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Research Article

Status of macro and micro nutrients from deposited tailings in reclamation area, PT Freeport Indonesia, Timika

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Abstract: The reclamation program of deposited tailings (SIRSAT) is the obligation of the mining concession holder PT Freeport Indonesia (PTFI). The monitoring of soil and plant qualities regularly is part of the study of the success or performance of mining reclamation. The objective of research in the reclamation area was to study the uptake of macro and micronutrients in inactive tailings, and representative plants that grow up on it. The result showed that pH was alkaline in the land of MP21 with its plants of *M. sago*and *C.nucifera*, MP27 with Matoa (*P.pinnata*), both of the representative locations with tailings/soil depth of 0-20 cm and 20-40 cm, except the surface layer of MP21 has lower pH, i.e. neutral. The organic matter tends to be higher at MP21 with *M. sago*, followed by *C. nucifera*, while at MP27 with *P. pinnata* was very low on the surface layer (topsoil) and the bottom layer. MP27 was reclaimed in 2003 with *P. pinnata*, however these plants tend to be abnormal after being planted more than 10 years. While MP21 with *M. sago* and *C. nucifera* was more fertile due to high content of organic matter. Besides that, the tailings deposition at MP21 had became inactive tailings for longer, and were used for the land reclamation activities since 1992/1993. The uptake of macronutrients, especially K was high, which was found in both productive and old leaves in the representative plants of inactive tailings and natural soil. While the old leaves of *P. pinnata* produced the highest content of S, i.e. > 0,1%. Mnwas the highest in both of old leaves of *C. nucifera* (379,50ppm) and *M. Sago* (558 ppm) which were planted in the natural soil. These concentration levels were higher than normal criteria (> 300 ppm Mn). The uptake of Zn includes normal criteria, except in the productive leaves (170,67ppm), and also the old leaves (160.33 ppm), or exceeds of the normal criteria (> 100 ppm Zn) found in *P. pinnata* MP21.

Keywords: *edible plant, plant tissue, reclamation, tailings*

Introduction

The Reclamation program in tailings (SIRSAT : sand tailings) is the obligation of the holder of the mining concessions of PT Freeport Indonesia (PTFI). Impact of the operation of copper and gold mining at Grasberg, PTFI has made reclaimed tailings at DLA (Double Levee Area) - Timika. There are inactive tailings at DLA region, it is about 10-20 years old as inactive tailings, with an area of approximately 1500 hectares which has functioned as Natural Succession and Reclamation Areas. Succession area has a depth of shallow ground water and is wet, so easily it was covered by *Phragmites karka* as a pioneer, while the Reclamation Area has a depth of ground water, deeper and dry, therefore reclaimed with agricultural crops and forestry. Both of these areas are located in the west of the old west levee, DLA and it has a particle size from north to south gradually, i.e. coarse, medium, fine and very fine (PTFI, 1998). Success of the reclamation program could be evaluated through the monitoring activities as to the availability of macro and micronutrients, and the uptake of nutrients by plants that were cultivated in the Reclamation Area. The availability of macro and micronutrients contained in tailings, and the uptake of nutrients for the plants growth were also analyzed to study the growth and the development of its plants cultivated. Therefore monitoring of the quality of soil and plants in the reclaimed land of tailings deposition is needed, as futher study of the success or performance of reclamation of the former mining area. The objective of research in the Land Reclamation was to study macro and micronutrients in inactive tailings, and its representative plants, and compared withnatural soil.

Materials and Methods

The research was conducted in the reclamation areas of MP21 and MP27 where the particle size of tailings were medium and fine, and non tailings as comparator of natural soil in Timika.Map of location is presented in Figure 1. The first research was conducted in 2011. The paper shows the observation data was in November 2013/2014 from the reclamation areas of MP 21 and MP27, and agricultural land of local people (SP4 and NWRP) in Timika.Sampling of tailings/soil were taken at two depths of 0-20 cm and 20-40 cm from land reclaimed with agricultural plants.Sampling of plant tissue (leaf) was taken from the shoots, middle, and bottom of the canopy, with consideration that the translocation of macro and micro nutrients are accumulated in the leaf tissue of plants. The study of the uptake of macro and micro nutrients was conducted by the analysis of samples at the Laboratory. The chemical properties include of pH, C, N, P, S, Al, base cations (Ca, Mg, K, Na), CEC, Hg, Cd, Fe, Mn, Cu, and Zn. The physical properties, i.e. texture (particle size). The nutrient uptake of plant tissue, i.e. C, N, P, S, Al, Ca, Mg, K, Na, Hg, Cd, Fe, Mn, Cu, and Zn. The analysis of soil fertility was conducted at the Laboratory of SEAMEO - BIOTROP, Bogor. Fertility status of inactive tailings and natural soil of Timika is presented in Table 1. The analysis of uptake metal was at Timika Environment Laboratory (TEL), Timika. The data analysis was conducted statistically by mean value with tabulation. The criteria of chemical properties referred to Balai Penelitian Tanah (2005), the criteria of metal from tailings/soil and plant tissue referred to the Handbook of Trace Elements (Pais and Jones, 1997; see Tables 2 and 3).

