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Effect of Mineral and Humic Substances on *Tailing* Soil Properties and Nutrient Uptake by *Pennisetum purpureum* Schumach

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ABSTRACT

Tin mining produces a by-product sand tailing from soil leaching with characteristic low pH and total organic carbon, and can be reclaimed by providing a suitable ameliorant. When available in situ, ameliorant materials can be economically used as they are required in large amounts. Fortunately, Bangka Belitung has sample stock of such kaolinite-rich minerals that can be utilized for improving soil chemical properties. Extracted organic materials, such as humic substances, can also be utilized as they influence the complex soil reactions, and promote plant growth. Thus, this study aimed to assess the effects of mineral, humic materials and interaction of both material on soil chemical properties and nutrient uptake of Pennisetum purpureum Schumach. A completely randomized design with 2 factors and 3 replications each was employed. Factor 1 was mineral matter is 0; 420; 840; 1.260 Mg ha^{-1} while Factor 2 was humic material is 0; 0.46; 0.92; 1.38 kg C ha^{-1}. Air-dried samples of tailing were applied with oil palm compost then mixed evenly with mineral and humic materials. *Penissetum purpureum* Schumach was planted after 4 weeks incubation, and maintained for another 4 weeks. The results demonstrated that the addition of mineral matter significantly increased soil organic carbon content, total N, exchangeable K, Fe, Mn and boosted nutrient - total Ca, Mg and Mn – uptake of the plant. But the application of humic material increased only soil organic carbon content. The interaction of both materials only lowered soil pH.

Keywords: Ameliorant, elephant grass, soil reclamation, post mining

INTRODUCTION

A common sight at an ex-tin mining area is a field of *tailing* materials that resembles a swamp or dry landscape. Such *tailing* usually consists of broken sand particles mixed with assorted pebbles. Compared to its original soil material, the chemical properties of such *tailing* sand are too poor to support plant growth. Hence, merely relying on the natural process for restoring ex-tin mining land without human intervention would require a considerably long time, and during that time span, the *tailing*-laden ex-mining land remains practically of no economic value, apart from some residual environmental impacts. This had been highlighted by Inonu (2009) who reported that, left to itself, the physical and chemical characteristics of *tailing* land did not change materially even after the lapse of more than 20 years. Similarly, in a study on vegetation development on *tailing* land at different age classes after tin mining in Bangka island, Nurtjahya *et al.* (2006) found that plant succession proceeded at a remarkably slow rate even over a period of 25 to 50 years. Given climatic and post-mining land conditions which are generally not conducive to higher plant (*e.g*. trees) development thus, the only plant species that can naturally settle rapidly on ex-tin mining land are grasses and brush.

There are a number of ways that can be employed to rehabilitate post-mining land towards re-vegetating it, including the use of soil ameliorants. However, these soil ameliorant materials should be made available in considerably large quantities in order to render the land technically and economically tenable to successful restoration. In this regard, Bangka Belitung island (Figure 1) holds a decided advantage in that it has substantial stores of natural resources, particularly mineral soil that contains high levels of kaolinite clay which can be viably used as soil ameliorant. Another potential soil ameliorant for ex-mining land are humic materials, since they render direct influence on plant growth *i.e.* increased enzymatic activity, membrane permeability (Pinton *et al.* 1992) as well as indirect impacts *e.g.* improved soil structure, increased cation exchange capacity (CEC), intensified soil microorganism activity, and boosted solubility and complex ion availability (Alianiello *et al*. 1991, Budianta *et al*. 2013). Humic substances likewise have the capability to form complex links with metal ions (Stevenson, 1982) which can lower the washing off of nutrients by irrigation water, as well as raise fertilizer efficiency on sandy soils (Selim *et al.* 2009; Qualls 2000). Many researches have been undertaken on the role of mineral materials and humic substances in improving the soil physical and chemical properties in ex-mining land. For instance, Herjuna (2010) found that the application of humic materials and fly ash on ex-coal mining land can boost the intake of N, K, Ca and Mg by sengon (*Albizia falcataria*) trees in plantation.

