for nutrient retention through biochar amendment techniques
2. Reduction of greenhouse gases (GHG) with biochar under flooded and upland rice cropping systems
3. Application of biochar with organic fertilizer in an organic farming system
4. Characterization of locally produced biochars

## CONCLUSION

Sustainable management and recycling of organic wastes in agriculture is a holistic approach which should be pursued not only with the sole objective of converting wastes into wealth but more seriously for its various benefits to crop production, the environment (clean water and air, and balanced carbon cycle) and, ultimately, human health.

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## BIOGRAPHY

**Rosenani Abu Bakar [PhD, Prof.]** was born on the 19th of March 1954 in Kedah, Malaysia. After graduation with a B.Sc. Agriculture from Universiti Pertanian Malaysia in 1978, she went on to further her studies at University of Ghent, Belgium, under a Belgian government scholarship, for her M.Sc. in Soil Chemistry. She embarked on her career as a lecturer in August 1980 at the Department of Soil Science, Faculty of Agriculture, Universiti Pertanian Malaysia, and later obtained her PhD. in Soil Chemistry and Plant Nutrition in 1990 from the University of Reading. She has served Universiti Putra Malaysia (UPM) for 34 years (1980 – March 2014). She is an expert and resource person, specifically in the fields of nitrogen and carbon cycles and organic waste recycling in sustainable agriculture.

As a lecturer, Rosenani taught diploma and undergraduate courses in Introductory Soil Science and Advance Soil Chemistry. Later, she was involved in developing and teaching the Land Contamination and Pollution course for M.Sc. programmes, and more recently an elective undergraduate course, 'Organic Production System'. She was awarded the Excellent Teaching Award from the Faculty of Agriculture, UPM in 2007. She also supervised final year student projects (to date 57 undergraduate students have completed their final year projects under her supervision) and postgraduates. To date, 4 PhD and 6 MSc. students have graduated under her supervision (as chairman of supervisory committees) and she has also co-supervised 4 PhD and 7 MSc. students. Currently, she is the chairman of supervisory committees of 2 PhD. and 7 MSc. students.

As a researcher, recycling of organic wastes in sustainable agriculture and nitrogen and carbon cycles are her subjects of interest. To date, she has completed 11 government funded research projects as the project leader and 7 research projects as a co-researcher. She has also received research grants to work on utilization of oil palm wastes as a mulch and in composting for conversion into organic fertilizers and soilless media under IRPA (1992-2006). She and her co-workers received a silver medal for work on the EFB mulch mat at the International Invention, Innovation and Technology Exhibition (ITEX) 2006 in Kuala Lumpur. After year 2006, her research work was focused on organic soil amendment and fertilizers in organic farming systems. Most recently, her research focused on the use of biochar (biological charcoal) as a soil amendment for improvement of crop production (vegetables in conventional and organic systems, rice and medicinal herbs) and soil carbon sequestration. In 2013, she was jointly awarded, with several other researchers, with grants under the NKEA Research Grant Scheme (NRGS) for research on improvement of biomass production of medicinal herbs, hempedu bumi (as a co-researcher ) and on organic production of dukung anak, misai kucing and hempedu bumi (as project leader).

Rosenani also received international research grants, i.e. from Southeast Asia Regional Centre for START (SARCS) and the European Union for research on greenhouse gas emissions (1993-1997), and established research links with international institutions, in collaborative projects: with the Rothamsted Experimental Station, UK (British Council CICHE programme, 1997-2000) on organic farming, and International Atomic Energy Agency (IAEA Vienna, 1982-84; 1996 -2000) on Azolla in rice systems and recycling of crop residues and sewage sludge in agricultural land. In April 2012, she was awarded, along with other workers, a research grant (EU 94,000) for a collaborative project, UPM - Leibniz-Institute for Agriculture Engineering Potsdam-Bornim (ATB), Germany, on the use of biochar to reduce nutrient leaching and N2O emission, and crop growth improvement. She has also conducted 3 contract research projects awarded by the Indah Water Konsortium (1999-2000), CCM Fertilizer Sdn. Bhd. (2006) and Aretae Pte Ltd, a Singapore-based consultancy company (2008).

