GROWTH AND RESIDUAL NUTRIENTS IN SOIL OF INTERCROPPED STAND OF *KHAYA SENEGALENSIS* AND *ORTHOSIPHON STAMINEUS* TREATED WITH PAPER MILL BIOSLUDGE

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ROSAZLIN A, WAN RASIDAH K, FAUZIAH CI, ROSENANI AB & ROZITA A. 2015. Growth and residual nutrients in soil of intercropped stand of *Khaya senegalensis* and *Orthosiphon stamineus* treated with paper mill biosludge. The effect of soil amendment with biological sludge from the paper mill on growth of *Khaya senegalensis* forest tree and *Orthosiphon stamineus* medicinal shrub was studied. Both crops received nutrient input early, i.e. after transplanting. Growth data were taken at fixed intervals for up to 1 year. *Orthosiphon stamineus* was measured for aboveground dry matter yield at four crop cycles. Residual nutrient level in soil after 1 year of application was evaluated. Comparison was made with inorganic fertiliser application and untreated soil. *Khaya senegalensis* responded positively to raw and composted biosludge applications, outperforming the widely used inorganic fertiliser. Biosludge application resulted in greater height increment, diameter growth and total plant biomass than the control and inorganic fertiliser. *Orthosiphon stamineus* also produced greater biomass with biosludge application and the trend remained the same for all crop cycles except for the relatively lower yield at the second, third and fourth crop cycles. Soil fertility parameters were most affected at the topsoil layer with overall accreting tendency under *K. senegalensis* tree with sludge application. Exchangeable K was the most limiting nutrient for *K. senegalensis* while P and K limited growth of *O. stamineus*.

Keywords: Mixed planting, nutrient use efficiency, compost paper sludge, soil quality, agroforestry

INTRODUCTION

Utilisation of paper mill sludge as fertiliser and soil amendments in Malaysia is still at a trial stage as industry application has yet to take off. As the pulp and paper mill industry in this country remains relevant, generation of mill wastes and biosludge will keep increasing. All paper mills produce sludge and papermaking using recycled pulp creates more sludge than that using virgin pulp. Landfill disposal is a popular option for managing this waste but for sludge categorised under scheduled waste, this option is costly. Pulp and paper mill sludges face increasingly stringent environmental regulations prior to discard (Feldkirchner et al. 2003).

With increasing popularity of organic by-products as soil amendments in agriculture and forestry (Kost et al. 1997, Phillips et al. 1997), paper mill sludge offers great potential for converting wastes into resources. This material contributes both organic matter and nutrients, which have potential benefits in improving soil quality and site productivity (Gagnon et al. 2003). The positive attribute of pulp and paper mill sludges on plant growth, soil fertility and nutrient properties as well as soil physical properties have been reported (Ritter et al. 1992, Bellamy et al. 1995, Phillips et al. 1997, Levy & Taylor 2003, Feldkirchner et al. 2003). Paper mill sludge contains several essential plant elements that may help plant growth including N, P, K, Ca and Mg (Feldkirchner et al. 2003). Based on experiments over a 10-year period, Bellamy et al. (1995) concluded that for a large range of crops, paper mill sludge is a beneficial organic amendment for potting media and field soil, provided sufficient N fertiliser is applied. Land

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application of paper mill sludge has significantly increased corn yields even in the absence of mineral fertiliser and increased total N in corn plants compared with the control (Curnoe et al. 2006). Increases in yield due to application of paper mill sludge for a range of crops on acid soil have been reported (Panda et al. 1990).

The use of pulp and paper mill sludge as soil amendments has resulted in wide crop responses. One reason can be variation in paper mill sludge composition due to differences in the production system or machinery used in pulp and papermaking, in addition to the type and amount of additives prescribed in waste treatment plant protocols. In land application scenario, pulp and paper mill sludges are a source of organic matter for soil and secondary sludges contain significant quantities of N and P (Logan & Esmaeilzadeh 1985, Zibilske 1987, Feagley et al. 1994) that can benefit crops. However, the rapid decomposition of N-rich pulp and paper mill sludges, once added to soil at high rates, can liberate constituents that may affect water quality (Kraske & Fernandez 1993, Catricala et al. 1996). On the contrary, irrigation with treated municipal wastewater leads to significant increase in the content of some macro- and micro-elements in the soil as well as heavy metal contents in broccoli and brussel sprout (Kalavrouziotis et al. 2008). However, for paper mill sludge, heavy metals are not a threat (Rosazlin et al. 2010a). This paper evaluates the effect of land application of paper mill biosludge on the growth of plantation forest tree and medicinal shrub. It also assessed fertility level of acid soil after 1 year of sludge application. Sludge used in this study consisted of biological secondary treated wastewater from a mill producing paper from recycled pulp.

MATERIALS AND METHODS

Site, climate, soil and treatment

The experiment was established at the University Agriculture Park, Puchong, Selangor (101° 38' E, 2° 59' N with altitude of 31 m above sea level). It was an almost flat land having a total rainfall of 2969 mm during the 13-month study period (Figure 1). High intensity rainfall from November till January coincided with the north-east monsoon season, while the peak in May was from the south-west monsoon. Soil at the site is mapped as Bungor series (Tipik Lutualemkuts, Malaysian Soil Taxonomy (Paramananthan 2000) or Typic Paleudult, USDA Classification). It has common features as the majority of Malaysian soil, i.e. acidic, low nutrients and low cation exchange capacity (Table 1). The texture of soil is sandy clay loam.

The agroforestry system implemented in this study was intercropping of the timber tree *Khaya senegalensis* and the medicinal shrub *Orthosiphon stamineus.* A total of 252 *K. senegalensis* seedlings were planted in mid-June 2009 at 4 m × 3 m distance with 18 trees in vertical line and 14 trees in horizontal line. The total area for the experimental set up was 0.3 ha (56 m × 56 m). From this total area, 16 plots of 60 m^2 (10 m × 6 m) were established and each plot consisted of six plants of *K. senegalensis. Orthosiphon stamineus* seedlings were planted at 1.5 m distance between rows of *K. senegalensis,* thus ending up with 10 measured plants for each plot. Healthy seedlings of *O. stamineus* were selected from among those raised at the University Agriculture Park in Puchong, Selangor, while *K. senegalensis* seedlings were obtained from the Forest Research Institute Malaysia, Kepong, Selangor.