On the other hand, the application of 50 mgC^{-l} humic substance increased both wet and dry weights of corn, raised Ca, N dan Zn in corn plants (Eyheraguible *et al*. 2008). A related study by Sutono (2012) also disclosed that the combined application of mineral material, compost, and steel slag can promote the absorption of N, P, K, Ca dan Mg by *gogo* (upland) paddy rice planted on *tailing* soil media from an ex-tin mine.

Towards minimizing the consequent negative impacts of tin mining in an effective and sustainable manner, mining land reclamation needs to be immediately followed by a proven re-greening regime using suitable, fast-growing plant species. Given the typically adverse land and climate conditions in the locality, a viable yet relatively simple land restoration and use approach is through adaptive cultivation of livestock feed crop. To illustrate, based on recent data from BPS (2011), Bangka Belitung province, with a mean air temperature of 27 ^{o}C, receives an average monthly rainfall of 341.10 mm. With a cattle population (2011) of 7,852 heads, livestock-raising appears to be a highly promising business venture. However, one major constraint in cattle husbandry is the limited land available for pasture and for growing livestock feed crop, brought about by the rapid development of oil palm, rubber and pepper plantations as well as tin mining in the area. Thus, the reclamation and restoration of ex-tin mining land for the cultivation of livestock feed crop offers not only a technically and economically viable alternative, but also as a sound multiple land-use management strategy in which the oftentimes competing needs of agriculture, livestock industry and mining can be optimally harmonized. One