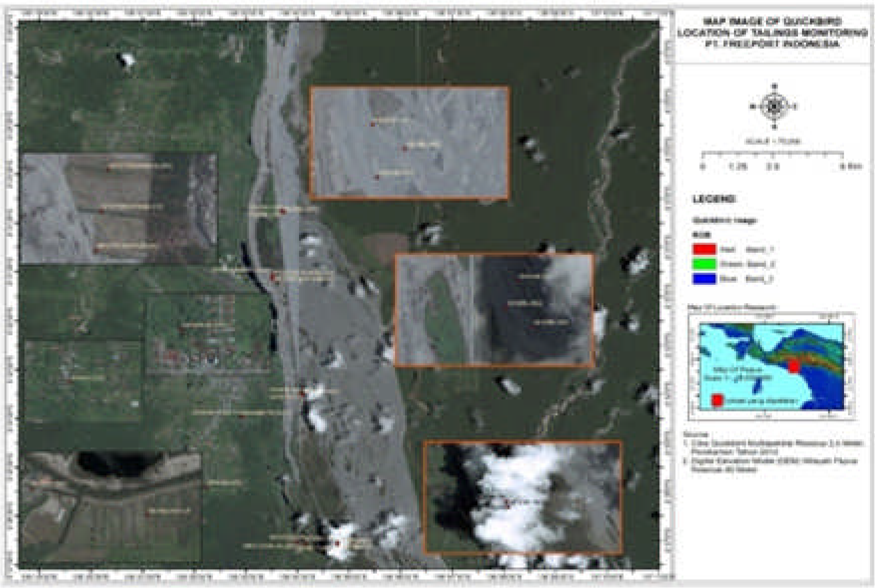

Figure 1. The representative location in Reclamation Area and Natural Soil, Timika

Results and Discussion

Status of nutrient content in incative tailings and natural soil

Tailings have characteristics of chemical difference when compared with natural soil, which was derived from the parent rock, that contains minerals group of sulphides, such as pyrite (FeS_2), chalcopyrite ($CuFeS_2$), covellite (CuS), bornite (Cu_5FeS_4), and digenite (Cu_2S) (PTFI, 1998). Although metal of copper (Cu) has been taken in the processing of ore at MP 74, but Cu is still found to be high, and includes FeS_2 and other micro nutrients, which potentially can create acidic conditions in the tailings when it is oxidized at DLA.

Table 1. Fertility status of inactive tailings and natural soil - Timika

Representative Location	Depth (cm)	pH (H_2O)	Organic-C (%)	OM (%)	Total N (%)	Available P (ppm)	Ca^{2+} me/	Mg^{2+} 100 g	K^+	Na^+	CEC
Inactive Tailings											
MP21	0 - 20	7.53	2.59	4.46	0.07	3.63	26.92	1.29	0.27	0.32	13.21
	20 - 40	7.70	1.65	2.85	0.05	4.33	29.44	1.06	0.27	0.30	5.31
MP27	0 - 20	7.73	0.36	0.62	0.02	91.17	1.25	1.81	0.35	0.30	2.79
	20 - 40	8.40	0.27	0.47	0.03	78.27	1.48	2.15	0.44	0.41	3.07
Natural Soil											
SP4	0 - 20	4.13	1.68	2.89	0.15	5.20	2.00	0.34	0.15	0.20	8.35
	20 - 40	4.73	0.93	1.60	0.12	5.07	0.80	0.17	0.12	0.17	7.12
NWRP	0 - 20	4.43	7.36	12.69	0.48	10.07	7.71	1.27	0.14	0.31	12.58
	20 - 40	5.37	2.49	4.30	0.29	20.63	6.26	1.38	0.16	0.27	14.04

Source : Analysis data was released by Soil Laboratory, SEAMEO - BIOTROP, Bogor (2014)

OM = Organic Matter, CEC = Cation Exchange Capacity, MP = Mile Point, SP= Satuan Pemukiman (unit of settlement), NWRP = Nawaripi