In consultancy work, Rosenani was appointed as an advisor to the Department of Agriculture (1998) on the use of Azolla for sustainable rice cultivation; assessment of industrial organic waste as an organic fertilizer (Meridian World Sdn. Bhd, 2006), rice straw and rice husk decomposition (LFGC Corporation Ltd., 2007), and currently as a technical advisor for manure management in Zoo Negara (since 2013). Her expertise and interests have also been generously shared with the Malaysian public while doing her extensive work in the field or as an expert and participant in several national exhibitions (e.g. MAHA).

Throughout her engagement in academic activities, she has written and co-authored 63 papers in peer reviewed journals, a few documented technical reports and presented a total of 103 papers in local and international conferences. She also co-authored a book entitled "Application of sewage sludge on an acid tropical soil: crop response, heavy metals uptake and accumulation in the soil" (LAP LAMBERT Academic Publisher, Germany)., and has two chapters in books, i.e. 'Application of biochar as a soil amendment to improve crop yield and soil carbon sequestration' in Advances in Tropical Soils Volume 1, UPM (as main author) and 'Golden apple *(Spondias dulcis Forst. syn .Spondias cytherea Sonn)*' in Postharvest Biology and Technology of Tropical and Subtropical Fruits, Elhadi M. Yahia (Ed), Woodhead Publiser, UK (as co-author). For the Long Distance Learning B.Sc. Agric. Programme, she has written two modules, i.e. 'Introduction to Soil Science' and 'Sustainable Agriculture'. Apart from academic publications, she has also written 17 articles (from 2003-2008) in the LamanAsia magazine, a popular quarterly publication on gardening for the general public.

Being a committed and active academician and researcher, she has been a member of several university, faculty and departmental committees for curriculum, research and postgraduate studies. At present, she is a member of the UPM Committee for Research Grant Evaluation, UPM (since 2013) and UPM Steering Committee for ISO1400 (since 2012), co-ordinator for Faculty of Agriculture MOU with East Asian institutions, member of Committee for the Master of Land Agriculture Resources Management Programme (LARM), and member of Committee for Long Distance Learning for the B.Sc.Agric. programme. She is also a resource person and trainer for 'Organic Farming' courses conducted by Taman Pertanian Universiti (TPU) and the University Community Transformation Center (UCTC), UPM (since 2012). Being active in research on biochar and System of Rice intensification (SRI), she was appointed as UPM representative in the UPM - FELCRA Research Collaboration on SRI Rice production.

Her commitment towards her research has also translated into active involvement in several local and international professional societies, such as the Malaysian Soil Science Society (member of management committee in 1982/83 and 1990/93), Environmental Management and Research Association (ENSEARCH), Malaysian Society of Plant Physiology, International Horticulture Society, International Biochar Initiative, International Soil Science Society, International Society of South East Asia Agricultural Sciences (ISSAAS), and member of Executive Committee SRI Mas. She served as the chairman of the organizing committee of the 2nd National System of Rice Intensification (SRI) Conference in February 2013 and chairman of the Organizing Committee of Workshop on Efficient Management on Natural Resources in Rice Cultivation, 19 May 2014. Currently, she is also the Protem President of the newly registered Biochar Malaysia Association

(BMA). Apart from being a member of professional bodies, she has also contributed to the community as a member of the Board of Muzium Alam Shah, Selangor for two terms (1996 – 2000) and was rewarded with the Ahli Mahkota Selangor medal by the Sultan of Selangor in 1999. She was also an Executive Committee member of PUSPANITA (an association for women in government agencies), Ministry of Science, Technology and Environment and also the chairman for PUSPANITA National Remote Sensing Centre (1990-2006).

She officially retired from government service on 19 March 2014, but due to her commitment to teaching, research and supervision of postgraduate students, her service to UPM has been extended for two years as a Contract Professor.

## ACKNOWLEDGEMENT

The author would like to extend her deepest gratitude to Universiti Putra Malaysia for entrusting her with this professorial position and providing facilities for her to pursue her research interests on the subject of soil chemistry and plant nutrition in sustainable agriculture. The university has given her invaluable support, such as research grants, infrastructure, equipment and manpower throughout her 34 years of service, making it possible for her to excel in her research activities.