The experimental set up was randomised complete block design with four treatments and four replications comprising different nutrient inputs for *K. senegalensis* and *O. stamineus* (Table 2). Selection of treatments was based on the results of a glasshouse study done earlier (Rosazlin et al. 2010b). Higher N input rate for biosludge was to counter the large portion of N present in organic form, whereas for inorganic fertiliser, N was in soluble form. This study was carried out for 1 year for *K. senegalensis* and four crop cycles for *O. stamineus* with harvesting interval every 3 months: first cycle 22 July–25 October 2009, second cycle 26 October 2009–27 January 2010, third cycle 28 January–1 March 2010 and fourth cycle 2 March–20 July 2010.

Raw biosludge, biosludge compost and fertiliser

Paper mill biosludge was obtained from the United Paper Board Sdn Bhd, Selangor with official approval from the Department of Environment, Malaysia. Raw biosludge was used as it was, while biosludge compost was produced based on Rosazlin et al. (2011). Basically, the

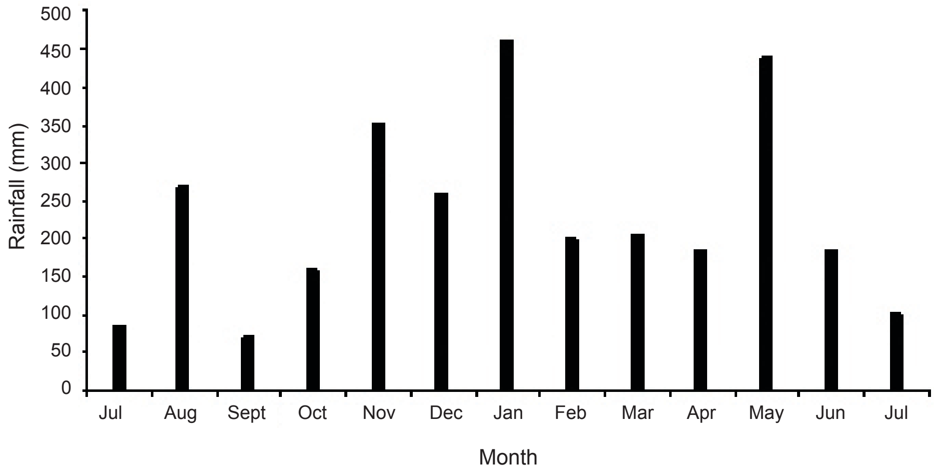

Figure 1 Rainfall distribution from July 2009 till July 2010

Table 1 Selected physico–chemical properties of the soil at 0–20 cm depth

Parameter	Value
pH (H_2O)	4.59
Total N (%)	0.14
Organic C (%)	1.36
Available P (mg kg^{-1})	14.28
EC (µS cm^{-1})	29.57
Exchangeable K ($cmol_{(+)}$ kg^{-1})	0.12
Exchangeable Ca ($cmol_{(+)}$ kg^{-1})	0.85
Exchangeable Mg ($cmol_{(+)}$ kg^{-1})	1.28
CEC ($cmol_{(+)}$ kg^{-1})	9.55
Bulk density (g cm^{-3})	1.28
Sand (%)	61.8
Silt (%)	4.60
Clay (%)	33.6

EC = electrical conductivity, CEC = cation exchange capacity

Table 2 Treatments established

Treatment	*Khaya senegalensis*	*Orthosiphon stamineus*
T1	Control (no fertiliser)	Control (no fertiliser)
T2	150 kg N ha^{-1} of inorganic fertiliser (recommended rate)	100 kg N ha^{-1} of inorganic fertiliser (recommended rate)
T3	300 kg N ha^{-1} of biosludge compost	200 kg N ha^{-1} of biosludge compost
T4	300 kg N ha^{-1} of raw biosludge	200 kg N ha^{-1} of raw biosludge

feedstock was a mixture of biosludge and shredded oil palm empty fruit bunch at a ratio of 1:1. The feedstock was placed in a polystyrene container of 0.6 m length, 0.5 m width and 0.4 m height to 90% volume and at 50% moisture content. The feedstock was turned every 3 days to ensure homogeneity and to dissipate heat. The compost was evaluated for maturity when temperature stabilised which occurred after 90 days.

Selected physico–chemical properties of raw and biosludge compost produced are shown in Table 3. Nitrogen concentration was reduced to almost half in the compost that we produced, averaging the low empty fruit bunch nitrogen concentration produced by Wan Asma et al. (2007). Heavy metal concentrations in both raw and composted biosludge were below the toxic levels and were discussed in detail in Rosazlin et al. (2010a). The application rates of both forms of sludge were based on the N content. Both forms were air dried and passed through a 4.7-mm sieve prior to application around the tree within 50 cm radius. This was carried out at the beginning of the experiment after transplanting.

Ammonium sulphate was applied as inorganic N fertiliser for inorganic fertiliser treatment (T2). To balance nutrient input, P was applied as triple super phosphate and K as muriate of potash, both at a rate of 150 kg ha^{-1} for *K. senegalensis* and 100 kg ha^{-1} for *O. stamineus,* to all treatments except for the control. To reduce cross-over effect of different treatments, every plot was skipped with one row of *K. senegalensis*, creating border trees. Drains were built in between the control and treatment plots to prevent runoffs and flowing across of dissolved nutrients from raw and composted biosludge to the other plots.

No chemical pesticides or herbicides were used to avoid heavy metal contamination. Weeding was done manually once every fortnight and plants were watered daily except on rainy days.

Harvesting and measurement of growth parameters

Orthosiphon stamineus was harvested every 3 months for four cycles. The aboveground biomass harvested for the first cycle was from seedling, while the second and subsequent cycles were developed from ratoon. Growth performance indicator was taken as weights of leaves and stems, measured separately. After the fourth cycle, destructive sampling was carried out to determine total plant biomass. For this purpose, harvested plants were separated into leaves, stems and roots, then weighed separately. These samples were dried in an oven (65–70 °C) until constant weight.

For *K. senegalensis*, growth parameters (basal diameter and height) were measured twice a month for the first 5 months and once a month for the next 7 months. Results were presented as height and basal diameter increments after subtracting the initial measurements. Destructive sampling of representative *K. senegalensis* trees was carried out to determine total plant biomass at the end of the 1 year. The tree biomass was separated into leaves, stems, branches and roots, and weighed. The samples were dried in an oven (65–70 °C) until constant weight and computed for dry matter yield.

