

# EFFECTS OF MULCHING AND FERTILISER ON NUTRIENT DYNAMICS OF SAND TAILINGS GROWN WITH ACACIA HYBRID SEEDLINGS

I Wan Asma<sup>1</sup>\*, K Wan Rasidah<sup>1</sup>, AB Rosenani<sup>2</sup>, H Aminuddin<sup>2</sup> & A Rozita<sup>1</sup>

<sup>1</sup>Forest Research Institute Malaysia, 52109 Kepong, Selangor Darul Ehsan, Malaysia

<sup>2</sup>Department of Land Management, Universiti Putra Malaysia, 34000 UPM Serdang, Selangor Darul Ehsan, Malaysia

Received September 2010

**WAN ASMA I, WAN RASIDAH K, ROSENANI AB, AMINUDDIN H & ROZITA A. 2011. Effects of mulching and fertiliser on nutrient dynamics of sand tailings grown with *Acacia* hybrid seedlings.** Studies on the contribution of oil palm empty fruit bunch (EFB) mulch mat and its impact on fertiliser loss through leaching on sand tailings are lacking. Sand tailings in Malaysia formed through tin mining activities are problematic soils for agriculture and forestry. An experiment with two types of EFB mulch mat applied in combination with NPK (nitrogen:phosphorus:potassium) fertiliser was established in pots containing sandy tin tailing soil to assess their effects on soil nutrient enrichment and leaching. Application of mulch mat reduced leaching of fertiliser compared with treatments without mulch mats. Incorporating fertiliser inside the mulch mat at the production stage could be the best way of applying inorganic fertiliser on sandy soils as the amounts of N, P and K loss was reduced significantly compared with treatments without mulch. There was poor synchronisation between fertiliser input and plant nutrient demand. The amount of fertiliser applied seemed to be in excess of the uptake capacity by roots especially for highly mobile nutrients N and K. Application of mulch mat on sand tailings however did not ameliorate the soil nutrient properties after 16 weeks. This could be due to the porous nature of the sand tailings.

Keywords: EFB mulch, NPK fertiliser, sandy soil, soil leachate

**WAN ASMA I, WAN RASIDAH K, ROSENANI AB, AMINUDDIN H & ROZITA A. 2011. Kesan sungkupan dan baja terhadap dinamik nutrien tanah bekas lombong yang ditanami anak biji benih hibrid *Acacia*.** Tidak banyak kajian dijalankan terhadap manfaat tikar sungkupan yang diperbuat daripada tandan kosong kelapa sawit (EFB) dan keberkesanannya dalam mengawal kehilangan baja melalui luluh larut di tanah bekas lombong. Aktiviti perlombongan bijih timah di Malaysia meninggalkan tanah bekas lombong yang bermasalah untuk kegiatan pertanian dan perladangan hutan. Satu kajian dijalankan terhadap dua jenis tikar sungkupan EFB yang diaplikasi bersama-sama baja NPK (nitrogen:fosforus:kalium) di atas tanah bekas lombong yang diisi dalam tabung besar untuk menilai kesannya terhadap peningkatan nutrient tanah dan luluh larut. Hasil kajian menunjukkan penggunaan tikar sungkupan berupaya mengurangkan jumlah luluh larut baja apabila dibandingkan dengan rawatan kawalan. Jika baja dimasukkan ke dalam tikar sungkupan semasa tikar tersebut dihasilkan, kehilangan N, P dan K melalui luluh larut berkurang secara signifikan berbanding rawatan tanpa sungkupan. Ini mungkin merupakan cara terbaik untuk membubuh baja inorganik di tanah bekas lombong. Input baja dan keperluan baja oleh pokok tidak selari. Kadar baja yang diberi adalah berlebihan berbanding kapasiti penyerapan akar lebih-lebih lagi untuk nutrien mudah larut seperti N dan K. Aplikasi tikar sungkupan bagaimanapun tidak berupaya untuk meningkatkan tahap nutrien tanah bekas lombong selepas 16 minggu penggunaannya, mungkin akibat sifat tanah yang sangat porous.

## INTRODUCTION

Tin mining operations in Malaysia had resulted in about 113 700 ha of degraded soils (Chan 1990). Approximately 80% of this area is sand while the rest is categorised as slime of either clay–silt or sandy slime (Lim et al. 1981). Slime tailing is less problematic and is considered fertile for planting but is prone to flooding. In contrast, sand tailing has poor water-holding capacity and

is prone to nutrient leaching due to high sand and low clay contents. Sand tailings also have high surface soil temperature and poor structural stability and are low in moisture, organic matter and nutrients (Lim et al. 1981, Shamsuddin et al. 1986). Temperature on tin tailing soils range from 31.7 to 49.4 °C at the surface, 28.9 to 38.9 °C at 10 cm depth and 27.2 to 35.0 °C at

\*E-mail: asma@frim.gov.my

20 cm depth while water retention capacity is 1 ml per 100 g (Palaniappan 1972). The low nitrogen (N) content relates to the low organic matter, while low phosphorus (P) is due to low pH and clay contents and leaching drains most of the potassium (K). These properties make planting of trees on sand tailing difficult. Various attempts have been made to utilise tin tailing soils in Malaysia. Planting agricultural and horticultural crops has achieved some degree of success but these crops only cover less than 10% of the total tin tailing areas, mainly on slime (Chan 1990).

Rehabilitation or reforestation of tin tailing area requires soil amendment for plant establishment and organic mulching is one of the options. Organic mulching using *Setaria anceps* and *Arachis hypogea* grasses showed promising results for forest planting, e.g. increased growth and biomass (Nik Muhammad et al. 1994), while mulching by adding organic materials on tin tailing soils was mostly reported for agricultural crops (Vimala & Zaharah 1992, Vimala & Salbiah 2002). The latter type of organic mulching was reported to improve soil organic carbon (SOC) content (Havlin et al. 1990, Duiker & Lal 1999). SOC ameliorated many of the soil physical, chemical and biological attributes (Jin et al. 2009, Farrell et al. 2010, Jordan et al. 2010). Compost amendments on a clay-loam topsoil were reported to raise pH, organic matter content and nutrient status of the soil as well as increase rooting depth and plant root biomass (Farrell et al. 2010). Compost and biochar produced from municipal green waste were added to residue sand from bauxite mining to improve its soil suitability and fertility parameters for plant growth (Jones et al. 2010).

On nutrient-rich soils, element outputs are largely mediated by internal sources whereas on nutrient-poor soils, atmospheric, i.e. external inputs are more dominant (Berger et al. 2009a). Hence, external input such as addition of fertiliser or mulch could be a major source of nutrient elements for nutrient-poor sandy tin tailing soil. Organic mulching improves the microenvironment of the rhizosphere or root zone, thus, improving root development which then improves nutrient uptake. Mulching could also regulate nutrient leaching. This study was carried out to evaluate the effects of oil palm empty fruit bunch (EFB) mulch mats on nutrient leaching in sandy tin tailing soil grown with *Acacia* hybrid seedling. The seedlings were subjected to different methods of NPK fertiliser application.