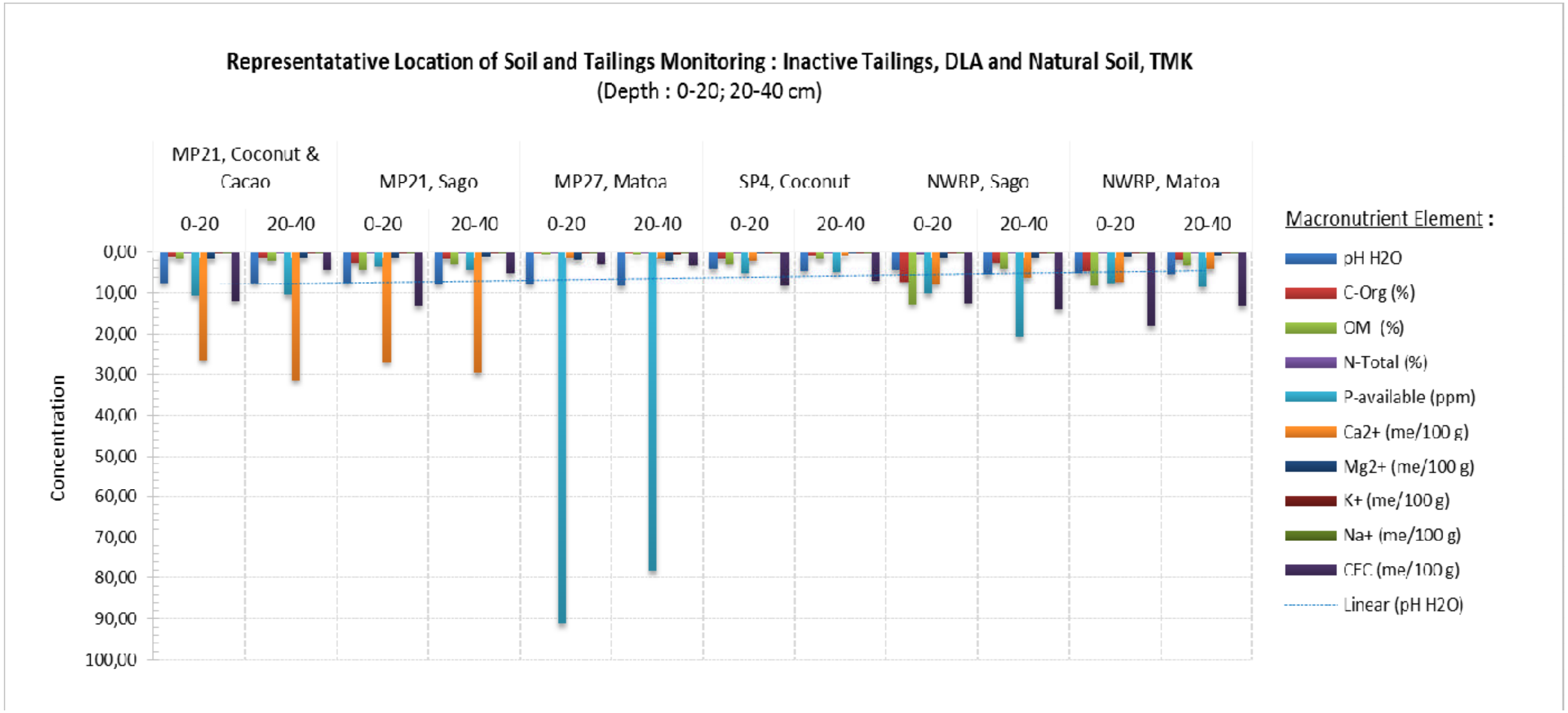

Figure 2. Status of Macronutrient Elements in the Land of Inactive TailingsandNatural Soil

To combat acidification due to the oxidation of sulfide mineral, tailings before they enter DLA have been limed at a neutralizing capacity at 1.5 times maximum potential acidity (PTFI, 2007). The material of CaO and $CaCO_3$ that keeps tailings in the pH ranged 7-8. The results of the chemical parameter to the tailings/soil fertility showed that the value of pH was slightly alkaline in inactive tailings of MP21 and MP 27, whereas natural soil of SP4 and NWRP (non tailings) was very acid and acid. The value of pH in natural soil in topsoil (0 - 20 cm) was lower than subsoil (20-40 cm). These phenomenon were different from inactive tailings, the value of pH tends to increase with increasing soil depth. The condition can occur because of the increasing of Ca^{2+} in subsoil 20-40 cm of inactive tailings of MP21 and MP27. The addition of lime material into the soil, will lead the reactions with soil colloids, in this case the colloid of tailings which was derived from organic materials. Soil colloids will obstruct the reactions equilibrium to absorb Ca^{2+}, so that the percentage of base saturation in the adsorption complex was higher. This condition causes the pH in the soil solution tend to increase. Therefore, organic C content decreased in subsoil with the increase of pH, especially on inactive tailings of MP21 and MP27.

The organic C content was high with the increasing CEC, particularly on the topsoil. The availability Ca content was the highest at MP21, i.e 26,92 me/100 g (0-20 cm) and 27,44 me/100 g (20-40 cm), followed by *non* tailing NWRP (7,71 me/100 g; 6,26 me/100 g), whereas MP 27 and SP4 had the availabiliy of Ca was low - very low. The natural phenomenon was found in natural soil also was seen in the inactive tailings area. Data showed that base cations of Ca were the highest, followed by Mg, Na, and K. These indicate that tailings material can be used as media of plant growth. However, it needs attention to the metal uptake in plant tissue. In consequence, planting of agricultural plants in the tailings needs organic matter as a chelating agent of the specific metals, so that is not absorbed by the plants directly, in excessive amounts.