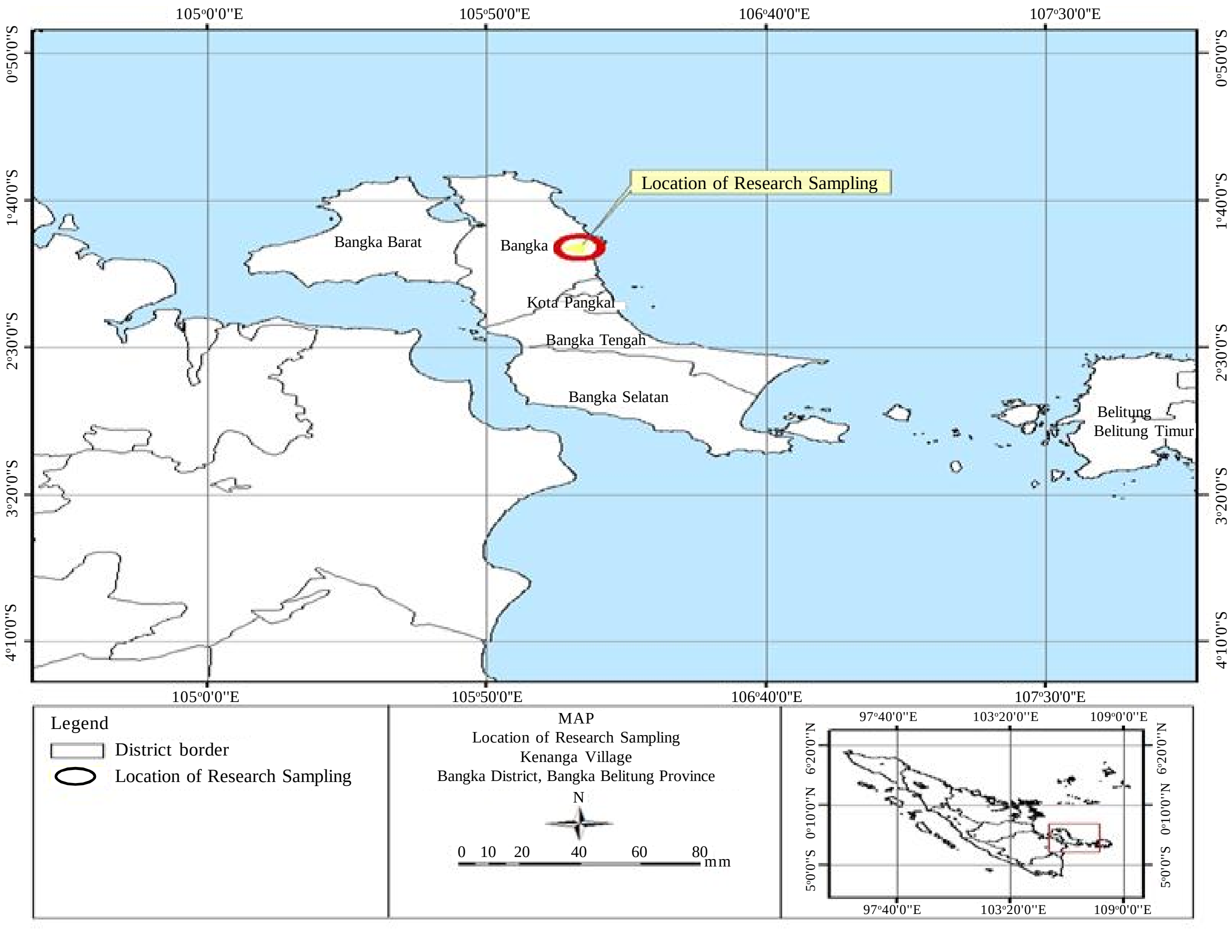

Figure 1. Sampling site Kenanga Village, District Bangka, Province of Bangka Belitung, Indonesia.

prospective livestock feed crop species with high adaptability when planted on marginal or even extremely poor soil, as in ex-mining land, is elephant grass (*Pennisetum purpureum* Schumach) (Ra *et al*. 2012; Ajayi 2011). It can thrive over a fairly wide range of soil types except on water-logged or excessively dry soils, respons well to fertilizer application, and exhibits high productivity, yielding as much as 100 to 200 Mg ha^{-1} yr^{-1} (Jayadi 1991; Liu *et al*. 2009).

Thus, in view of the recognized vital role played by humic substances and mineral materials in improving the residual properties of ex-mining land, the objective of this study was to examine the effects of *in situ* mineral matter and humic substances on the chemical attributes of the soil, as well as their influence on the nutrient uptake of *P. purpureum* Schumach.

MATERIALS AND METHODS

Sampling Location

Soil samples were taken from *tailing* sand aged 0 year after tin mining coming from Kenanga village, Central Bangka Regency (Figure 1), mineral matter was collected from Rangkui village, Pangkalpinang, humic material was extracted from lignite coal, and compost from empty oil palm fruit bunches was sourced from PTPN 7. The characteristics of tailing sand, mineral matter, humic matterial, and compost are described at Table 1.

Setting of Study

This study was conducted inside a plant nursery greenhouse. A mixture of *tailing* sand, compost from left-over oil palm fruit bunches, mineral matter (M), and humic material (H) was used. As growing medium, a soil sample was incubated for 4 weeks, after which basic fertilizer - urea, KCl, and SP 36 - were added, then planted with *P. purpureum* grass, and monitored over 4 weeks. A complete randomized experimental design consisting of 2 factors with 3 replications each (total of 48 experimental pots) was employed. The first factor was mineral matter (M) at 4 dosage levels: M_0 (no mineral matter added), M_1 (2.10 kg mineral matter 10 kg^{-1} *tailing* added), M_2 (4.20 kg mineral matter 10 kg^{-1} *tailing were* added), and M_3 (6.30 kg mineral matter 10 kg^{-1} *tailing* added); or corresponding to 0, 420, 840, and 1,260 Mg ha^{-1}, respectively. On the other hand, the second factor represented humic solution (H) applied at 4 dosage levels: C_0 (no humic material added), H_1 (2.32 mg C 10 kg^{-1} *tailing* were added), H_2 (4.64 mg C 10 kg^{-1} *tailing* added), H_3 (6.96 mg C 10 kg^{-1} *tailing* added), or corresponding to 0, 0.46, 0.92 and 1.38 kg C ha^{-1} were applied. Treatment combinations and dosage levels per ameliorant are summarized in Table 2.

Soil Sample Preparation

The land surface from which *tailing* sand, and mineral matter samples were collected at age 0 year

Table 1. Some chemical and physical characteristics of materials used before experiment.