Soil texture properties and addition of organic matter influenced soil hydraulic properties and moisture retention capacity (Wesseling et al. 2009). Therefore, this study also examined the changes in soil nutrient concentration after four months of planting.

## MATERIALS AND METHODS

### Preparation of soils and seedlings

The soil used in this study was sand tailing obtained from a former tin mining area in Bidor, Perak, Malaysia. It consists of over 90% sand (coarse and fine) uniformly distributed throughout the 20 cm soil depth. The soil has low levels of N, C and exchangeable K, and also low cation exchange capacity (CEC) (Table 1). However, its pH is 6.5 and this value is suitable for planting. Available P content, even though low, is comparable with the majority of highly weathered soils in Peninsular Malaysia.

One-year-old *Acacia* hybrid seedlings produced through tissue culture techniques were used for this experiment. The seedlings had seven to nine phylloids and their average height was 30 cm. The seedlings had been acclimatised to normal nursery conditions for about eight months prior to planting and their performance were expected to be similar to plants propagated through other vegetative methods or from seeds.

### Preparation of mulch mat incorporated with fertiliser

Dried EFB fibres (1 kg) were sprayed with 200 ml of 3% solution of polyvinyl acetate binder after which they were divided into three equal portions. Since this experiment was conducted in a container and for only four months, we used 50 g fertiliser per plant. Each fibre portion was placed alternately with 25 g of NPK (15:15:15)

**Table 1** Properties of soil used in this study

Soil parameter	Value
pH	6.5
Total N (%)	0.013
Organic C (%)	0.14
Available P ( $\mu\text{g g}^{-1}$ )	1.40
Exchangeable K ( $\text{Cmol kg}^{-1}$ )	0.02
Exchangeable Ca ( $\text{Cmol kg}^{-1}$ )	0.04
Exchangeable Mg ( $\text{Cmol kg}^{-1}$ )	0.01
Cation exchange capacity ( $\text{Cmol kg}^{-1}$ )	3.50

compound fertiliser with total equivalent rate of 50 g per plant in a wooden mould starting with the first fibre portion and ending with the third fibre portion on the top. The lid of the mould was put into place and pressed manually to form a pre-formed mat. The pre-formed mat was then covered with a steel plate prior to loading into a mechanical press. The fibres were then cold-pressed at 1000 psi for 2 min after which the press was released and the mat was taken out to air dry before use (Wan Asma 2006). The chemical properties of mat used in this study are given in Table 2.

### Experimental layout

The experiment was carried out in an open environment using plastic containers 38 cm in diameter and 50 cm in height. The containers were filled with sandy tin tailings to a depth of 40 cm to provide sufficient space for root development. *Acacia* hybrid seedlings of uniform size were planted with one plant per container. The containers were placed on wooden racks with platform stands 100 cm above the ground. Nine treatments with four replications were established and labelled as S (control: no fertiliser, no mulch), Sf (compound fertiliser broadcasted), M (laboratory-produced mat), Mt (mat M with fertiliser broadcasted on mat), Mc (mat M with fertiliser incorporated inside), Mb (mat M with fertiliser broadcasted underneath mat), CM (commercial mat), CMt (mat CM with fertiliser broadcasted on mat) and CMb (mat CM with fertiliser broadcasted underneath mat). Altogether there were 36 containers and 36 treated seedlings. Holes were made at the base of each container for drainage and another plastic container of 10-l capacity was placed on the ground beneath with mouth covering the holes to collect the leachates. The containers

were covered with plastic sheets around the base to protect the leachate from being contaminated with rain water.

The mulch mats, both laboratory-produced and commercial, were cut to 25 × 25 cm and a hole of 5 cm diameter was made in the centre of the mat. A cut was also made from the edge towards the centre of the mat in order to ease its application on the plants. The air-dry weights of the mats were recorded before application. When applying the mat, care was taken to ensure that the stem was in the hole at the centre but not touching the mat.

At one week after planting, 50 g of NPK (15:15:15) compound fertilisers were applied in all treatments with fertiliser addition except for treatment where the fertiliser was incorporated inside the mat. Fertiliser was applied at the same time as mulch mat application. It was distributed evenly on top of the mulch mat for treatments Mt and CMt while for treatments Mb and CMb, evenly distributed on the soil surface around the plant before placing the mulch mat. For treatment Mc, the fertiliser was already incorporated inside the mulch mat during production.

One litre of distilled water was applied to each container on dry days and the amount of rainfall received during the four months of experiment was recorded.

### Soil leachate

The leachate was collected for analysis every two weeks or when the container was nearly full. The volumes collected were measured using a measuring cylinder and about 200 ml from each treatment were brought back to the laboratory, filtered, acidified with concentrated hydrochloric acid to inhibit fungal growth and kept in a refrigerator before analysis. A total of 10 ml leachate were subjected to Kjeldahl

**Table 2** Chemical properties of mulch mats used in this study

Parameter	Mulch material	
	Laboratory-produced mat	Commercial mat
N (%)	1.32	0.50
C (%)	37.40	39.80
C/N	28.30	79.60
P (%)	0.14	0.04
K (%)	2.83	1.29
Ca (%)	0.56	0.09
Mg (%)	0.23	0.07

digestion for N determination and another 10 ml were used for the determination of P and K using inductively coupled plasma (ICP). The amounts of N, P and K leached were calculated by multiplying the volume of leachate collected by the concentration of N, P and K. The percentage of N, P and K leached out of the total input was calculated using the equation below.

$$P_{\text{nutrient}} = [(X)_{\text{nutrient}} / (Y)_{\text{nutrient}}] \times 100$$

where

$P_{\text{nutrient}}$  = percentage of nutrient N, P or K leached of total nutrient N, P or K input respectively

$X_{\text{nutrient}}$  = total concentration of nutrient N, P or K obtained in leachate ( $\text{mg kg}^{-1}$ )

$Y_{\text{nutrient}}$  = total amount of nutrient N, P and K added to treatment ( $\text{mg kg}^{-1}$ )

### Chemical analysis of soils

Soil samples at three depths, namely, 0–5, 5–15 and 15–30 cm were sampled after four months of seedling growth. The soil was sampled using an auger at five random points in the container and combined into one composite sample. These samples were air dried and ground, and particles of > 2 mm were discarded. For analysis of total N and organic C, the sieved soils were crushed into fine powder. The pH value was measured in water (1:2.5), total N by Kjeldahl digestion, available P by Bray and Kurtz No. 2 method, organic C by Walkley and Black method and exchangeable cations were extracted through a leaching column using neutral ammonium acetate solution (Wan Rasidah et al. 1990, Anderson & Ingram 1993).

All data were tested for statistical differences through analysis of variance (ANOVA) and Duncan's multiple range tests (DMRT) using Statistical Analysis System (SAS) Software Package Version 6.1. Interactions of the main factors against dependent variables were carried out to determine their significance.