Micro nutrients (heavy metal) in inactive tailingsandnatural soil

Tailings or natural soils have a limited buffer capacity to the heavy metals. This characteristicis determined by several factors such as pH, organic matter content, and CEC (cation exchange capacity) (Lepp, 1981). The presence of organic materials in the soil, besides being utilized by microorganisms as a source of energy, can react with the heavy metals to form the organ metallic complex, to reduce the toxicity of heavy metals (Stevenson, 1982). Figure 3a-b, and 4 showed the total of Al, Fe, K was high enough on the tailings and natural soil, except Ca was found higher in the tailings (MP 21, MP27), because of the additional process with lime materials by the flotation technique of precious minerals and before tailings enter the lowlands, where they are deposited in the deposition area of DLA. Similarly, the total S was relatively higher in the tailings than natural soil and was very low due to the parent material of Grasberg which contains the group of sulphide minerals (PTFI, 1998).

Macro and micronutrients of the plant leaf tissue in incative tailings and natural soil

Plants need the essential nutrients for growth. It is estimated that there are 60 types of nutrients needed by plant. From mainly nutrients, there are only as many as 16 elements essential nutrients, to the plants, which are needed to support its growth and most of them, obtainablefrom the soil, while C, HandO$_2$are taken from the air. The macro nutrients inlcude C, H, O, N, P, K, Ca, and S is the essential nutrient with concentration ≥ 0,1 % or ≥ 1000 ppm, the micro nutrients of Cl, Fe, B, Mn, Zn, Cu, and Mo with concentration < 0,1% or < 1000 ppm. Nutrient deficiencies have affect on the plant growth, disrupting the plant growth, and finally reducing theproduction of plant (Lehman dan Schroth, 2003; Havlin *et al*., 2005). Figure 5 and 6 showed that nutrient uptake in the leaf tissue of Matoa on MP21 and MP27 were different in particle size, i.e moderate and fine. The uptake of Ca, Mg, K, and S were found high on both locations of inactive tailings, except K was higher in young leaf than productive and old leaves. However the nutrient uptake tends to be higher on Matoa which was grownat MP21. While in MP 27, provisional estimates that low organic matter and P excess cause the absorption of other elements wereinhibited. High P concentrations inhibit the movement of Fe in the plant. Inhibition is greater when the plants are grown at a pH of 7 or above, compared with lower pH values (Biddulph, 1953). Instead excess of Ca has an impact to increase pH in the tailings (Taberima et al., 2008).In addition, the condition of tailings has not yet formed the soil structure that causes nutrients uptake to tend to be obstructed because of leached by rain. Therefore, the application with organic matter is needed for the further purpose of reclaimed tailings.