Material charateristics	*Tailing* sand	Mineral matter	Humic material (solution characteristics)	Compost
Sand (%)	98.42	67.59	-	-
Dust (%)	1.32	6.90	-	-
Clay (%)	0.27	25.51	-	-
pH H_2O	5.65	4.90	8.66	7.20
$C_{organic}$ (%)	0.29	2.15	2.32	45.90
N_{total} (%)	0.02	0.22	-	0.74
$P_{available}$ (mg kg^{-1})	1.25	3.86	21.49	26.57
$K_{exchangeable}$ ($cmol^{(+)}kg^{-1}$)	0.02	0.26	21.78	15.31
$Ca_{exchangeable}$ ($cmol^{(+)}kg^{-1}$)	0.85	1.33	0.01	24.91
$Mg_{exchangeable}$ ($cmol^{(+)}kg^{-1}$)	0.19	0.59	0.18	17.99
Fe (mg kg^{-1})	2.54	6.30	9.98	17.20
Mn (mg kg^{-1})	0.05	0.33	1.36	26.67
Zn (mg kg^{-1})	0.47	0.45	0.92	8.89
Density content	-	-	9.23	-
Dust content	-	-	4.84	-

Table 2. Treatment combinations and dosage levels of mineral matter and humic solution applied.

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Treatment	*Tailing*sand (kg)	Compost (Oil Palm) (kg 10 kg^{-1} *tailing*)	Mineral Matter (kg 10 kg^{-1} *tailing*)	Humic Solution (mg C 10 kg^{-1} *tailing*)	Total Applied pot^{-1} (kg)
M_0H_0	10	2.5	0.0	0.00	12.5
M_0H_1	10	2.5	0.0	2.32	12.5
M_0H_2	10	2.5	0.0	4.64	12.5
M_0H_3	10	2.5	0.0	6.96	12.5
M_1H_0	10	2.5	2.1	0.00	14.6
M_1H_1	10	2.5	2.1	2.32	14.6
M_1H_2	10	2.5	2.1	4.64	14.6
M_1H_3	10	2.5	2.1	6.96	14.6
M_2H_0	10	2.5	4.2	0.00	16.7
M_2H_1	10	2.5	4.2	2.32	16.7
M_2H_2	10	2.5	4.2	4.64	16.7
M_2H_3	10	2.5	4.2	6.96	16.7
M_3H_0	10	2.5	6.3	0.00	18.8
M_3H_1	10	2.5	6.3	2.32	18.8
M_3H_2	10	2.5	6.3	4.64	18.8
M_3H_3	10	2.5	6.3	6.96	18.8

Notes: The letter M indicates mineral matter, while H refers to humic solution, that were used as soil ameliorant.

after tin mining, were respectively cleared of plants, litter and dirt. Composite soil samples were taken up to a depth of 30 cm. The *tailing* sand and mineral matter were air-dried and filtered using a 2-mm sieve. The air-dried *tailing* sand were then divided into 10-kg lots and each lot was mixed with 2.5 kg (oil palm) compost, and mineral matter at dosage levels of 0, 2.10, 4.20, 6.30 kg^{-1}10 kg *tailing* as well as humic solution at dosage levels of 0, 2.32, 4.64 and 6.96 mgC 10 kg^{-1} *tailing* (the humic material was diluted 100 times before application into the *tailing* soil). The resulting mixture was then filled into plastic pots (20-liter volume and 32-cm height) without holes. Watering of the soil mixture used in this study was done using ion-free water through aeration pipe. The soil material was incubated for 4 weeks.

Planting

After incubation for 4 weeks, the soil mixture was planted with seedlings of *P. purpureum* grass, and applied with basic urea fertilizer 5 g pot^{-1}, KCl 2.5 g pot^{-1} and SP36 2.5 g pot^{-1}. Fertilizer was applied only once at time of planting. Plant maintenance was done by watering using ion-free water by means of aeration pipe. At the age of about 4 weeks (plant height of more than 2 m), the plants were harvested by cutting the stalks up to 5 cm above ground level. The harvested plants were then weighed (green weight) and oven-dried at 60^{o}C to determine its dry weight.

Soil Analysis

Soil analysis was conducted during the first harvest by obtaining a composite soil sample from the pot up to a depth of 30 cm which was then air-dried, followed by analysis of the following parameters: pH H_2O (Electrode glass), Organic C (Walkey and Black), total N (Kjeldahl), available P [Bray I (Spectrophotometer), $K_{exchangeable}$ [NH_4OAC 1*N* pH 7 (Flamephotometer)], $Ca_{exchangeable,}$ $Mg_{exchangeable}$ [NH_4OAC 1*N* pH 7 (*AAS*)], and micro-elements (Fe, Mn, Zn) [HCl 0.05*N* (*AAS*)]. The parameters for sample plant analysis were: Ca, Mg, Fe, Mn dan Zn [Dry ash (AAS), K [Dry ash (Flamephotometer)].