## RESULTS

### Amount of leachate collected

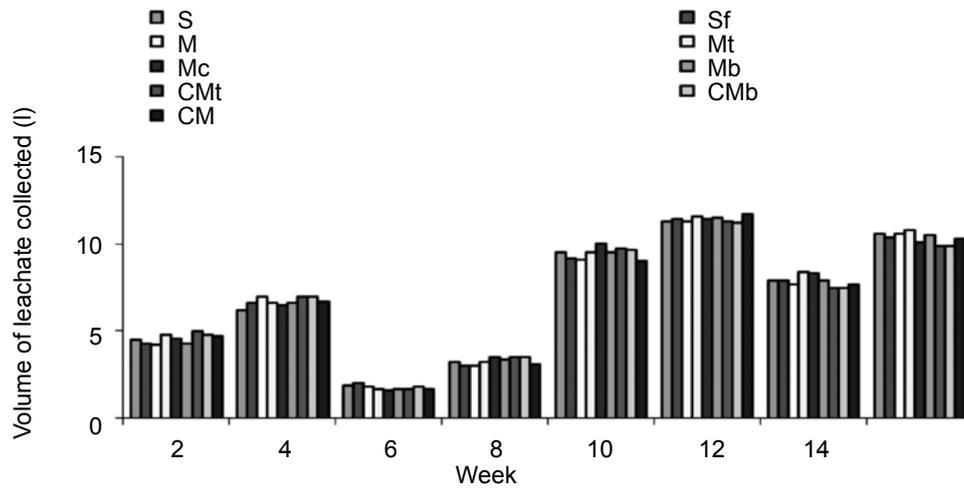
The amount of leachate collected every two weeks for 16 weeks for all treatments are shown in Figure 1. As expected, the volume of leachate

corresponded with the volume of rainfall received which peaked at week 12 (Figure 2). The cumulative volumes of leachate collected showed significantly lower volumes for treatments with mat application towards the end of the experiment compared with control treatments, reflecting the functionality of EFB mulch mat to retain moisture (Figure 3). However, commercial mulch mats were less effective than mats produced in the laboratory. Overall, volume of leachate collected ranged from 62.9 to 69.9 l per treatment.

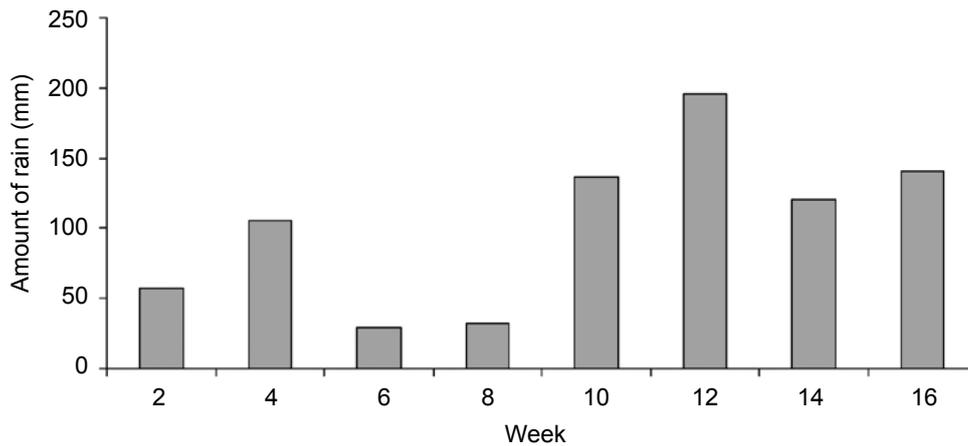
### Leaching of major nutrients

The cumulative amount of N leached from all treatments at fortnightly intervals is shown in Figure 4. Data were plotted up to only eight weeks as only trace levels of N were measured in leachates collected after this period. Rapid leaching of N occurred within the first two weeks in all treated soils. After week 2, the amount of N leached gradually declined, almost reaching a plateau until the eighth week. Initial N concentration in soil was low (0.07%), hence leaching in untreated soil (control treatment) was almost negligible. The N leached from treatments without fertiliser application (S, M and CM) was significantly lower than treatments receiving fertiliser. The total amount of N leached out as a percentage of total N input is given in Table 3. The highest percentage of N loss was from the treatment Sf (30.6%) followed by the commercial mat treatments (CMt 26.9%, CMb 18.6%). Among the laboratory-produced mats, 8.8 and 11.0% of N leached out in treatments Mt and Mb respectively but only 2.8% in treatment Mc which had fertiliser incorporated inside it. Mulch mats also leached out small percentages of N, i.e. 1.7% by the laboratory-produced mat and 6.7% by the commercial mat.

A higher rate of P leaching from treatments applied with fertilisers, i.e. Sf, Mt, Mb, CMt and CMb was observed during the first four weeks of the study with values exceeding 200 mg. However, after that leaching was more gradual until the 16th week (Figure 5). Total amounts of P leached out from these treatments were almost equal. Treatment with fertiliser incorporated inside the mat, Mc, showed more gradual leaching with significantly lower total amount of leachate P within 16 weeks compared with treatments having fertiliser. As expected, treatments without fertiliser had lower nutrient leaching. With



**Figure 1** The effect of mulch mat with different methods of fertiliser application on the volume of leachate collected every two weeks for 16 weeks; S = control, Sf = compound fertiliser broadcasted, M = laboratory-produced mat, Mt = mat M with fertiliser broadcasted on mat, Mc = mat M with fertiliser incorporated inside, Mb = mat M with fertiliser broadcasted underneath mat, CM = commercial mat, CMt = mat CM with fertiliser broadcasted on mat, CMB = mat CM with fertiliser broadcasted underneath mat