The author also greatly appreciates and is extremely grateful to her co-researchers (Che Fauziah Ishak, Siti Hajar Ahmad, Thohirah Abdullah Lee, Siti Aishah Hassan, Siti Zauyah Darus and Shamshuddin Jusop) for their invaluable contributions in many of her projects, in terms of their time and efforts, innovative ideas and comments during the implementation of the projects. She would particularly like to thank Dr. Siti Hajar Ahmad, a co-researcher in many of her projects, a colleague and most of all a close friend, for her inspiration, endless support and friendship. Not forgetting also and extending her most sincere thanks also to all the laboratory/ science assistants that had served under her, and her postgraduate and undergraduate students (including those who had graduated) who not only assisted her with full dedication and sacrifices in her research but also in her teaching responsibilities. She particularly owes her achievements in producing publications to all postgraduate students under her supervision and co-supervision. Special thanks also to all the academic and non- academic staff of the Department of Land Management, particularly the present and past Head of Department, for contributing either directly or indirectly to the author's success as an academician. Without the cooperation and support of all of these people, the author would not be where she is today.

She is also grateful and extends her thanks and appreciation to the sponsors of her research projects which include: UPM Research University Grant Scheme (RUGS), , Ministry of Higher Education (FRGS and LRGS), Ministry of Science, Technology and Innovation (eSciencfund) and Ministry of Agriculture (NKEA Research Grant Scheme, NGRS). Her research would not have been possible without these financial supports.

This long successful journey would not have been possible without Allah's will and the strength and support of her family. The author is ever grateful to her husband Dato' Nik Nasruddin Wan Mahmood who has been patient and continuously given her moral support and encouragement in her pursuit of success in her career. She also thanks her wonderful children (Nik Jasmin Hazwa and Nik Haris) for their love and patience, and being the source of her inspiration. Last but not least, she gives thanks to her late father (Abu Bakar Osman) and mother (Zainab Zainul Rashid) and her brothers and sisters, for their unfailing love, guidance and endless prayers. Their contributions have never been never out of her thoughts and appreciation.

## LIST OF INAUGURAL LECTURES

1. Prof. Dr. Sulaiman M. Yassin
*The Challenge to Communication Research in Extension*
22 July 1989

2. Prof. Ir. Abang Abdullah Abang Ali
*Indigenous Materials and Technology for Low Cost Housing*
30 August 1990

3. Prof. Dr. Abdul Rahman Abdul Razak
*Plant Parasitic Nematodes, Lesser Known Pests of Agricultural Crops*
30 January 1993

4. Prof. Dr. Mohamed Suleiman
*Numerical Solution of Ordinary Differential Equations: A Historical Perspective*
11 December 1993

5. Prof. Dr. Mohd. Ariff Hussein
*Changing Roles of Agricultural Economics*
5 March 1994

6. Prof. Dr. Mohd. Ismail Ahmad
*Marketing Management: Prospects and Challenges for Agriculture*
6 April 1994

7. Prof. Dr. Mohamed Mahyuddin Mohd. Dahan
*The Changing Demand for Livestock Products*
20 April 1994

8. Prof. Dr. Ruth Kiew
*Plant Taxonomy, Biodiversity and Conservation*
11 May 1994

9. Prof. Ir. Dr. Mohd. Zohadie Bardaie
*Engineering Technological Developments Propelling Agriculture into the 21st Century*
28 May 1994

10. Prof. Dr. Shamsuddin Jusop
*Rock, Mineral and Soil*
18 June 1994

11. Prof. Dr. Abdul Salam Abdullah
*Natural Toxicants Affecting Animal Health and Production*
29 June 1994

12. Prof. Dr. Mohd. Yusof Hussein
*Pest Control: A Challenge in Applied Ecology*
9 July 1994

13. Prof. Dr. Kapt. Mohd. Ibrahim Haji Mohamed
*Managing Challenges in Fisheries Development through Science and Technology*
23 July 1994

14. Prof. Dr. Hj. Amat Juhari Moain
*Sejarah Keagungan Bahasa Melayu*
6 Ogos 1994

15. Prof. Dr. Law Ah Theem
*Oil Pollution in the Malaysian Seas*
24 September 1994

16. Prof. Dr. Md. Nordin Hj. Lajis
*Fine Chemicals from Biological Resources: The Wealth from Nature*
21 January 1995

17. Prof. Dr. Sheikh Omar Abdul Rahman
*Health, Disease and Death in Creatures Great and Small*
25 February 1995

18. Prof. Dr. Mohamed Shariff Mohamed Din
*Fish Health: An Odyssey through the Asia - Pacific Region*
25 March 1995

19. Prof. Dr. Tengku Azmi Tengku Ibrahim
*Chromosome Distribution and Production Performance of Water Buffaloes*
6 May 1995