Data on soil and plant tissue analysis were subjected to statistical Analysis of Variance (ANOVA) with F-test at 5% level of significance. Significant treatment differences were further analyzed using Duncan Multiple Range Test (DMRT) at 5% significance level.

RESULTS AND DISCUSSION

Effect of Mineral Matter on the Chemical Properties of *Tailing* Sand

Contents of Organic C and total N of Soil

The effects of mineral matter application on soil organic C and total N after plant harvest are

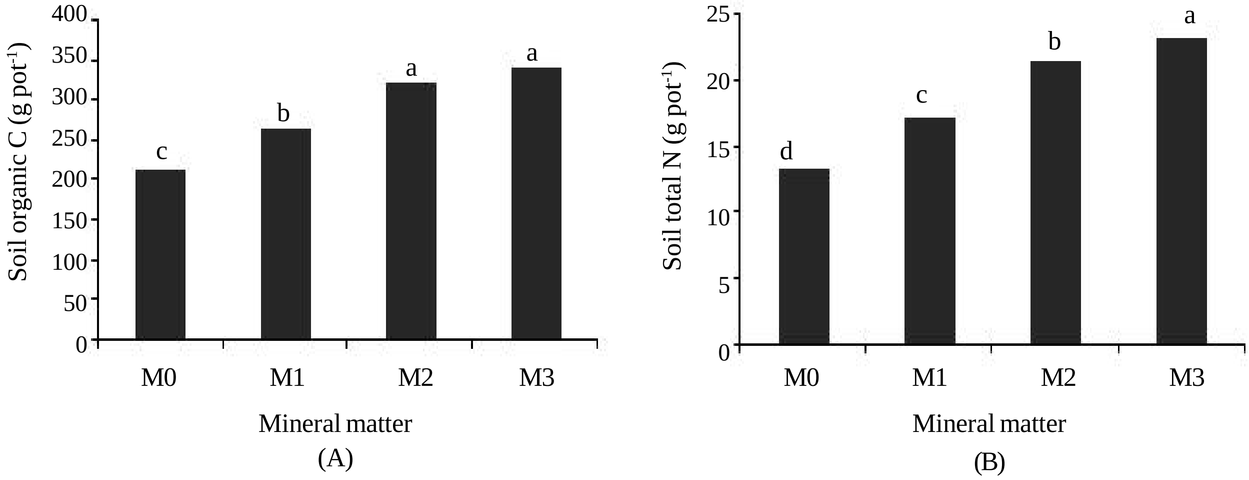

Figure.2. Effect of mineral matter application on soil organic C (A) and total N (B) content after plant harvest. Numerical values that are followed by similar letters indicate "not significant difference" at 5% significance level based on DMRT. M_0 (Control= no mineral matter added, 10 kg *tailing*, and 2.5 kg compost); M_1; M_2; M_3 = dosage of mineral matter at 2.10; 4.20; and 6.30 kg per (10 kg *tailing* and 2.50 kg compost, respectively).

illustrated in Figure 2. The statistical test showed a highly significant effect: the addition of mineral matter appreciably increased both soil organic C and total N contents. This was brought about by the fact that the levels of organic C (2.15%) and total N (0.22%) in the mineral matter were much higher than those in the *tailing* soil, namely: organic C (0.29%) and total N (0.02%). The application of mineral matter raised the content of organic C by as much as 60.69% in M_3 (338.62 g pot^{-1}) referenced from M_0 (210.73 g pot^{-1}), and increased total N content up to 75.30% in M_3 (23.07 g pot^{-1}) against M_0 (13.16 g pot^{-1}). Kusumawati (2005) showed that the mineral matter of soil on 1, 6, 16, 25 years after tin mining increased organic C and total N on soil.

Content of Soil Available P

Effect of mineral matter application on soil available P after plant harvest is depicted in Figure 3. The result of the statistical test, as depicted in Figure 3, demonstrates that the application of mineral matter not significantly affect available P in the soil after plant harvest. However, there was a tendency towards higher level of available P as more soil ameliorant was added.