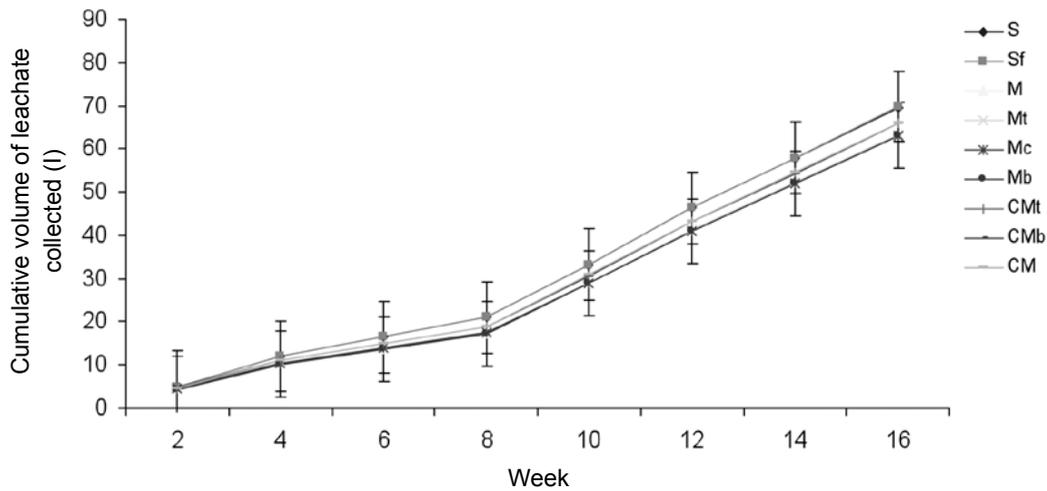


**Figure 2** Rainfall intensity in the study area during the period of experiment

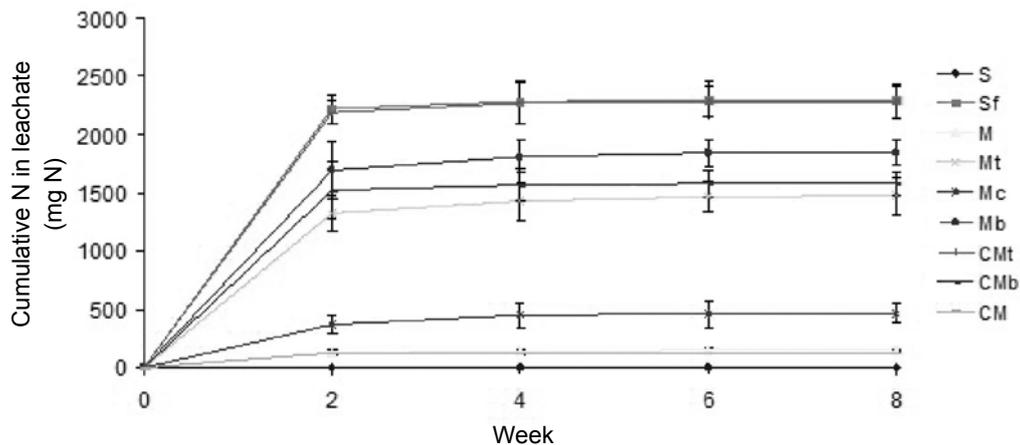
mulch mat application (M), significantly more P was detected in the leachate compared with the control (S) and commercial mat (CM). The initial amount of P in the laboratory-produced mat was 11 folds higher than the amount in commercial mat (Table 4). The lowest P leaching in comparison with P input was observed in treatment Mc (3.8%); even the controls leached a higher percentage of P (5.84%).

Potassium leaching was rapid during the first two weeks for treatments with fertiliser (Sf, Mt, Mb, Mc, CMt and CMb) (Figure 6). Between weeks 4 and 8, leaching was more gradual until week 8 and became stable thereafter. The highest cumulative K leaching was from treatment Mt

followed by Mb; significantly less K leached from treatment Mc. Laboratory-produced mats leached significantly more K than commercial mats, both for fertilised and unfertilised treatments. Leaching of K from soil itself was negligible. The total amount of K leached out as a percentage of total K input was high for almost all treatments (Table 5); only commercial mat treatment (CM) was similar to the control. As leaching from soil was negligible (0.02%), the laboratory-produced mulch mat itself leached close to 26% of its initial K content within 16 weeks of application. The highest leaching was observed in treatments Mt and Mb with 42.5 and 38.5% K loss respectively. The rest of the fertilised treatments, i.e. Sf, CMt,



**Figure 3** Cumulative volume of leachate collected for different mulch and fertiliser treatments; vertical bars denote standard error of means ( $p < 0.5$ ); S = control, SF = compound fertiliser broadcasted, M = laboratory-produced mat, Mt = mat M with fertiliser broadcasted on mat, Mc = mat M with fertiliser incorporated inside, Mb = mat M with fertiliser broadcasted underneath mat, CM = commercial mat, CMt = mat CM with fertiliser broadcasted on mat, CMb = mat CM with fertiliser broadcasted underneath mat.



**Figure 4** The effects of mulching and different methods of fertiliser application on the cumulative amount of N in leachate; vertical bars denote standard error of means ( $p < 0.05$ ); S = control, SF = compound fertiliser broadcasted, M = laboratory-produced mat, Mt = mat M with fertiliser broadcasted on mat, Mc = mat M with fertiliser incorporated inside, Mb = mat M with fertiliser broadcasted underneath mat, CM = commercial mat, CMt = mat CM with fertiliser broadcasted on mat, CMb = mat CM with fertiliser broadcasted underneath mat.

CMb and Mc leached between 29.0 and 33.7% of applied K.

**Soil pH, total N, available P and organic C**

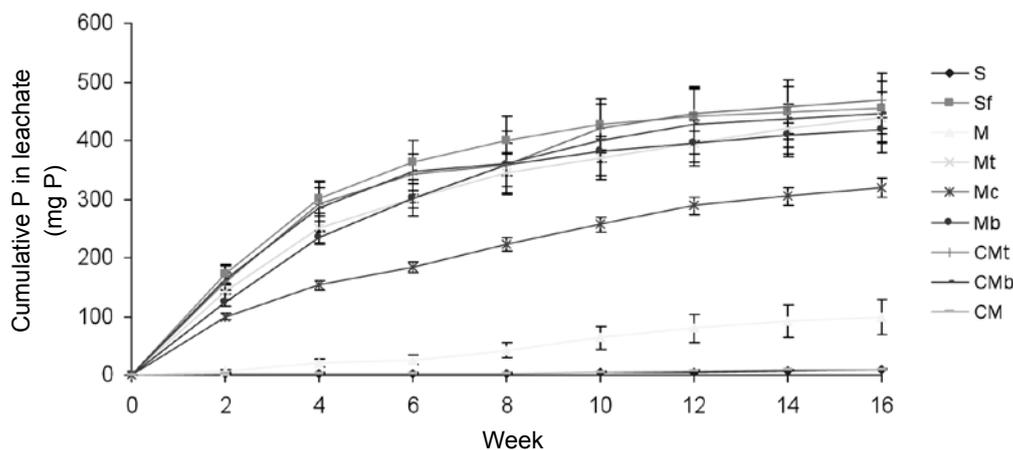
Soil chemical properties before planting and after growing the *Acacia* hybrid plants for four months are shown in Table 6. No significant increase in pH was observed at all depths after

four months of planting. Total N also showed no significant changes except at the 5–15 cm soil depth where a significant increase occurred in treatments with combined fertiliser and organic mulch. Available P concentrations at 0–5 cm increased significantly in treatments Mt, Mb, CMt and CMb. At 5–15 cm, a significant increase in available P was observed in all fertilised treatments, i.e. Sf, Mt, Mb, Mc, CMt and CMb. At

**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 (%)
	Fertiliser	Mat	Soil			
S	0	0	11.7	11.7	0	0.0b
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

n = 4; values in same column with the same letter are not significantly different (p < 0.05); S = control, Sf = compound fertiliser broadcasted, M = laboratory-produced mat, Mt = mat M with fertiliser broadcasted on mat, Mc = mat M with fertiliser incorporated inside, Mb = mat M with fertiliser broadcasted underneath mat, CM = commercial mat, CMt = mat CM with fertiliser broadcasted on mat, CMb = mat CM with fertiliser broadcasted underneath mat.