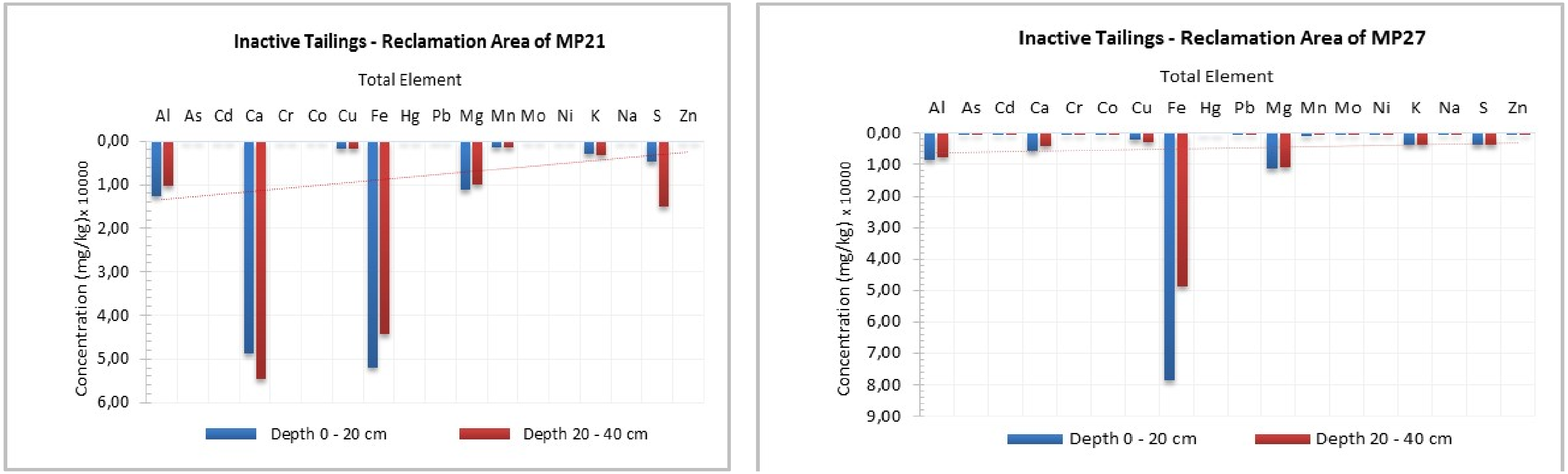

Figure 3a-b. Total of elements content in inactive tailings of MP21 and MP27

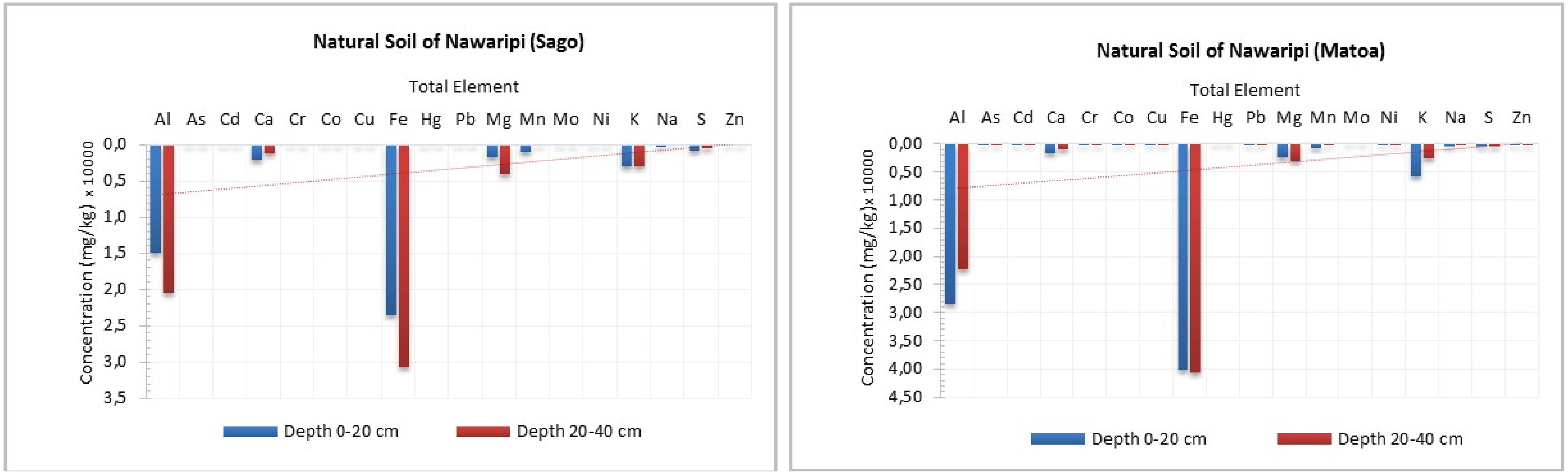

Figure 4. Total of elements content in natural soil of Nawaripi (NWRP)

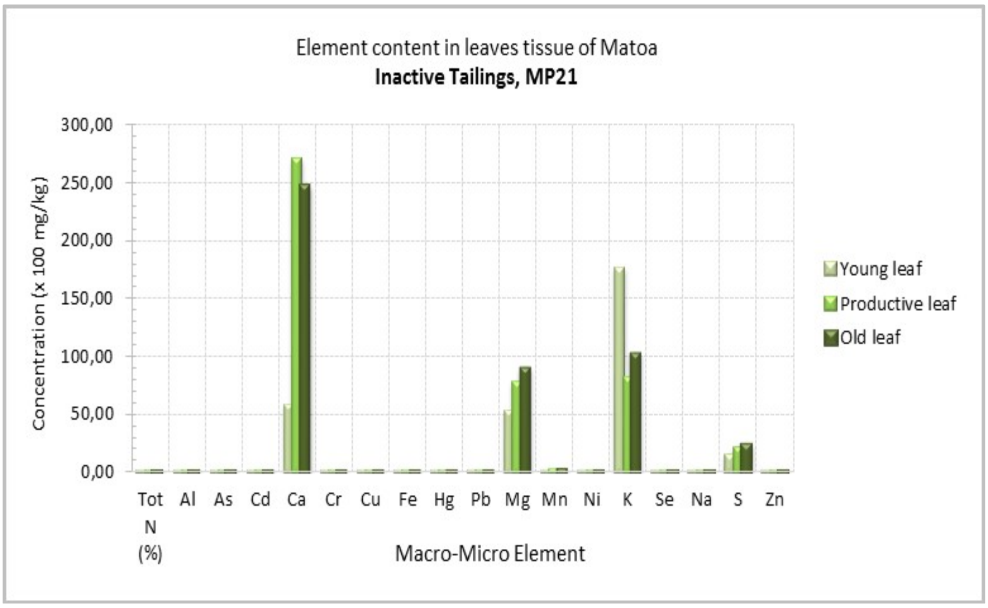

Figure 5. Status of nutrient content in leaf tissue of Matoa, inactive tailings of MP21