Table 3 Selected chemical properties of raw biosludge and biosludge compost used in the experiment

Parameter	Raw biosludge	Biosludge compost
pH (H_2O)	7.84	7.18
Total N (%)	4.05	2.68
Organic C (%)	33.67	52.52
CEC (cmol $_{(+)}$ kg^{-1})	28.07	–
P (%)	0.78	0.71
K (%)	0.42	0.69
Ca (%)	0.53	0.47
Mg (%)	0.45	0.29

CEC = cation exchange capacity

Soil sampling

To determine residual plant nutrients in soil at the end of the study, laboratory analyses were carried out for soil samples under *K. senegalensis* and *O. stamineus*. Soil samples of both crops were taken at three depths: 0–15, 15–30 and 30–45 cm using a stainless steel auger. These samples were air dried, ground and those having sizes of less than 2 mm were analysed for fertility level comprising acidity, conductivity, cation exchange capacity (CEC) and macronutrients. pH was determined from the supernatant of the mixed sample and distilled water ratio of 1:2.5 using pH meter. Electrical conductivity (EC) was measured from a solution collected from the saturated paste using EC meter. Total carbon was measured by the combustion technique (Merry & Spouncer 1988) using carbon analyser. Total N was determined using the modified Kjeldahl method (Bremner & Mulvaney 1982). Available P was extracted using the Bray and Kurtz no. 2 extractant (Bray & Kurtz 1945). Soil exchangeable bases (K^+, Ca^{2+} and Mg^{2+}) and CEC was determined by the NH_4OAc (pH 7) method (Thomas 1982). The leached bases were determined by atomic absorption spectrophotometer.

Data analysis

All data were analysed using analysis of variance (ANOVA). Where significant, Tukey's test was used to compare the mean values using Statistical Analysis System software.

RESULTS AND DISCUSSION

Growth performance

Figure 2a shows the trend for height increment of *K. senegalensis* after 1-year application of raw and composted paper mill biosludge in comparison with NPK inorganic fertiliser and control under field condition. *Khaya senegalensis* achieved 4.45 m in height with raw biosludge application, followed by composted biosludge (4.2 m), inorganic fertiliser (3.8 m) and control (3.3 m) treatments. Increments for both forms of biosludge were significantly different than the control and NPK fertilised plants. Differences in height between organic and inorganic nutrient inputs appeared after 4 months while differences with unfertilised plants happened at 60 days. These are clear indications of the potential of raw and composted biosludge as effective soil amendment for improving plant height growth. Either forms of sludge are as effective but the compost form is marketable.

Diameter growth of *K. senegalensis* proceeded at a slower pace initially then picked up gradually. At 4 months, significant differences emerged for basal diameter growth between all treated plots and the control, and the trend remained throughout (Figure 2b). The largest diameter could be seen in the raw biosludge treatment (10.3 cm), followed by biosludge compost (9.3 cm) and inorganic fertiliser (8.7 cm), while the lowest was the control (7.2 cm).

Biomass distribution for the entire plant of *K. senegalensis* was found mostly concentrated in the stems followed by roots, leaves and branches (Figure 2c). After 1 year, application of either raw or composted biosludge produced equivalent biomass and both gave higher total biomass yield compared with the inorganic fertiliser or the control. Higher tuber yield was reported in a 3-year rain fed potato culture using composted and raw paper mill sludge (Fahmy et al. 2000).

The aboveground biomass yields for *O. stamineus* for the four crop cycles are depicted in Figure 3. Regardless of the crop cycles, treatment with biosludge compost gave the highest biomass yields, followed by raw biosludge, inorganic fertiliser and untreated control. The trends were similar for all crop cycles. In the first, second and third cycles, there were no significant differences between treatments except for composted sludge. For the fourth cycle, dry matter yield was low and both raw and composted sludge gave comparable results. Hence, it could be concluded that raw and composted biosludges were able to perform just as good as or better than the inorganic fertiliser in improving biomass productionof *O. stamineus*.

Soil reactivity and nutrient level

Table 4 shows soil reactivity and C levels at the planting site after 1-year application with biosludge, grown with *K. senegalensis* and *O. stamineus*. Soil pH was significantly