**Figure 5** The effect of mulching and different methods of fertiliser application on the cumulative amount of P in leachate; vertical bars denote standard error of means (p < 0.05).

15–30 cm, a significant increase in available P was found only in treatments Sf, CMb and CMt. The unfertilised treatments (S, M and CM) had lower soil nutrient contents even though mulch mats contained nutrients. Soil organic C contents in the upper (0–5 cm) soil were significantly higher than before planting in treatments Mt (0.42%) and CMt (0.26%) in which fertiliser was placed on top of the mats. Significantly lower organic C values were obtained in treatment CM. At 5–15 cm, only treatment M has higher organic C content at four months after planting compared with the rest of the mat treatments. There were no differences in organic C at 15–30 cm depth compared with before the experiment.

**Soil CEC and exchangeable cations**

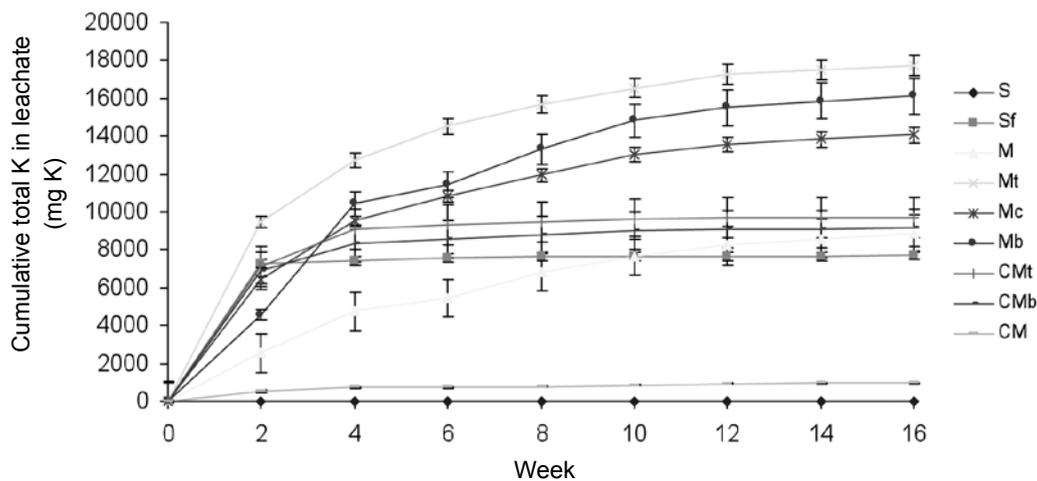
Cation exchange capacity values of the soil for all treatments after harvest at depths 0–5, 5–15 and 15–30 cm ranged from 3.40–4.00, 3.00–3.60 and 2.85–4.20 cmol<sub>c</sub> kg<sup>-1</sup> respectively; however they were not significantly different from initial values (Table 7). At 15–30 cm, treatment M, Mc and CM showed significant CEC increase over Mt treatment.

Exchangeable K values for treatments Mt, Mc and CMt were significantly higher than the initial soil at 0–5 cm depth (Table 7). There were no changes at lower depths.

**Table 4** Percentage of total P leached corresponding to total P input in all treatments

Treatment	Source of P input (mg P)			Total P input (mg P)	Amount of total P in leachate (mg P)	Total P leached of total P input (%)
	Fertiliser	Mat	Soil			
S	0	0	140.5	140.5	8.2	5.84 a
Sf	7500	0	140.5	7640.5	456.1	5.97 a
M	0	700	140.5	840.5	42.2	5.02 a
Mt	7500	700	140.5	8340.5	438.4	5.26 a
Mc	7500	700	140.5	8340.5	319.0	3.83 b
Mb	7500	700	140.5	8340.5	419.0	5.02 a
CM	0	60	140.5	200.5	10.1	5.03 a
CMt	7500	60	140.5	7700.5	468.1	6.08 a
CMb	7500	60	140.5	7700.5	446.8	5.80 a

n = 4; values in same column with the same letter are not significantly different ( $p < 0.05$ ); S = control, SF = compound fertiliser broadcasted, M = laboratory-produced mat, MT = mat M with fertiliser broadcasted on mat, MC = mat M with fertiliser incorporated inside, MB = mat M with fertiliser broadcasted underneath mat, CM = commercial mat, CMT = mat CM with fertiliser broadcasted on mat, CMB = mat CM with fertiliser broadcasted underneath mat.



**Figure 6** The effects of mulching and different methods of fertiliser application on the cumulative amount of K in leachate; vertical bars denote standard error of means ( $p < 0.05$ ); S = control, S = compound fertiliser broadcasted, M = laboratory-produced mat, Mt = mat M with fertiliser broadcasted on mat, Mc = mat M with fertiliser incorporated inside, Mb = mat M with fertiliser broadcasted underneath mat, CM = commercial mat, CMt = mat CM with fertiliser broadcasted on mat, CMb = mat CM with fertiliser broadcasted underneath mat.

For exchangeable Mg, all treatments with a combination of fertiliser and mulch application (Mc, CMb, Mb, CMt and Mt) had significantly higher values than the initial soil ( $S_0$ ) at the upper two soil layers (Table 7). Exchangeable Mg in treatment with fertiliser but without mulch mats (Sf) was not significantly different from  $S_0$ , CM or M at 15–30 cm. At this depth too, exchangeable Mg contents of all treatments were

not significantly different from the non-mulched and non-fertilised soil.

The influence of mulch and fertiliser treatments on soil exchangeable Ca also differed between depths. Fertiliser applied with organic mulch significantly improved exchangeable Ca in soil at 0–5 cm depth. At 5–15 cm, only treatment Mc showed significant increase over all other treatments. Treatment Sf resulted in increased

**Table 5** Percentage of total K leached corresponding to total K input in all treatments

Treatment	Source of K input (mg K)			Total K input (mg K)	Amount of total K in leachate (mg K)	Total K leached of total K input (%)
	Fertiliser	Mat	Soil			
S	0	0	20 075	20 075	3.92	0.02 c
Sf	7500	0	20 075	27 575	7990.0	29.0 b
M	0	14150	20 075	34 225	8870.1	25.9 b
Mt	7500	14150	20 075	41 725	17 712.5	42.5 a
Mc	7500	14150	20 075	41 725	14 076.9	33.7 b
Mb	7500	14150	20 075	41 725	16 099.6	38.5 a
CM	0	1935	20 075	22 010	969.0	4.4 c
CMt	7500	1935	20 075	29 510	9697.0	32.9 b
CMB	7500	1935	20 075	29 510	9152.6	31.0 b

n = 4; values in same column with the same letter are not significantly different ( $p < 0.05$ ); S = control, SF = compound fertiliser broadcasted, M = laboratory-produced mat, MT = mat M with fertiliser broadcasted on mat, MC = mat M with fertiliser incorporated inside, MB = mat M with fertiliser broadcasted underneath mat, CM = commercial mat, CMT = mat CM with fertiliser broadcasted on mat, CMB = mat CM with fertiliser broadcasted underneath mat.