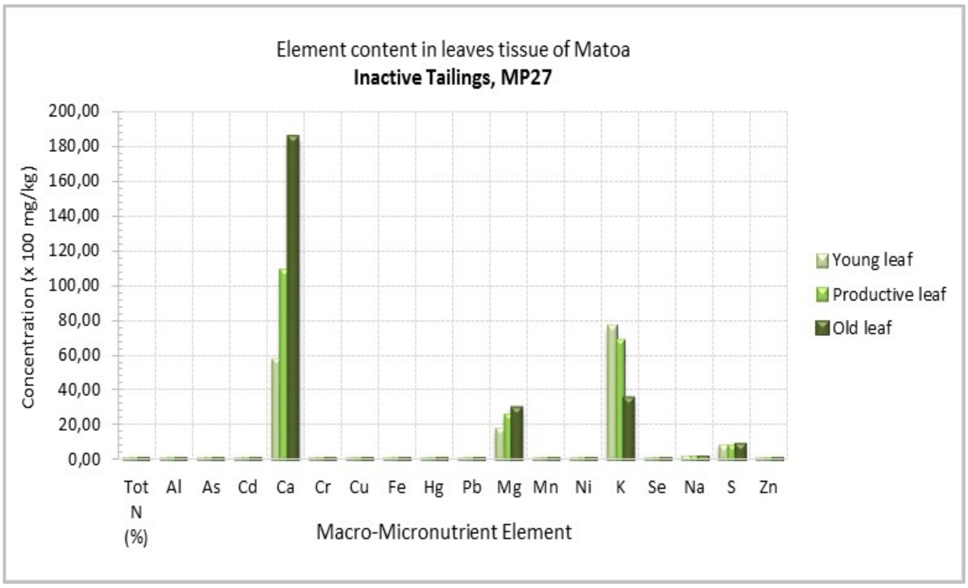

Figure 6. Status of nutrient content in leaf tissue of Matoa, inactive tailings of MP27

Figure 7-9 illustrates the general phenomenon of plants with higher K uptake, It tends to cause an antagonism among other macro nutrients. Potassium (K) excess causes the absorption of Ca and Mg were inhibited, and also plant growth, so the plants became deficient of these nutrients (Havlin et al., 2005). Nevertheless K was needed by plants to improve its resistance to disease plus formation and strengthening of generative organs.

Sulfur (S) was absorbed higher in the productive and old leaves than in young leaves. Absorbed S was varied in the plant tissue, which was found on Matoa of MP27 (> 0,1% S) and MP21 (> 0,1% S); Coconut of MP21 (< 0,1 - > 0,1% S), SP4 (< 0,1 - > 0,1% S); and Sago of NWRP (> 0,1% S) respectively with the highest absorption in the productive and old leaves, but the highest uptake was found in the leaf tissue of Matoa (MP21), followed by Sago (NWRP) with concentration more than 0,1% S. Generally total S in the soil ranged from 30 to 1000 ppm with the approximation of mean value is 700 ppm (0,07%) (Lindsay, 1979).Tabatabai et al. (1988) stated thattotal of S in the natural soil ranged from < 20 ppm on sandy soil until> 600 ppm on soil textured solid, while most of soil contains S between 100 and 500 ppm. At the Double Leeve Area (DLA), total S is relatively high because parent material from Grasberg contains the group of sulphide minerals. MacDonald and Arnold (1994) reported that total S content in the parent material of Grasberg mined, was 1,59 %. Related to the plant need, S is an essential element in the formation of various types of amino acid and leaf green (chlorophyll), as well as Fe, Mn, Zn, and Mg butin less concentrations.