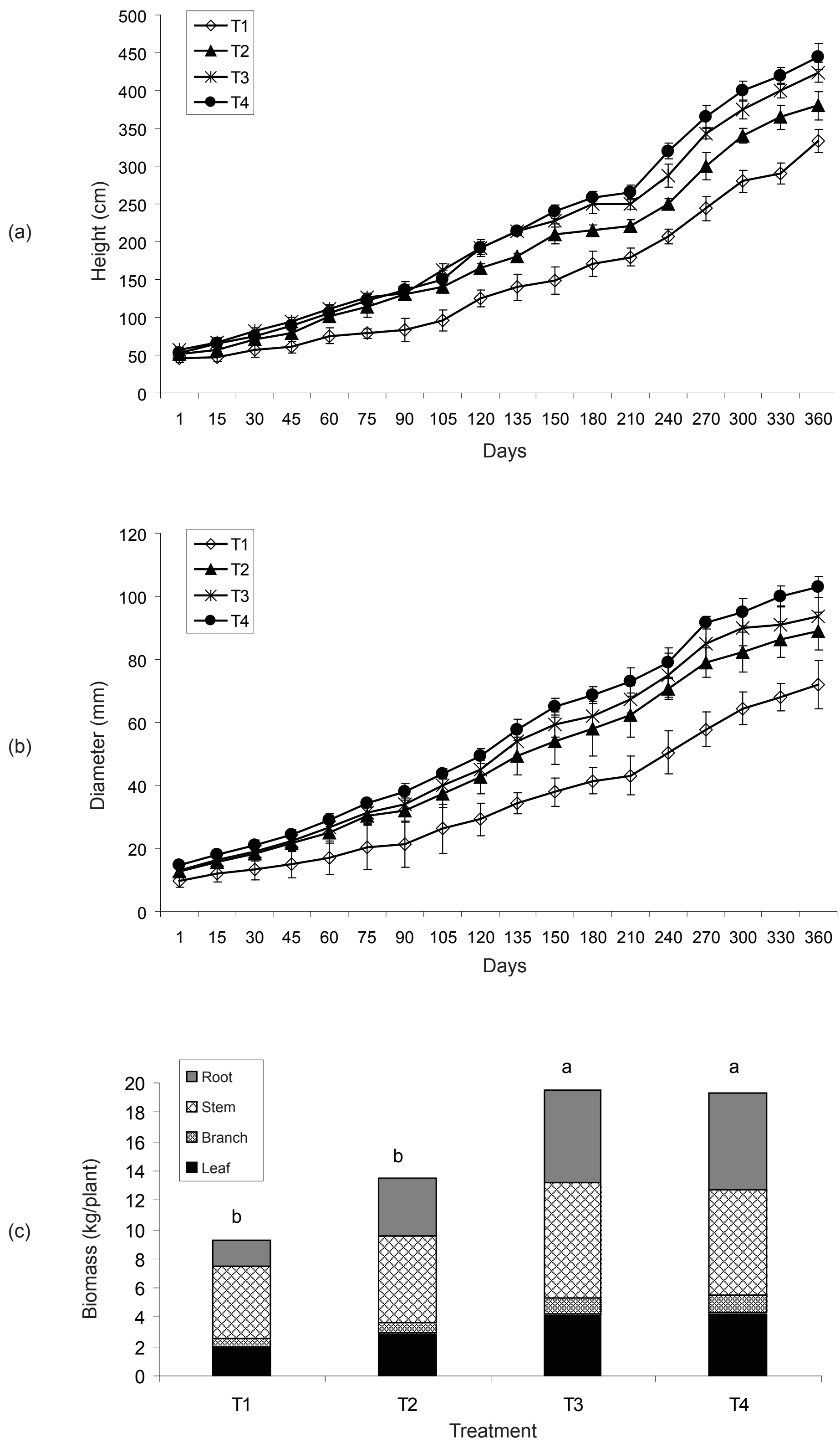

Figure 2 (a) Height increment, (b) diameter growth and (c) plant biomass of *Khaya senegalensis* after 1-year application of composted and raw biosludges under field condition; means with the same letter on the bars are not significantly different by Tukey's test at 5% level; T1= control, T2 = inorganic fertiliser N, T3 = biosludge paper compost, T4 = raw paper biosludge

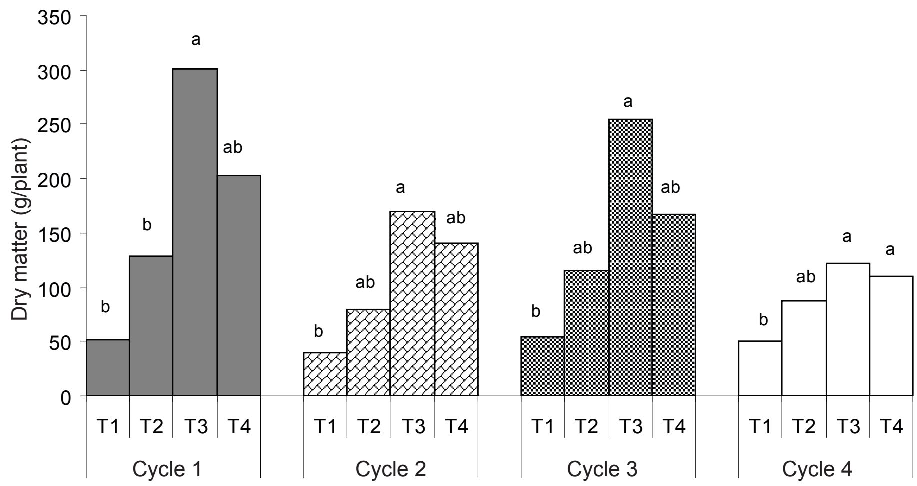

Figure 3 Mean dry matter yield for the four crop cycles of *Orthosiphon stamineus* amended with raw and composted paper mill biosludge under field condition; values with the same letter on the bars within cycles are not significantly different by Tukey's test at 5% level; T1 = control, T2 = inorganic fertiliser N, T3 = biosludge paper compost, T4 = raw paper biosludge

increased at all depths under *K. senegalensis* with highest increment recorded for raw biosludge application. Paper mill biosludge may increase soil pH substantially (Beyer et al. 1997) or not affect the soil at all (Tripepi et al. 1996) depending on the sludge and soil attributes. Still at acidic level, this increase can have important influence on many of the soil reactions, particularly in adsorption and retention of soil nutrients. The alkalinity of paper mill sludge used in this study typically arises from caustic materials added during the papermaking process and/or $CaCO_3$ used in the paper finishing process (Camberato et al. 2006). Under *O. stamineus* planting, only the first two upper soil layers had significant increase in pH with raw and composted biosludge applications. Inorganic fertiliser treatment also reduced soil acidity particularly in the 15–30 cm. Increase in soil pH indicates the usefulness of paper mill biosludge as liming agent to ameliorate acid soil for crop cultivation.

Soil EC had variable changes with raw and composted biosludge amendments but significantly increased with inorganic fertiliser application (Table 4). Accumulation of salts from fertiliser could cause the increase but this was not clearly reflected in exchangeable cation data (Table 5). The increase may be also caused by accumulation of NO_3^-/NH_4^+ and PO_4^{3-}. Raw sludge application increased soil conductivity under *K. senegalensis* trees (compared with the control and composted sludge) but did not affect soil under *O. stamineus* (Table 4). However, the values obtained were far below the threshold value of 4 mS cm^{-1} where EC needed to be monitored and the application rate adjusted.

Paper mill biosludge increased total C only in the 0–15 cm layer at 1-year application in sites grown with *K. senegalensis* and *O. stamineus* (Table 4). This indicates that these materials can help to restore or maintain C status of cultivated (or degraded) soil. On sandy soil, Beyer et al. (1997) found that the amount of total organic carbon increased due to the fact that secondary paper mill sludge application disappeared within 1 year. Increase in soil organic carbon following paper mill sludge application has been reported by Logan and Esmaeilzadeh (1985) and Phillips et al. (1997).

Cation exchange capacity was increased by raw biosludge only in the topsoil layer under *K. senegalensis*, indicating a greater capacity to hold cations (Table 4). Paper mill sludge addition was reported to increase soil CEC (Rodella et al. 1995). However, under the shallow-rooted medicinal shrub *O. stamineus*, no significant effect was detected with any treatment for all soil depths.