Ca concentrations at 15–30 cm soil depth while at the upper two depths the concentrations were similar. Treatment with mulch mats only, M and CM, showed no significant changes in the soil exchangeable Ca either with  $S_0$  or between depths.

## DISCUSSION

The seepage data in this study revealed a direct influence of rainfall intensity on soil solute downward movement. The amount of leachate collected through the 40-cm soil depth increased with the increase in rainfall intensity. Application of mulch mat showed reduced cumulative soil seepage that was more pronounced after 10 weeks (Figure 3). Obviously, these organic materials retained some water, with the laboratory-produced mats showing better efficiency than the commercial mats. The thick organic layer on top of mineral soil transpired a major part of water into the plants, reducing loss of water flowing down through the sandy soil (Berger et al. 2009a). Soil nutrient fluxes revealed the positive role of organic mulch mat in reducing soil nutrient losses through leaching. However, in this study, significant amounts of soluble nutrients, in particular N and K, were lost through leaching. Amounts of N, P and K leached showed significant differences with application of different mat types and fertiliser application techniques (Figures 4, 5 and 6). Nitrogen leaching was lowest with application of the laboratory-

produced mat. With fertiliser incorporated inside the mulch mat (Mc), leaching of N was reduced by 27.8% compared with fertilising without mulch (Sf) (Table 3). The N loss through leaching was reduced by 19.3% when fertiliser was applied on the soil surface under the mulch mat (Mb), and 21.8% when applied on top of the mulch mat (Mt). It is possible that if sufficient moisture is available, some of the N in the fertiliser will be ephemerally immobilised by organic mulch to restore microbial activities (Lloyd et al. 2001, Forge et al. 2003). Decomposition of organic materials with N concentrations of less than 2% immobilised N initially (Myers et al. 1994). Both the laboratory-produced and commercial mats had initial N contents of less than 2% (Table 2).

Since P was the least mobile of the three elements studied, leaching loss was found to be correspondingly low in all treatments. The sandy soil without treatment leached 5.84% of its available P, meaning a large portion of leached P came from labile P in the soil. The P could be locked in organic complexes and was released gradually upon mineralisation. P is released also for plant uptake through hydrolysis of organic P by extracellular and periplasmic phosphatase enzymes and during oxidation of organic C by soil organisms (Harrison 1987).

Being a mobile nutrient element, high leaching of K is not unusual, particularly in high permeability sandy soil. The fertiliser treated soil (Sf) leached 29% of its K after two weeks of application. High leaching (26%) was

**Table 6** The effects of mulching and different methods of fertiliser application on soil pH, total N, available P and organic C after four months of planting *Acacia* hybrid at three soil depths

Treatment	0–5 cm soil depth				5–15 cm soil depth				15–30 cm soil depth			
	pH	Total N (%)	Available P (µg g <sup>-1</sup> )	Organic C (%)	pH	Total N (%)	Available P (µg g <sup>-1</sup> )	Organic C (%)	pH	Total N (%)	Available P (µg g <sup>-1</sup> )	Organic C (%)
S <sub>0</sub>	6.50 a	0.013 a	1.40 c	0.14 cd	6.50 a	0.013 c	1.40 c	0.14 bc	6.50 a	0.013 a	1.40 cd	0.14 a
S	6.64 a	0.013 a	0.96 c	0.08 de	6.48 a	0.025 a	0.75 e	0.07 bcd	6.50 a	0.002 a	1.02 d	0.08 a
Sf	6.52 a	0.016 a	2.43 c	0.09 de	6.42 a	0.015 abc	6.12 abc	0.03 cd	6.46 a	0.016 a	6.11 ab	0.11 a
M	6.60 a	0.017 a	1.56 c	0.11 cde	6.59 a	0.023 abc	1.53 de	0.33 a	6.43 a	0.026 a	1.22 cd	0.16 a
Mt	6.70 a	0.018 a	5.31 b	0.42 a	6.56 a	0.020 abc	6.98 ab	0.18 b	6.54 a	0.021 a	3.57 bcd	0.16 a
Mc	6.73 a	0.014 a	3.13 bc	0.18 bc	6.57 a	0.023 abc	4.68b cd	0.01 d	6.51 a	0.022 a	2.58 cd	0.10 a
Mb	6.66 a	0.014 a	9.13 a	0.11 cde	6.54 a	0.014 bc	3.13 cde	0.07 bcd	6.40 a	0.019 a	4.24 bc	0.12 a
CM	6.49 a	0.014 a	1.42 c	0.03 e	6.50 a	0.024 ab	0.80 e	0.10 bcd	6.50 a	0.022 a	0.98 d	0.05 a
CMt	6.43 a	0.015 a	10.49 a	0.26 b	6.59 a	0.023 abc	8.70 a	0.16 b	6.52 a	0.026 a	7.29 a	0.12 a
CMb	6.48 a	0.018 a	9.18 a	0.13 cd	6.42 a	0.024 ab	6.49 ab	0.09 bcd	6.48 a	0.019 a	8.44 a	0.06 a

S<sub>0</sub> = soil properties before planting; values in the same column with the same letter are not significantly different (p < 0.05); S = control, Sf = compound fertiliser broadcasted, M = laboratory-produced mat, Mt = mat M with fertiliser broadcasted on mat, Mc = mat M with fertiliser incorporated inside, Mb = mat M with fertiliser broadcasted underneath mat, CM = commercial mat, CMt = mat CM with fertiliser broadcasted on mat, CMb = mat CM with fertiliser broadcasted underneath mat.

**Table 7** The effects of mulching and different methods of fertiliser application on soil cation exchange capacity (CEC), exchangeable (Exch.) K, Ca and Mg after four months of planting *Acacia* hybrid at three soil depths