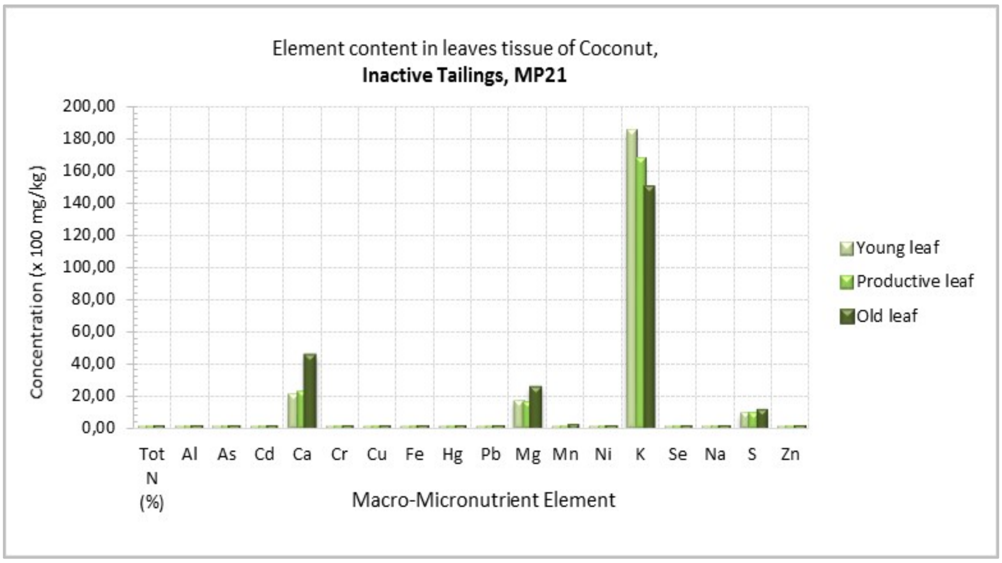

Figure 7. Nutrient content in leaf tissue of Coconut, inactive tailings of MP21

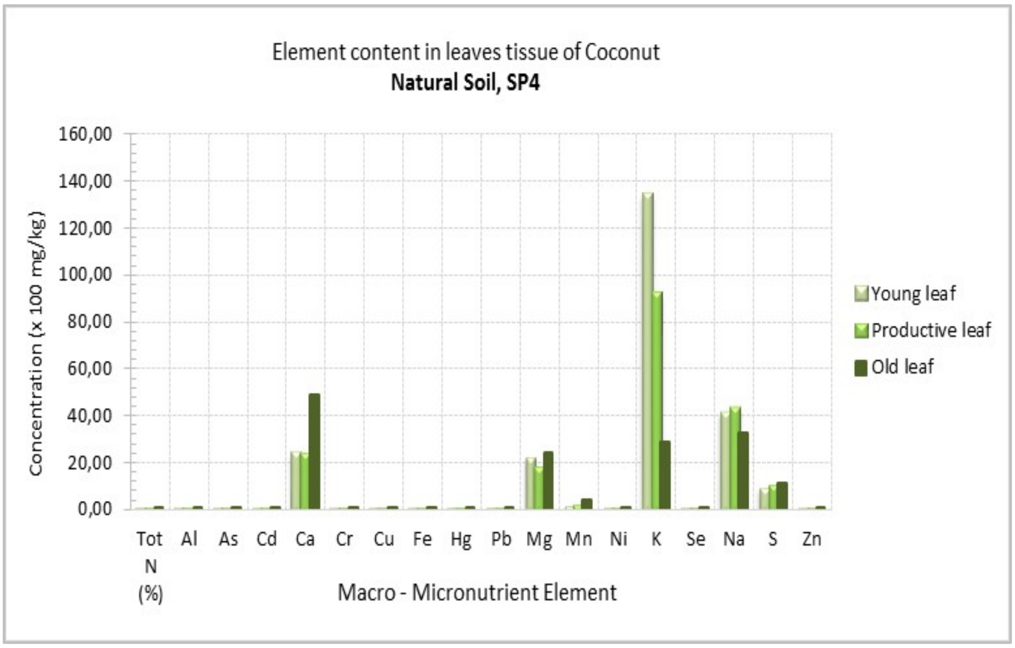

Figure 8. Nutrient content in leaf tissue of Coconut, natural soil of SP4

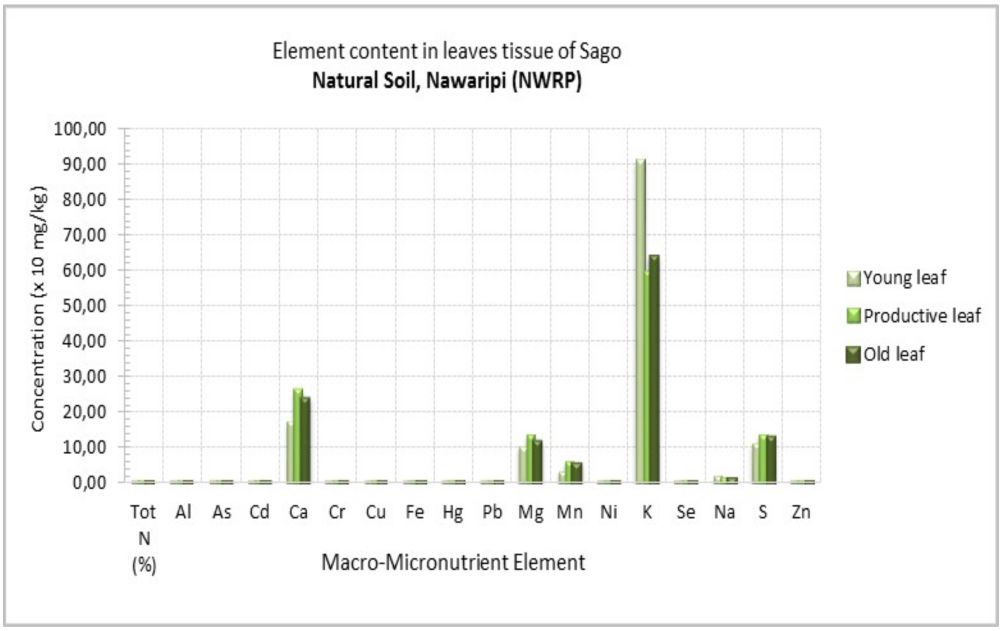

Figure 9. Nutrient content in leaf tissue of Sago, natural soil of NWRP

Base on data of the absorption of micro nutrients which is tolerable by plants (Pais dan Jones, 1991) that Fe contained in plant leaves of matoa, coconut, and sago which growing up on inactive tailings and natural soils are categorized as sufficient and normal with ranges less than 100 ppm, while Mn is the highest in old leaves of coconut (379,50 ppm) and sago (558 ppm) which growing up on natural soil and exceed of normal criteria (> 300 ppm Mn). At the same time Cu uptake includes normal category, i.e. 4-20 ppm in young, productive, and old leavesas the representative plants that growing up in the inactive tailings or natural soil. Reuther and Labanauskas (1975) reported that Cu is protected in most soils with values of pH ranged 7-8, and inadequately protected with pH of neutral to acid. It was reported that liming to the soil up to pH 6 tends to reduce the toxicity of Cu, includes Fe, Mn, and Zn. The uptake of Zn includes normal category, except in leaf tissue of matoa MP21 was found the absorption of Zn exceed of normal criteria, i.e more than 100 ppm Zn. It was found in productive and old leaves, i.e 170,67 ppm and 160,33 ppm respectively. There is a tendency of micro-nutrient uptake in the plant tissue, i.e when Zn uptake is high that the uptake of Cu tends to decrease as well as between Fe and Mn. This phenomenon may occur due to the micro element has oxidation numberof two divalent cation (+2) with the same size, that there is a competition among nutrients uptake from the soil solution towards the plant tissue.

Tabel 2. Approximate concentration of the micronutrients in mature leaf tissue generalized for various plant species

Micronutrients	Deficient	Sufficient or Normal	Excessive or Toxic
		mg/kg (ppm)	
Boron (B)	5 - 30	10 - 200	50 - 200
Chlorine (Cl)	< 100	100 - 500	500 - 1000
Copper (Cu)	2 - 5	5 - 30	20 - 100
Iron (Fe)	< 50	100 - 500	> 500
Manganese (Mn)	15 - 25	20 - 300	300 - 500
Molybdenum (Mo)	0.03 - 0.15	- 2.0	> 100
Zinc (Zn)	1 - 20	27 - 100	100 - 400

Remarks :The Handbook of Trace Elements, page 158 (Pais and Jones, 1997)

Tabel 3.Amount of various trace elements tolerable to plants