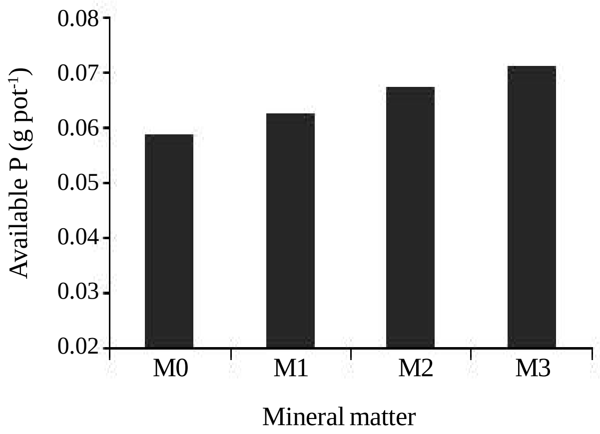

Figure 3. Effect of mineral matter application on available P content after plant harvest.

Table 2 shows the effects of mineral matter application on soil Ca_{exch}, Mg_{exch} and K_{exch} contents. The results of the statistical analysis, as depicted in Table 2, proves that the application of mineral matter caused a highly significant response in the contentl of K_{exch}, although not in the case of Mg_{exch} and Ca_{exch} contents. Generally though, the contents of Mg_{exch} and Ca_{exch} tended to rise with greater amounts of mineral matter added, particularly at the highest level of mineral matter applied – 6.30 kg pot^{-1} (M_3). $K_{exchangeable}$ increased up to 150% at treatment M_3 (1.30 g pot^{-1}) referenced from treatment M_0 (0.52 g pot^{-1}), largely because its level (0.20 cmol$^{(+)}$kg^{-1}) in the mineral matter was at least 10 times greater than that of the *tailing* sand (0.02 cmol$^{(+)}$kg^{-1}).

Contents of Micro-elements (Fe, Zn dan Mn)

The addition of mineral matter resulted into some effects on the contents of soil Fe, Zn, and Mn after plant harvest, as can be seen in Table 3. The application of mineral matter produced a highly significant effect on the content of soil Fe, but inversely on soil Zn and Mn. The Fe content 124.32%

Table 2. Effects of mineral matter application on soil Ca_{exch}, Mg_{exch} and K_{exch} contents.

Treatment	Ca_{exch}	Mg_{exch}	K_{exch}
	---------------------------- ($g\ pot^{-1}$)	--------------------------	
M_0	5.88	0.96	0.52c
M_1	6.03	1.01	0.61c
M_2	6.49	1.10	0.86b
M_3	6.68	1.19	1.30a

Similar letter in the same coloumn is not significantly difference" at 5% significance level based on DMRT (*Duncan's Multiple Range Test*). M_0 (Control= no mineral matter added, 10 kg *tailing*, and 2.5 kg compost); M_1; M_2; M_3 = dosage of mineral matter at 2.10; 4.20; and 6.30 kg per (10 kg *tailing* and 2.50 kg compost, respectively)

Table 3. Effects of the addition of mineral matter on the contents of soil Fe, Zn, and Mn after plant harvest.

Treatment	Fe	Zn	Mn
	---------------------- ($mg\ pot^{-1}$)	-------------------------	
M_0	205.92d	38.99	115.11
M_1	280.52c	40.84	117.05
M_2	359.88b	41.68	118.88
M_3	461.93a	44.71	121.08

at treatment M_3 (461.93 mg pot^{-1}) was 124.32% higher than treatment M_0 (205.92 mg pot^{-1}). These effect could be attributed to the fact that the levels of Fe (6.30 mg kg^{-1}) in the mineral matter were higher compared to those in *tailing* soil -Fe (2.54 mg kg^{-1}). On the other hand, the addition of mineral matter did not significantly affect the contents of soil Zn dan Mn.

Effect of Humic Material on Chemical Properties of *Tailing* Sand

In general, humic substances promote the release of nutrient elements from mineral soil. In this study, humic material was derived from lignite coal.

Contents of Soil organic C, total N, and Available P

Table 4 summarizes the effects of humic material application on soil organic C, total N, and available P after plant harvest.