Macronutrient availability in soil at 1 year after application of inorganic fertiliser, biosludge compost and raw biosludge is presented in

Table 4 Soil reactivity and carbon levels (± standard errors) after 1-year application with composted and raw paper mill biosludge

Treatment	pH	EC ($\mu S\ cm^{-1}$)	Total C (%)	CEC ($cmol_{(+)}\ kg^{-1}$)
Khaya senegalensis				
		Soil depth 0–15 cm		
T1	4.59 ± 0.10 b	30.07 ± 2.40 b	1.77 ± 0.10 b	11.66 ± 0.40 ab
T2	4.80 ± 0.10 a	35.90 ± 4.90 a	1.75 ± 0.10 b	10.61 ± 0.60 b
T3	4.82 ± 0.20 a	31.57 ± 1.40 b	2.20 ± 0.10 a	14.92 ± 0.40 ab
T4	4.98 ± 0.20 a	36.53 ± 3.20 a	1.89 ± 0.20 ab	15.83 ± 0.70 a
		Soil depth 15–30 cm		
T1	4.68 ± 0.10 ab	29.83 ± 4.60 b	1.36 ± 0.10 a	11.94 ± 0.60 a
T2	4.63 ± 0.10 b	36.80 ± 1.70 a	1.11 ± 0.10 a	12.50 ± 0.40 a
T3	4.78 ± 0.20 ab	30.77 ± 3.20 b	1.47 ± 0.10 a	13.86 ± 0.50 a
T4	4.79 ± 0.20 a	36.87 ± 5.50 a	1.48 ± 0.20 a	15.17 ± 0.30 a
		Soil depth 30–45 cm		
T1	4.70 ± 0.20 bc	32.43 ± 6.00 b	0.98 ± 0.00 a	10.33 ± 0.40 a
T2	4.62 ± 0.10 c	32.20 ± 1.60 b	1.05 ± 0.10 a	10.71 ± 0.50 a
T3	4.78 ± 0.10 b	32.60 ± 3.70 b	1.04 ± 0.10 a	9.55 ± 0.70 a
T4	4.99 ± 0.10 a	38.90 ± 2.50 a	1.30 ± 0.10 a	11.83 ± 0.60 a
Orthosiphon stamineus				
		Soil depth 0–15 cm		
T1	4.74 ± 0.13 b	40.06 ± 5.50 a	1.82 ± 0.10 b	11.80 ± 0.40 a
T2	4.80 ± 0.10 b	41.63 ± 3.70 a	1.75 ± 0.10 b	11.73 ± 0.50 a
T3	4.92 ± 0.25 ab	36.60 ± 2.60 a	2.26 ± 0.20 a	13.02 ± 0.60 a
T4	5.04 ± 0.15 a	32.23 ± 1.80 a	2.24 ± 0.20 a	12.52 ± 0.60 a
		Soil depth 15–30 cm		
T1	4.62 ± 0.14 b	38.12 ± 1.80 b	1.22 ± 0.10 a	11.81 ± 0.40 a
T2	4.82 ± 0.15 a	42.13 ± 1.80 a	1.37 ± 0.10 a	11.74 ± 0.50 a
T3	4.90 ± 0.13 a	40.20 ± 1.80 ab	1.55 ± 0.10 a	12.76 ± 0.40 a
T4	4.92 ± 0.05 a	34.06 ± 1.80 bc	1.62 ± 0.10 a	12.19 ± 0.60 a
		Soil depth 30–45 cm		
T1	4.64 ± 0.13 a	35.77 ± 3.10 a	0.89 ± 0.00 a	10.59 ± 0.30 a
T2	4.82 ± 0.50 a	38.13 ± 2.80 a	1.09 ± 0.10 a	11.23 ± 0.80 a
T3	4.79 ± 0.50 a	35.23 ± 4.30 a	1.01 ± 0.10 a	12.33 ± 0.70 a
T4	4.75 ± 0.20 a	35.20 ± 3.70 a	1.13 ± 0.20 a	10.95 ± 0.50 a

Means with the same letter within a column and soil depth are not significantly different by Tukey's test at 5% level; T1 = control; T2 = inorganic fertiliser N, T3 = biosludge paper compost, T4 = raw paper biosludge; EC = electrical conductivity, CEC = cation exchange capacity

Table 5. There was no significant difference in total N content between treatments except at the depth of 0–15 cm in *K. senegalensis* plots. However, total N concentration in the soil treated with raw and composted biosludge showed increases over inorganic fertiliser and control plots. This was related mostly to the organic N added by the paper mill sludge.

Significantly higher concentrations of available P were observed in soil treated with biosludge, either in raw or composted forms, at 0–15 cm soil depth under both forest tree and medicinal shrub. While the increase in available P may have been associated with the addition of paper mill sludge, this increase may also be partially related to the increase mass of crop

Table 5 Concentration of macronutrients (± standard errors) in soil after 1-year application with composted and raw paper mill biosludge