Treatment	0–5 cm depth						5–15 cm depth						15–30 cm depth					
	CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	Exch. K (cmol <sub>c</sub> kg <sup>-1</sup> )	Exch. Mg (cmol <sub>c</sub> kg <sup>-1</sup> )	Exch. Ca (cmol <sub>c</sub> kg <sup>-1</sup> )	CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	Exch. K (cmol <sub>c</sub> kg <sup>-1</sup> )	Exch. Mg (cmol <sub>c</sub> kg <sup>-1</sup> )	Exch. Ca (cmol <sub>c</sub> kg <sup>-1</sup> )	CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	Exch. K (cmol <sub>c</sub> kg <sup>-1</sup> )	Exch. Mg (cmol <sub>c</sub> kg <sup>-1</sup> )	Exch. Ca (cmol <sub>c</sub> kg <sup>-1</sup> )	CEC (cmol <sub>c</sub> kg <sup>-1</sup> )	Exch. K (cmol <sub>c</sub> kg <sup>-1</sup> )	Exch. Mg (cmol <sub>c</sub> kg <sup>-1</sup> )	Exch. Ca (cmol <sub>c</sub> kg <sup>-1</sup> )		
S <sub>0</sub>	3.50 a	0.02 b	0.010 c	0.04 b	3.50 a	0.020 ab	0.010 b	0.040 bcd	3.50 ab	0.02 ab	0.01 a	0.04 a	3.50 ab	0.02 ab	0.01 a	0.04 a		
S	4.00 a	0.01 b	0.010c	0.05 b	3.45 a	0.010 b	0.010 b	0.060 ab	3.20 ab	0.01 b	0.01 a	0.05 a	3.20 ab	0.01 b	0.01 a	0.05 a		
Sf	3.40 b	0.02 b	0.005d	0.02 b	3.51 a	0.010 b	0.010 b	0.020 d	3.52 ab	0.03 ab	0.01 a	0.06 a	3.52 ab	0.03 ab	0.01 a	0.06 a		
M	3.70 a	0.02 b	0.005 d	0.02 b	3.60 a	0.023 ab	0.010 b	0.020 cd	4.20 a	0.03 ab	0.01 a	0.02 a	4.20 a	0.03 ab	0.01 a	0.02 a		
Mt	3.70 a	0.04 a	0.02 00b	0.04 ab	3.10 a	0.030 a	0.020 a	0.05 bcd	2.85 b	0.04 a	0.01 a	0.02 a	2.85 b	0.04 a	0.01 a	0.02 a		
Mc	3.60 a	0.04 a	0.0300 a	0.07 a	3.00 a	0.023 ab	0.023 a	0.090 a	4.10 a	0.02 ab	0.02 a	0.05 b	4.10 a	0.02 ab	0.02 a	0.05 b		
Mb	3.70 a	0.02 b	0.020b	0.07 a	3.30 a	0.018 ab	0.023 a	0.045 bcd	3.30 ab	0.03 ab	0.02 a	0.04 a	3.30 ab	0.03 ab	0.02 a	0.04 a		
CM	3.80 a	0.006 b	0.005 d	0.02 b	3.30 a	0.010 b	0.010 b	0.050 bcd	3.70 a	0.013 b	0.02 a	0.04 a	3.70 a	0.013 b	0.02 a	0.04 a		
CMt	3.80 a	0.04 a	0.020 b	0.07 a	3.20 a	0.030 a	0.020 a	0.040 bcd	3.20 ab	0.03 ab	0.02 a	0.03 a	3.20 ab	0.03 ab	0.02 a	0.03 a		
CMb	3.60 a	0.016 b	0.03 0a	0.07 a	3.45 a	0.017 ab	0.023 a	0.053 bcd	3.50 ab	0.02 ab	0.02 a	0.03 a	3.50 ab	0.02 ab	0.02 a	0.03 a		

S<sub>0</sub> = soil properties before planting; values in the same column with the same letter are not significantly different (p < 0.05); S = control, Sf = compound fertiliser broadcasted, M = laboratory-produced mat, Mt = mat M with fertiliser broadcasted on mat, Mc = mat M with fertiliser incorporated inside, Mb = mat M with fertiliser broadcasted underneath mat, CM = commercial mat, CMt = mat CM with fertiliser broadcasted on mat, CMb = mat CM with fertiliser broadcasted underneath mat.

also observed in the laboratory-produced mat compared with commercial mat (4.4%). The former mat retained most of the parenchyma tissues during production, which was also rich in soluble nutrients, thereby higher leaching was exhibited. Fertiliser applied either on top or beneath the mulch mat resulted in the highest leaching of K. However, leaching of K was significantly reduced when using mulch mat with fertiliser incorporated inside it. Since the leaching of K from the soil was negligible, it was concluded that K leached from the fertiliser and mulch mat. Overall leaching data showed that placing inorganic fertiliser inside the mulch mat during production was a better option to reduce nutrient loss from applied fertiliser on sandy soil. There was poor synchronisation between fertiliser input and plant nutrient demand. The amount of fertiliser applied seemed to be in excess of the uptake capacity by roots; this is most obvious for highly mobile nutrients N and K.

Soil properties did not show much improvement after four months of mulch mat and fertiliser treatments (Tables 6 and 7). The duration of experiment, i.e. four months, was not sufficient for EFB to biodegrade (it requires 8–10 months) and improve the soil properties. The sandy soil was not able to hold the nutrients and prevent them from leaching. At the end of the experiment, the soil pH, N, C, P, exchangeable K, Ca and Mg increased slightly compared with initial values. Total N in the soil changed only in the middle layer (5–15 cm). Regardless of the treatment, only trace amounts of N was detected in the leachate after eight weeks of application (Figure 4). This meant that significant portions of N were retained in the soil. Decomposing products such as phenolics, quinones and carbohydrates formed during degradation of cellulose, hemicelluloses and lignin can bind part of N (Palviainen et al. 2010). Moreover, leaching of N usually occurs in the form of nitrate as plants prefer ammonium-N since roots require much less energy to absorb it (Lewis 1986). Nitrate leaching is not a direct wash-through process but is governed by complex processes influenced by many factors such as acidification of soil (Berger et al. 2009b). Our data showed that substantial amount of N that mineralised from decomposition of mulch mats was not captured by the sandy soil. Apart from leaching, this N could also have been taken up by the plant or released to the environment in gaseous forms.

Treatments with fertiliser applied in combination with mulch mat showed significantly higher values of exchangeable Mg and Ca in the upper layers of the soil. The increase in organic C in the soil was not able to alleviate the CEC values of the soil, perhaps due to the short planting period. All treatments carried out did not show any significant increase or decrease in CEC compared with the original soil at all depths. It was reported that CEC values decreased for soils at 0–15 cm depth treated with fertiliser alone but increased for soils treated with either EFB alone or EFB with fertiliser (Rosenani & Wingkis 1999). This indicates that cations are being released from the fertiliser and held by organic matter (mulch) in the soil where mulch is present as opposed to the rapid leaching of cations with soils treated with fertiliser only. However, in this study, the increase in the amount of organic C from the decomposition of mulch mats (Table 6) in the soil was not able to increase the CEC value compared with before planting. More pronounced results could have been obtained with a longer planting period. Increased soil CEC and exchangeable K, Ca and Mg have been reported in decomposition of EFB in mineral soil compared with soil without mulch (Wingkis 1998, Rosenani & Wingkis 1999). The authors also reported that addition of fertilisers showed a higher increase in these properties due to the faster decomposition rates of EFB. However, results obtained from this experiment were contradictory to these reports and it could be due to the different soil used. Unlike mineral soil, sand has poor water-holding capacity and lack organic matter, hence ions are easily leached.