The statistical analysis implied that the addition of humic material significantly affected the contents of soil organic C but not on total N, and available P (Table 4). Organic C content increased significantly because the humic of soil material contained a much higher level of organic C (2.30%) compared to that of *tailing* sand (0.29%).

Table 4. Effects of humic material application on soil organic C, total N, and available P.

Treatment	organic C	total N	available P
	-------------- ($g\ pot^{-1}$)	--------------------	
H_0	269.212 b	17.735	0.062
H_1	272.492 b	18.559	0.063
H_2	300.673 a	19.375	0.069
H_3	275.104 b	18.927	0.065

Similar letter in the same coloumn is not significantly difference" at 5% level based on DMRT. H_0 (Control= no humic material added, 10 kg *tailing*, and 2.5 kg compost); H_1; H_2; H_3 = dosage of humic material at 2.32, 4.64 and 6.96 mgC per (10 kg *tailing* and 2.50 kg compost, respectively)

Cation exchange capacity ($Ca_{exchangeable}$, $Mg_{exchangeable}$ and $K_{exchangeable}$), Fe, Zn and Mn

The results of data analysis on the application of humic material on cation exchange capacity (Ca_{exch}, Mg_{exch} and K_{exch}), Fe, Zn and Mn of the soil after plant harvest in this study are shown in Table 5.

The addition of humic material significantly affected the contents of Mn but not on Ca_{exch}, Mg_{exch} and K_{exch}, Fe, Zn but there was a tendency to raise Ca_{exch} and K_{exch}, at the application of 4.64 mg cC pot^{-1} (treatment H_2), and to increase Fe and Zn contents at the addition of 6.96 mgC pot^{-1} (H_3) humic material, compared to the corresponding contents of Ca_{exch}, K_{exch}, Fe and Zn at treatment H_0.

Table 5. Effect application of humic material on Ca_{exch}, Mg_{exch} and K_{exch}, Fe, Zn and Mn after plant harvest.

Treatment	Ca_{exch}	Mg_{exch}	K_{exch}	Fe	Zn	Mn
	-----------(g pot^{-1})------------			------------(mg pot^{-1})-----------		
H_0	6.27	1.16	0.82	340.09	41.51	119.89b
H_1	6.07	0.96	0.74	314.04	38.68	98.65c
H_2	6.65	1.08	0.97	317.23	42.15	133.67a
H_3	6.09	1.07	0.75	336.89	43.87	119.91b

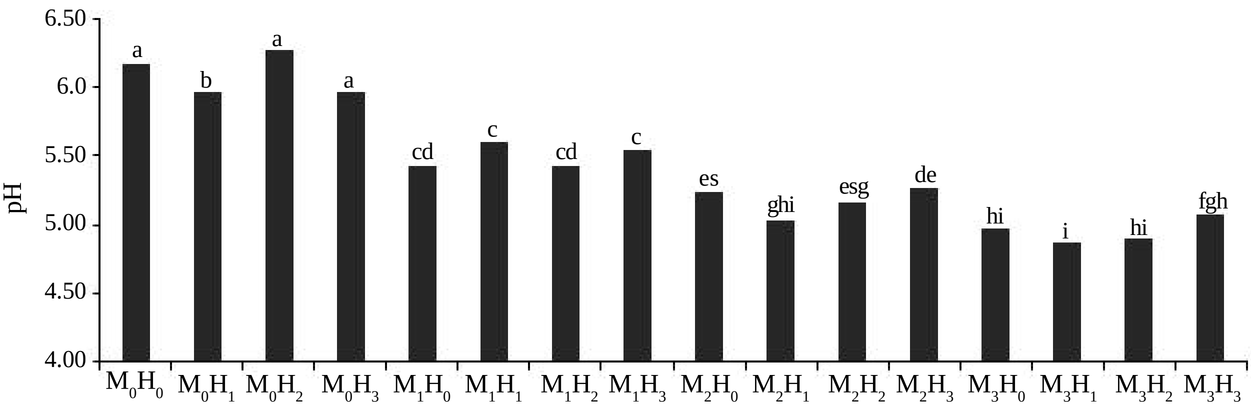

Figure 4. Interaction Effect of application of combined mineral and humic material on soil pH after plant harvest. Numerical values that are followed by similar letters indicate “not significant difference” at 5% significance level based on DMRT. M_0H_0 (Control= no humic matter added, no humic material added, 10 kg *tailing*, and 2.50 kg compost); M_1; M_2; M_3 = dosage of mineral matter 2.10, 4.20, 6.30 kg per 10 *kg tailing* and 2.50 compost, respectively. H_1; H_2; H_3 = dosage of humic material at 2.32, 4.64 and 6.96 mgC per (10 kg *tailing* and 2.50 kg compost, respectively).