Treatment	Total N (%)	Available P (mg kg^{-1})	Exchangeable K ($cmol_{(+)}$ kg^{-1})	Exchangeable Ca ($cmol_{(+)}$ kg^{-1})	Exchangeable Mg ($cmol_{(+)}$ kg^{-1})
Khaya senegalensis					
			Soil depth 0–15 cm		
T1	0.14 ± 0.01 c	14.28 ± 1.50 b	0.11 ± 0.01 a	0.70 ± 0.10 c	1.54 ± 0.10 a
T2	0.21 ± 0.01 b	15.02 ± 1.10 b	0.11 ± 0.01 a	0.85 ± 0.10 b	1.43 ± 0.10 a
T3	0.27 ± 0.01 ab	23.69 ± 3.30 a	0.09 ± 0.01 a	1.32 ± 0.20 ab	1.57 ± 0.20 a
T4	0.29 ± 0.01 a	20.69 ± 2.20 a	0.10 ± 0.01 a	1.68 ± 0.20 a	1.32 ± 0.10 a
			Soil depth 15–30 cm		
T1	0.16 ± 0.01 a	9.72 ± 1.50 a	0.07 ± 0.01 a	0.83 ± 0.10 b	0.76 ± 0.10 a
T2	0.14 ± 0.01 a	9.33 ± 0.60 a	0.07 ± 0.01 a	0.89 ± 0.10 b	0.70 ± 0.10 a
T3	0.17 ± 0.02 a	11.11 ± 2.40 a	0.08 ± 0.02 a	1.51 ± 0.10 a	0.63 ± 0.20 a
T4	0.17 ± 0.01 a	10.43 ± 1.60 a	0.10 ± 0.01 a	1.48 ± 0.10 a	0.72 ± 0.20 a
			Soil depth 30–45 cm		
T1	0.12 ± 0.01 a	8.59 ± 1.80 a	0.08 ± 0.01 a	0.64 ± 0.20 a	0.49 ± 0.01 a
T2	0.12 ± 0.01 a	9.02 ± 1.20 a	0.05 ± 0.01 a	0.63 ± 0.20 a	0.57 ± 0.01 a
T3	0.14 ± 0.01 a	9.89 ± 2.00 a	0.07 ± 0.01 a	0.78 ± 0.10 a	0.45 ± 0.01 a
T4	0.15 ± 0.01 a	9.56 ± 1.20 a	0.09 ± 0.01 a	0.79 ± 0.20 a	0.44 ± 0.01 a
Orthosiphon stamineus					
			Soil depth 0–15 cm		
T1	0.14 ± 0.01 a	9.46 ± 1.70 b	0.11 ± 0.01 a	0.70 ± 0.10 c	1.31 ± 0.10 a
T2	0.15 ± 0.01 a	11.62 ± 3.60 b	0.12 ± 0.02 a	1.07 ± 0.10 ab	1.25 ± 0.10 a
T3	0.16 ± 0.01 a	12.08 ± 2.60 ab	0.12 ± 0.02 a	1.23 ± 0.20 a	1.18 ± 0.20 a
T4	0.18 ± 0.02 a	13.54 ± 1.70 a	0.10 ± 0.01 a	1.33 ± 0.20 a	1.24 ± 0.20 a
			Soil depth 15–30 cm		
T1	0.17 ± 0.01 a	10.13 ± 1.50 a	0.11 ± 0.01 a	0.72 ± 0.10 b	0.70 ± 0.10 a
T2	0.18 ± 0.01 a	11.28 ± 2.50 a	0.11 ± 0.01 a	0.77 ± 0.10 b	0.63 ± 0.10 a
T3	0.19 ± 0.02 a	11.81 ± 1.20 a	0.12 ± 0.02 a	0.92 ± 0.20 a	0.72 ± 0.20 a
T4	0.19 ± 0.01 a	11.34 ± 1.90 a	0.11 ± 0.01 a	1.10 ± 0.20 a	0.74 ± 0.20 a
			Soil depth 30–45 cm		
T1	0.14 ± 0.01 a	8.98 ± 0.70 a	0.09 ± 0.01 a	0.55 ± 0.10 a	0.46 ± 0.10 a
T2	0.16 ± 0.02 a	8.06 ± 0.90 a	0.12 ± 0.02 a	0.59 ± 0.10 a	0.44 ± 0.10 a
T3	0.19 ± 0.01 a	9.07 ± 1.00 a	0.11 ± 0.01 a	0.59 ± 0.10 a	0.49 ± 0.20 a
T4	0.15 ± 0.02 a	9.16 ± 2.00 a	0.09 ± 0.01 a	0.65 ± 0.10 a	0.49 ± 0.10 a

Means with the same letter within a column and soil depth are not significantly different by Tukey's test at 5% level; T1 = control; T2 = inorganic fertiliser N, T3 = biosludge paper compost, T4 = raw paper biosludge

and increase P mobilisation through microbial activity after addition of supplementary nutrients (Lee et al. 1990).

Exchangeable cations have variable effects depending on the type of element. Exchangeable K and Mg levels were not affected regardless of treatment, soil depth and crop. This agreed with the findings of Aitken et al. (1998) who reported that the concentration of exchangeable K was unaffected following addition of paper mill sludge. Nevertheless, soil amended with raw and composted biosludge resulted in significant higher concentration of exchangeable Ca than the control at 0–15 cm and 15–30 cm soil layers under both crops (Table 5). This could be related to the high content of Ca in raw (0.53%) and composted (0.47%) biosludge (Table 3).

Further analysis of soil reactivity and nutrient levels comparing the initial and 1-year treatment data gives a better perspective on changes in fertility level. Figures 4 and 5 depict percentages of parameter increase or decrease from the initial level at the beginning of the study. Only 0–15 cm layer data are shown.

Soil under *K. senegalensis* showed important improvement in fertility attributes with the use of sludge with the exception of exchangeable K (Figure 4). Over 80% increase in total N and above 40% increase in available P were recorded which were higher compared with inorganic fertiliser. The increase in CEC could be partly due to increase in organic colloids while higher exchangeable Ca was inclined towards high Ca concentration in oil palm empty fruit bunches used in composting (Rosazlin et al. 2011) and high composition of Ca in biosludge materials. Ca is a less mobile nutrient, thus the high accumulation.

There was no improvement in soil exchangeable K for all treatments under both crops (Figures 4 and 5). In fact, deficit was about 25% for sludge-treated plots grown with *K. senegalensis*. Losses from control plots were consistent at 8% for both crops. Deficits in available P were obvious only in soil grown with *O. stamineus*. We can deduce from this analysis that external input of P and K fertilisers is needed to sustain the present plant growth rate. Input of N is also deemed necessary for selected treatment plots.

Initial soil total N level at 0–15 cm depth was 0.14%. Without amendment, there seemed to be no change in N at the topsoil after 1 year in both plants. Interestingly, even after 1 year of application, the fact that fertilised soil showed significant improvement in total N levels was due to addition of organic N from paper mill sludge and partly the inorganic form (NO_3^-/NH_4^+). This indicates high residual N from biosludge that can be released gradually upon mineralisation of organic materials to the next crop. We believe that at the initial stage, plants utilised soluble N from soil and sludge to grow since values of height and diameter increments throughout the season were above the control and inorganic fertiliser(Figures 2a and b).