## CONCLUSIONS

This study showed that there was poor synchronisation between soil nutrient supply and nutrient demand by *Acacia* hybrid seedling. Up to 30% of the applied N and 42% K drained out of the rooting zone within four months of application. Phosphorus was the main growth-limiting nutrient and the least leached (about 5%). The best method to apply mineral NPK fertiliser on sandy tin tailing soil was by incorporating it inside the mulch mat. Mulching with EFB mat did not improve soil nutrient concentration of the sand tailings. The mulch mat is able to reduce nutrient losses through leaching. This could contribute to enhanced uptake of nutrients K and P by plants.

## ACKNOWLEDGEMENTS

The authors acknowledge contributions from O Ahmad Sharafi, MS Shamsuri and G Ab Rasip. Many thanks to the Director-General of FRIM, Public Service Department and Ministry of Science, Technology and Innovation, Malaysia for the research grants.

## REFERENCES

- ANDERSON JM & INGRAM JSI. 1993. *Tropical Soil Biology and Fertility: A Handbook of Methods*. Second edition. CAB International, Wallingford.
- BERGER TW, INSELSBACHER E, MUTSCH F & PFEFFER M. 2009a. Nutrient cycling and soil leaching in eighteen pure and mixed stands of beech (*Fagus sylvatica*) and spruce (*Picea abies*). *Forest Ecology and Management* 258: 2578–2592.
- BERGER TW, UNTERSTEINER H, TOPLITZER M & NEUBAUER J. 2009b. Nutrient fluxes in pure and mixed stands of spruce (*Picea abies*) and beech (*Fagus sylvatica*). *Plant and Soil* 322: 317–342.
- CHAN YK. 1990. The mining land—an overview of the current situation in Peninsular Malaysia. Paper presented at the Seminar on Ex-Mining Land and BRIS Soils: Prospects and Profits. 15–16 October, Kuala Lumpur
- DUIKER SW & LAL R. 1999. Crop residue and tillage effects on carbon sequestration in a Luvisol in central Ohio. *Soil and Tillage Research* 52: 73–81.
- FORGE TA, HOGUE E, NEILSEN G & NIELSEN D. 2003. Effects of organic mulches on soil microfauna in root zone of apple: implications for nutrient fluxes and functional diversity of soil food web. *Applied Soil Ecology* 22: 39–54.
- FARRELL M, PERKINS WT, HOBBS PJ, GRIFFITH GW & JONES DL. 2010. Migration of heavy metals in soil as influenced by compost amendments. *Environmental Pollution* 158: 55–64.
- HARRISON AF. 1987. *Soil Organic Phosphorus: A Review of World Literature*. CAB International, Wallingford.
- HAVLIN JL, KISSEL DE, MADDUS LD, CLAASSEN MM & LONG JH. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. *Soil Science Society American Journal* 54: 448–452.
- JIN K, CORNELIS WM, GABRIELS D, BAERT M, WU HJ, SCHIETTECATTE W, CAI DX, DE NEVE S, JIN JY, HARTMANN R & HOFFMAN G. 2009. Residue cover and rainfall intensity effects on runoff soil organic carbon losses. *Catena* 78: 81–86.
- JONES BEH, HAYNES RJ & PHILLIPS IR. 2010. Effect of amendment of bauxite processing sand with organic materials on its chemical, physical and microbial properties. *Journal of Environmental Management* 91: 2281–2288.
- JORDAN A, ZAVALA LM & GIL J. 2010. Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. *Catena*: 81: 77–85.
- LEWIS OAM. 1986. *Plants and Nitrogen*. Studies in Biology No. 166. Edward Arnold Publishers, London.
- LIM KH, MAENE LM, MAESSCHALK G & WAN SULAIMAN WH. 1981. Reclamation of tin tailings for agriculture in Malaysia. *Faculty of Agriculture Technical Bulletin* 1: 61–65.
- LLOYD J, HERMS D, STINNER B & HOITINK H. 2001. Mulch effects on soil microbial activity, nutrient cycling, and plant growth in ornamental landscapes. *Ohio State Bulletin Special Circular* 186: 1–6.
- MYERS RJK, PALM CA, CUEVAS E, GUNATILLEKE IUN & BOSSARD M. 1994. The synchronization of nutrient mineralization and plant nutrient demand. Pp 81–116 in Woomer PL & Swift MJ (Eds) *The Biological Management of Tropical Soil Fertility*. John Wiley & Sons, Chichester.
- NIK MUHAMMAD M, AZIZAH H & IDRIS A. 1994. Rehabilitation of ex-tin mining land by agroforestry practice. *Journal of Tropical Forest Science* 7: 113–127.
- PALANIAPPAN VM. 1972. History, flora and edaphology of tin tailings areas around Kuala Lumpur. *Tropical Ecology* 13: 203–213.
- PALVIAINEN M, FINE R L, LAIHO R, SHOROHVA E, KAPITSA E & VANHA-MAJAMAA I. 2010. Carbon and nitrogen release from decomposing Scots pine, Norway spruce and silver birch stumps. *Forest Ecology and Management* 259: 390–398.
- ROSENANI AB & WINGKIS R. 1999. Empty fruit bunch application to newly transplanted oil palm: its decomposition and nutrient release. Pp 112–119 in Fauziah CI et al. (Eds) *Proceedings of Soil Science Conference of Malaysia*. 15–18 April 1999, Seremban.
- SHAMSUDDIN J, MOKHTAR N & PARAMANATHAN S. 1986. Morphology, mineralogy and chemistry of an ex-mining land in Ipoh, Perak. *Pertanika* 9: 89–97.
- VIMALA P & SALBIAH H. 2002. Effect of palm oil mill effluent on turmeric (*Cucurma domestica*) grown on sand-tailings. Pp 121–124 in Hawa ZJ et al. (Eds) *SOILS 2002: Applications of Modern Tools in Agriculture. Proceedings of the Malaysian Society of Soil Science*. 17–20 April 2002, Kota Kinabalu.
- VIMALA P & ZAHARAH AR. 1992. Chili cultivation on problem soils in Malaysia. Pp 32–37 in Chew BH et al. (Eds) *Proceedings of the Conference on Chili Production in the Tropics*. 13–14 October 1992, Kuala Lumpur.
- WAN ASMA I. 2006. Optimization of mulch mat production from oil palm empty fruit bunches and its effects on growth performance of *Acacia* hybrid seedlings on sandy tailings. PhD thesis, Universiti Putra Malaysia, Serdang.
- WAN RASIDAH AK, ROZITA A & BLASEKR. 1990. Determination of nitrogen, cation exchange capacity, phosphorus and ammonium nitrogen using autoanalyzer. In *A Laboratory Manual*. Forest Research Institute Malaysia, Kepong. (Unpublished)
- WESSELING JG, STOOF CR, RITSEMA CJ, OOSTINDIE K & DEKKER LW. 2009. The effect of soil texture and organic amendment on the hydrological behavior of coarse-textured soils. *Soil Use and Management* 25: 274–292.
- WINGKIS R. 1998. Chemical composition of oil palm empty fruit bunch and its decomposition in the fields. Masters of Agriculture Science thesis, Universiti Pertanian Malaysia, Serdang.