20. Prof. Dr. Abdul Hamid Mahmood
*Bahasa Melayu sebagai Bahasa Ilmu-Cabaran dan Harapan*
10 Jun 1995

21. Prof. Dr. Rahim Md. Sail
*Extension Education for Industrialising Malaysia: Trends, Priorities and Emerging Issues*
22 July 1995

22. Prof. Dr. Nik Muhammad Nik Abd. Majid
*The Diminishing Tropical Rain Forest: Causes, Symptoms and Cure*
19 August 1995

23. Prof. Dr. Ang Kok Jee
*The Evolution of an Environmentally Friendly Hatchery Technology for Udang Galah, the King of Freshwater Prawns and a Glimpse into the Future of Aquaculture in the 21st Century*
14 October 1995

24. Prof. Dr. Sharifuddin Haji Abdul Hamid
*Management of Highly Weathered Acid Soils for Sustainable Crop Production*
28 October 1995

25. Prof. Dr. Yu Swee Yean
*Fish Processing and Preservation: Recent Advances and Future Directions*
9 December 1995

26. Prof. Dr. Rosli Mohamad
*Pesticide Usage: Concern and Options*
10 February 1996

27. Prof. Dr. Mohamed Ismail Abdul Karim
*Microbial Fermentation and Utilization of Agricultural Bioresources and Wastes in Malaysia*
2 March 1996

28. Prof. Dr. Wan Sulaiman Wan Harun
*Soil Physics: From Glass Beads to Precision Agriculture*
16 March 1996

29. Prof. Dr. Abdul Aziz Abdul Rahman
*Sustained Growth and Sustainable Development: Is there a Trade-Off 1 or Malaysia*
13 April 1996

30. Prof. Dr. Chew Tek Ann
*Sharecropping in Perfectly Competitive Markets: A Contradiction in Terms*
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31. Prof. Dr. Mohd. Yusuf Sulaiman
*Back to the Future with the Sun*
18 May 1996

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*Enzyme Technology: The Basis for Biotechnological Development*
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*The Fascinating Numbers*
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*Fungi: Friends or Foes*
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*Genetic Diversity of Some Southeast Asian Animals: Of Buffaloes and Goats and Fishes Too*
10 August 1996

36. Prof. Dr. Nazaruddin Mohd. Jali
*Will Rural Sociology Remain Relevant in the 21st Century?*
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37. Prof. Dr. Abdul Rani Bahaman
*Leptospirosis-A Model for Epidemiology, Diagnosis and Control of Infectious Diseases*
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*Plant Biotechnology - Strategies for Commercialization*
21 December 1996

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*Market Relationships in the Malaysian Fish Trade: Theory and Application*
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*Food and Its Healing Power*
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*A Distributed Collaborative Environment for Distance Learning Applications*
17 June 1998

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*Advancing the Fruit Industry in Malaysia: A Need to Shift Research Emphasis*
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*Avian Respiratory and Immunosuppressive Diseases- A Fatal Attraction*
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*Biological Control of Plant Pathogens: Harnessing the Richness of Microbial Diversity*
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*The Endomycorrhiza: A Futile Investment?*
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*Molecular Plant Virology: The Way Forward*
2 February 2000

47. Prof. Dr. Muhamad Awang
*Do We Have Enough Clean Air to Breathe?*
7 April 2000

48. Prof. Dr. Lee Chnoong Kheng
*Green Environment, Clean Power*
24 June 2000

49. Prof. Dr. Mohd. Ghazali Mohayidin
*Managing Change in the Agriculture Sector: The Need for Innovative Educational Initiatives*
12 January 2002

50. Prof. Dr. Fatimah Mohd. Arshad
*Analisis Pemasaran Pertanian di Malaysia: Keperluan Agenda Pembaharuan*
26 Januari 2002

51. Prof. Dr. Nik Mustapha R. Abdullah
*Fisheries Co-Management: An Institutional Innovation Towards Sustainable Fisheries Industry*
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52. Prof. Dr. Gulam Rusul Rahmat Ali
*Food Safety: Perspectives and Challenges*
23 March 2002

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*Nutrient Management Strategies for Sustainable Crop Production in Acid Soils: The Role of Research Using Isotopes*
13 April 2002