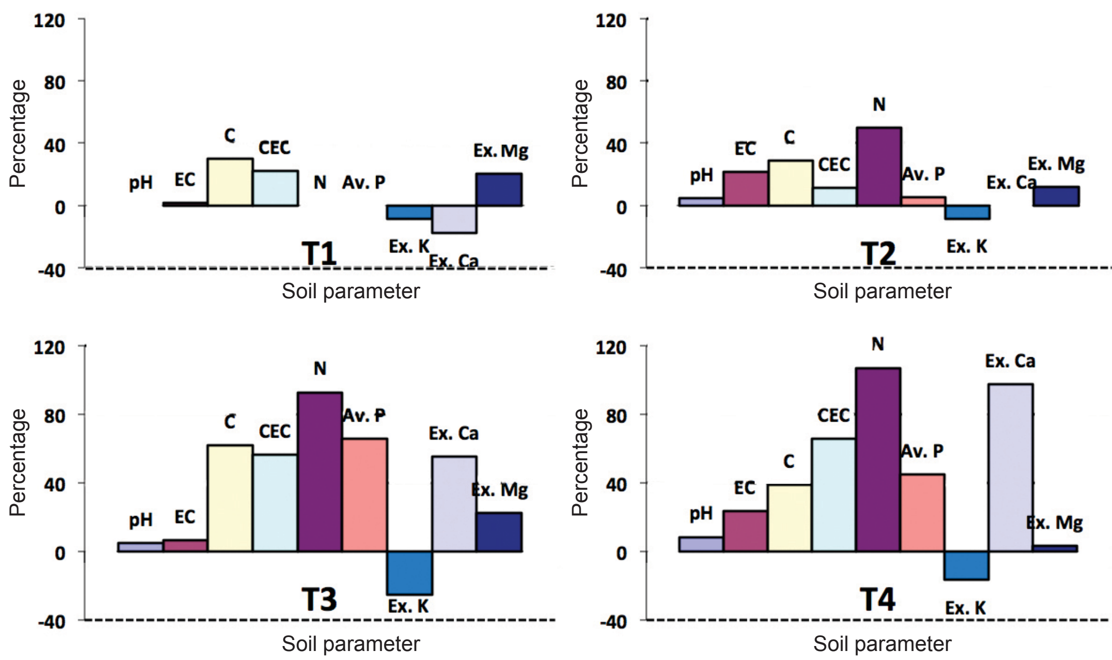

Figure 4 Percentage of increase/decrease of nutrient residual level in the 0–15 cm soil layer 1 year after treatment in plots under *Khaya senegalensis*; T1 = control, T2 = inorganic fertiliser N, T3 = biosludge paper compost, T4 = raw paper biosludge

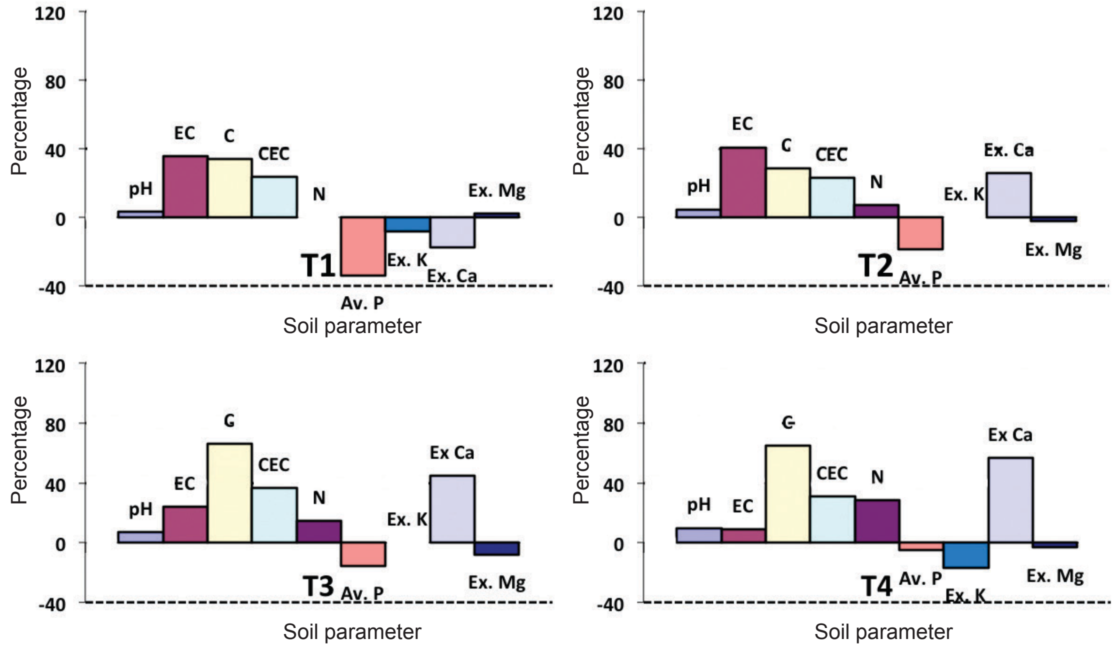

Figure 5 Percentage of increase/decrease of nutrient residual level in the 0–15 cm soil layer one year after treatment in plots under *Orthosiphon stamineus;* T1 = control, T2 = inorganic fertiliser N, T3 = biosludge paper compost, T4 = raw paper biosludge

CONCLUSIONS

Non-recyclable pulp from paper producing mill could serve as effective organic soil amendment to improve plant productivity. Both the biosludge paper mill compost and raw paper mill biosludge increased the early growth of both forest tree and medicinal shrub on acid soil and improved many soil properties. Height of *K. senegalensis* was 40 cm taller and stem diameter 6 mm wider with biosludge than with inorganic fertiliser application. Likewise, total biomass yield for *K. senegalensis* treated with biosludge was 5.4 kg higher compared with tree receiving inorganic fertiliser treatment. For *O. stamineus*, biosludge compost treatment gave the highest biomass yield for each crop cycle, close to 300 g/plant for the first cycle and 125 g/plant for the fourth cycle. Biosludge application also caused significant increase in soil pH by 0.3–0.4 over the control and in total C at the top 0–15 cm soil layer. However, depletion in soil exchangeable K was observed under *K. senelegansis*, while *O. stamineus* required additional input of P and K fertilisers for optimal growth. For this crop, upper plant parts are collected for downstream product development, thus organic and inorganic fertilisers need to be added to the field to replace nutrient losses through plant removal.

REFERENCES

Aitken MN, Evans B & Lewis JG. 1998. Effect of applying paper mill sludge to arable land on soil fertility and crop yields. *Soil Use and Management* 14: 215–222.

Bellamy KL, Chong C & Cline RA. 1995. Paper sludge utilization in agriculture and container nursery culture. *Journal of Environmental Quality* 24: 1074–1082.