Effect Interaction between Mineral and Humic Materials on the Chemical Properties of *Tailing* Sand

Figure 4 illustrates the interaction effect of the combined application of mineral and humic materials . . *tailing* soil pH after plant harvest. The ensuing statistical analysis on the application of combined mineral and humic materials exhibited significant interaction in bringing down soil pH (Figure 4), it was caused mainly by the lower pH of the mineral matter (4.90) compared to that of the *tailing* soil (5.65), even though the pH level of the humic material was much higher (8.66). However, this combined effect could not yet raise the soil pH since the total amount of humic material applied was not sufficient enough to elevate pH.

Effect of Application of Mineral and Humic Materials on Nutrient Uptake by *P. purpureum* Schumach

As shown in Table 6, data analysis suggests that the application of mineral and humic materials on *tailing* soil influenced the nutrient intake of *P. purpureum* Schumach. Mineral matter significantly raised the uptake of Ca, Mg, dan Mn up to 22.41%; 26.53% and 51.69%, respectively at treatment M_2 relative to treatment M_0. This increase in nutrient absorption could be attributed to the optimal addition of around 840 Mg ha^{-1} (treatment M_2), but surprisingly, it declined at the dosage level of 1260 Mg ha^{-1} (treatment M_3). This phenomenon could have been caused by the watering process during incubation and planting stages that was done by aeration pipe thereby resulting into soil water differential that likewise influenced nutrient absorption through the plant roots. In comparison, the application of humic material did not significantly alter nutrient absorption although there was a tendency to raise absorption of Ca, Mg, K, Fe, Zn, and Mn within the plant with the addition of 0.92 kgC ha^{-1} (treatment H_2), and which tended to decline at the dosage of 1.38 kgC ha^{-1} (treatment H_3). According to Ayuso *et al.* (1986), the absorption of Fe, Mn, and Zn in barley increased with the application of humic materials up to a dosage level below 10 mg C L^{-1}, and decreased at dosages higher than 10 mg C L^{-1}.

Table 6. Nutrient uptake by *P. purpureum* Schumach.

Treatment	Ca total	Mg total	K total	Fe total	Zn total	Mn total
	--------------------g pot^{-1}	-----------------		----------------mg pot^{-1}	------------------	
M_0	0.058 bc	0.049 b	1.222	3.297	0.549	0.89 b
M_1	0.069 ab	0.055 ab	1.276	4.154	0.654	1.11 b
M_2	0.071 a	0.062 a	1.362	4.245	0.695	1.35 a
M_3	0.054 c	0.045 b	1.081	3.609	0.607	0.99 b
H_0	0.055	0.046	1.158	3.260	0.599	0.90
H_1	0.062	0.053	1.160	4.105	0.602	1.09
H_2	0.070	0.055	1.340	4.561	0.678	1.21
H_3	0.064	0.056	1.282	3.378	0.626	1.15

Similar letter in the same coloumn is not significantly difference" at 5% level based on DMRT. M_0H_0 (Control= no humic matter added, no humic material added, 10 kg *tailing*, and 2.50 kg compost); M_1; M_2; M_3 = dosage of mineral matter 2.10, 4.20, 6.30 kg per 10 *kg tailing* and 2.50 compost, respectively. H_1; H_2; H_3 = dosage of humic material at 2.32; 4.64; and 6.96 mgC per (10 kg *tailing* and 2.50 kg compost, respectively).

CONCLUSIONS

The application of mineral matter on *tailing* soil increased the value of organic C, total N, K_{exch} and Fe. On the other hand, the addition of humic material raised the value of organic C and Mn in the soil. It follows that the interaction effect of combined application of mineral and humic materials lowers soil pH. Mineral matter can also boost the uptake of essential soil nutrients - Ca, Mg, and Mn – by the plant.

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