54. Prof. Dr. Maisom Abdullah
*Productivity Driven Growth: Problems & Possibilities*
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*Immunodiagnosis and Vaccination for Brugian Filariasis: Direct Rewards from Research Investments*
6 June 2002

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*Agro-ento Bioinformation: Towards the Edge of Reality*
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*Sustainability of Tropical Animal-Agricultural Production Systems: Integration of Dynamic Complex Systems*
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*The Economics of Exchange Rates in the East Asian Countries*
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*Contractual Justice in Asean: A Comparative View of Coercion*
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*Chemical Modification of Polymers: Current and Future Routes for Synthesizing New Polymeric Compounds*
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*Is the KLSE Efficient? Efficient Market Hypothesis vs Behavioural Finance*
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*Blueprint for Transformation or Business as Usual? A Structurational Perspective of the Knowledge-Based Economy in Malaysia*
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*Chemical Diversity of Malaysian Flora: Potential Source of Rich Therapeutic Chemicals*
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*Psychotheraphy for Rural Malays - Does it Work?*
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*Bioremediation-A Hope Yet for the Environment?*
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*The Wonder of Our Neuromotor System and the Technological Challenges They Pose*
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    *Rumen Microbes and Some of Their Biotechnological Applications*
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    *Haemorrhagic Septicaemia in Cattle and Buffaloes: Are We Ready for Freedom?*
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    *Activating Teachers' Knowledge and Lifelong Journey in Their Professional Development*
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    *Internet Unwired*
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    *Development and Innovation in the Fracture Management of Animals*
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    *Strategic Feeding for a Sustainable Ruminant Farming*
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    *Green Organic Chemistry: Enzyme at Work*
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    *Managing Change - The Fads and The Realities: A Look at Process Reengineering, Knowledge Management and Blue Ocean Strategy*
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    *Expert Systems for Environmental Impacts and Ecotourism Assessments*
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    *Pathogens and Residues; How Safe is Our Meat?*
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    *Hubungan Sesama Manusia*
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    *Planning for Equal Income Distribution in Malaysia: A General Equilibrium Approach*
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    *Palm Oil: Still the Best Choice*
    1 February 2008

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    *Probing the Microscopic Worlds by Lonizing Radiation*
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*Waste-to-Wealth Through Biotechnology: For Profit, People and Planet*
28 March 2008

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*Metrology at Nanoscale: Thermal Wave Probe Made It Simple*
11 April 2008

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*The Future of Pesticides Technology in Agriculture: Maximum Target Kill with Minimum Collateral Damage*
25 April 2008

111. Prof. Dr. Mohd. Yazid Abd. Manap
*Probiotics: Your Friendly Gut Bacteria*
9 May 2008

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*Sustainable Supply of Wood and Fibre: Does Malaysia have Enough?*
23 May 2008

113. Prof. Dato' Dr. Makhdzir Mardan
*Connecting the Bee Dots*
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*Gender & Career: Realities and Challenges*
25 July 2008

115. Prof. Dr. Nor Aripin Shamaan
*Biochemistry of Xenobiotics: Towards a Healthy Lifestyle and Safe Environment*
1 August 2008

116. Prof. Dr. Mohd Yunus Abdullah
*Penjagaan Kesihatan Primer di Malaysia: Cabaran Prospek dan Implikasi dalam Latihan dan Penyelidikan Perubatan serta Sains Kesihatan di Universiti Putra Malaysia*
8 Ogos 2008

117. Prof. Dr. Musa Abu Hassan
*Memanfaatkan Teknologi Maklumat & Komunikasi ICT untuk Semua*
15 Ogos 2008

118. Prof. Dr. Md. Salleh Hj. Hassan
*Role of Media in Development: Strategies, Issues & Challenges*
22 August 2008

119. Prof. Dr. Jariah Masud
*Gender in Everyday Life*
10 October 2008

120 Prof. Dr. Mohd Shahwahid Haji Othman
*Mainstreaming Environment: Incorporating Economic Valuation and Market-Based Instruments in Decision Making*
24 October 2008

121. Prof. Dr. Son Radu
*Big Questions Small Worlds: Following Diverse Vistas*
31 Oktober 2008

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*Responding to Changing Lifestyles: Engineering the Convenience Foods*
28 November 2008

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*Aesthetics in the Environment an Exploration of Environmental: Perception Through Landscape Preference*
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