Beyer L, Frund R & Mueller K. 1997. Short-term effects of a secondary paper mill sludge application on soil properties in a Psammentic Haplumbrept under cultivation. *The Science of the Total Environment* 197: 127–137.

Bray RH & Kurtz LT. 1945. Determination of total, organic, and available forms of phosphorus in soils. *Soil Science* 59: 39–45.

Bremner JM & Mulvaney CS. 1982. Nitrogen total. Pp 595–622 in Page AL, Miller RH & Keeney DR (eds) *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*. American Society of Agronomy, Madison.

Camberato JJ, Gagnon B, Angers DA, Chantigny MH & Pan WL. 2006. Pulp and paper mill by-products as soil amendments and plant nutrients sources. *Canadian Journal of Soil Science* 86: 641–653.

Catricala CE, Bowden WB, Smith CT & McDowell WH. 1996. Chemical characteristics of leachate from pulp and paper mill residuals used to reclaim a sandy soil. *Water, Air and Soil Pollution* 89: 167–187.

Curnoe WE, Irving DC, Dow CB, Velema G & Unc A. 2006. Effect of spring application of a paper mill soil conditioner on corn yield. *Agronomy Journal* 98: 423–429.

Fahmy S, Lalande R, Gagnon B & Gillam K. 2000. Effects of composted and non-composted pulp fibre residue waste as soil amendment on soil moisture, potato yield and soil nitrogen. Pp 737–758 in Warman PR & Taylor BR (eds) *Proceedings of the International Composting Symposium (ICS'99)*. Volume 2. Coastal BioAgresearch Ltd, Truro.

Feagley SE, Valdez MS & Hudnall WH. 1994. Bleached primary papermill sludge effect on bermuda grass grown on a mine soil. *Soil Science* 157: 389–397.

Feldkirchner DC, Wang C, Gower ST, Kruger EL & Ferris J. 2003. Effects of nutrient and paper mill biosolids amendments on the growth and nutrient status of hardwood forests. *Forest Ecology and Management* 177: 95–116.

Gagnon B, Simard RR, Lalande R & Lafond J. 2003. Improvement of soil properties and fruit yield of native lowbush blueberry by papermill sludge addition. *Canadian Journal of Soil Science* 83: 1–9

Kalavrouziotis IK, Robolas P, Koukoulakis PH & Papadopoulos AH. 2008. Effects of municipal reclaimed wastewater on the macro- and microelements status of soil and of *Brassica oleracea* var. *italica*, and *B. oleracea* var. *gemmifera*. *Agricultural Water Management* 95: 419–426.

Kost D, Boutelle DA, Larson MM, Smith WD & Vimmerstedt JP. 1997. Papermill sludge amendments, tree protection and tree establishment on an abandoned coal mine soil. *Journal of Environmental Quality* 26: 1409–1416.

Kraske CR & Fernandez IJ. 1993. Biogeochemical responses of a forested watershed to both clearcut harvesting and papermill sludge application. *Journal of Environmental Quality* 22: 776–786.

Lee D, Han XG & Jordan CF. 1990. Soil phosphorus fractions, aluminium and water retention as affected by microbial activity in an Ultisol. *Plant and Soil* 121: 125–136.

Levy JS & Taylor BR. 2003. Effects of pulp mill solids and three composts on early growth of tomatoes. *Bioresource Technology* 89: 297–305.

Logan TJ & Esmaeilzadeh H. 1985. Utilizing paper mill sludge: use on croplands. *Biocycle* 26: 52–53.

Merry RH & Spouncer LR. 1988. The measurement of carbon in soils using a microprocessor-controlled resistance furnace. *Communication in Soil Science and Plant Analysis* 19: 707–720.

Panda D, Pattnaik RN & Mishra M. 1990. Effect of different sources of phosphorous and levels of lime on groundnut. *Indian Journal of Agronomy* 35: 426–427.

Paramananthan S. 2000. *Soils of Malaysia: Their Characteristics and Identification*. Academy of Sciences Malaysia and Param Agricultural Soil Surveys, Kuala Lumpur.

Phillips VR, Kirkpatrick N, Scotford IM, White RP & Burton RGO. 1997. The use of paper-mill sludges on agricultural land. *Bioresource Technology* 60: 73–80.

Ritter WF, McDermott JG & Chirnside AEM. 1992. Use of paper mill residuals as soil amendments. *Communication in Soil Science and Plant Analysis* 23: 469–488.

Rodella AA, Fischer KR & Alcarde JC. 1995. Cation exchange capacity of an acid soil as influenced by different sources of organic litter. *Communication in Soil Science and Plant Analysis* 26: 2961–2967.

Rosazlin A, Fauziah CI, Wan Rasidah K & Rosenani AB. 2010a. Leaching of heavy metals (Cu, Mn, Zn, Ni, Pb and As) after six months application of raw and composted recycled paper mill sludge. Pp 162–165 in Gilkes RJ & Prakongkep N (eds) *Proceedings of the 19th World Congress of Soil Science: Soil Solutions for a Changing World*. 1–6 August 2010, Brisbane.

Rosazlin A, Fauziah CI, Wan Rasidah K & Rosenani AB. 2010b. Effect of soil amended with raw and composted recycled paper mill sludge as nitrogen source for misai kucing (*Orthosiphon stamineus*). Pp 187–191 *in Proceedings of the International Conference on Balanced Nutrient Management for Tropical Agriculture*. 12–16 April 2010, Kuantan.

Rosazlin A, Fauziah CI, Wan Rasidah K, Rosenani AB & Kala DR. 2011. Assessment on the quality of recycled paper mill sludge mixed with oil palm empty fruit bunch compost. *Malaysian Journal of Soil Science* 15: 49–62.

Thomas GW. 1982. Exchangeable cations. Pp 159–165 in Page AL, Miller RH & Keeney DR (eds) *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*. American Society of Agronomy, Madison.

Tripepi RR, Zhang X & Campbell AG. 1996. Use of raw and composted paper sludge as a soil additive or mulch for cottonwood plants. *Compost Science and Utilization* 4: 26–36.

Wan Asma I, Wan Rasidah K & Mohd Nor MY. 2007. *Turning Oil Palm Residues Into Products*. Research Pamphlet No. 127. Forest Research Institute Malaysia, Kepong.

Zibilske LM. 1987. Dynamics of nitrogen and carbon in soil during papermill sludge decomposition. *Soil Science* 143: 26–33.