Element	Range (mk/kg)	Common Level (mg/kg)	Amount Tolerable (Proposed)
Arsenic (As)	1.0 - 5.0	2.0 - 20	50
Beryllium (Be)	0.1 - 10	1.0 - 5	10
Boron (B)	0.01 - 1.0	5.0 - 30	100
Cadmium (Cd)	0.01 - 1.0	0.1 - 1.0	5
Chromium (Cr)	1.0 - 100	10 - 50	100
Cobalt(Co)	1.0 - 50	0.1 - 10	50
Copper (Cu)	2.0 - 100	5.0 - 20	100
Lead (Pb)	0.1 - 10	0.1 - 5	100
Mercury (Hg)	0.01 - 1.0	0.1 - 1.0	5
Molybdenum (Mo)	0.2 - 1.0	1.0 - 5	10
Nickel (Ni)	1.0 - 100	10 - 50	100
Selenium (Se)	0.1 - 10	1.0 - 5	10
Zinc (Zn)	10 - 300	10 - 50	300

Remarks :The Handbook of Trace Elements, page 50 (Pais and Jones, 1997)

Based on the observation of several agricultural plants as the representatives that are growing up in Reclamation Area, the result data of monitoring activity is to study the impact of macro and micronutrients uptake by plants or natural soil/tailings. Therefore there is not recommendation yet can be issued at the moment, because the research is still ongoing with further tests of edible plant for several months period to study the metals uptake as well as macro and micro nutrients in tailings media and natural soil as comparator (non tailings).

Conclusion

The organic matter tends to be higher at MP21 with sago, followed by coconut at the same area of inactive tailings, while at MP27 with matoawas very low in concentration on the surface layer and the bottom layer.

MP27 has been reclaimed since 2003 with matoa, however its growth tend to be abnormal after being planted more than 10 years. While MP21 with sago and coconut were more fertile due to high content of organic matter. Besides that, the tailings deposition had became inactive tailings for longer, and were used for the land reclamation activities since 1992/1993.

Macro nutrient uptake, especially potassium (K) was quite high in the productive and old leaves of plants that grownat the inactive tailings and natural soil. The uptake of S was the highest in the leaves tissue of matoa at MP21, followed by sago at NWRP with concentration of Mn uptake was > 0.1%. The uptake of Mn was the highest in the old leaves of coconut (379.50 ppm), and sago (558 ppm) from natural soil, which concentration of Mn has exceeded of normal criteria (> 300 ppm Mn). The uptake of Zn was categorized as normal, except in the productive leaves (170.67 ppm), and the old leaves (160.33 ppm) were exceeds of normal criteria (> 100 ppm Zn) which found at MP21 with matoa.

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