Fertility status of soils developed on an inactive mine tailings deposition area in Papua

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Abstract
Tailings are the residue of mined material after separation of metals such as copper, gold and silver elements. Separation of minerals involves crushing of the host material to fine particles and separation of the metals by flotation or other techniques. The total amount of tailings produced by PTFI from their Grasberg mine is about 230,000 tons/day. These tailings are deposited in a lowland area and are confined by two levees. There are two types of plant growth on inactive tailings according to land use (natural succession area or reclaimed agricultural area). This study of soil fertility on the mine tailings was required to contribute to information on the management of tailings. Representative sampling locations were chosen based on soil texture. Soil (0 - ≤ 50 cm depth) was subjected to laboratory analysis. Total soil N is very low (< 0.02%), CEC low to medium (≤ 20 me/100g), and organic C ranges from 0.1 - 2%. pH is 7 - 8 resulting in the low availability of some nutrients, but values of extractable Cu may be high (≥ 300 mg/kg). Nutrient elements are more abundant in soils on fine textured tailings.

Key Words
Fertility, soil development, tailing ModADA.

Introduction

Tailings are the portion of the original mineral-bearing rock left after extraction of copper, gold and silver minerals. The separation of these minerals involves crushing and grinding the rock into a fine sandy material and separation of ore minerals by a flotation technique. This process is done at Mile-74, where the tailings are deposited into the Aghwagon river located at an altitude of 2,800 m asl and tailings flow gravitationally to the lowlands, where they are deposited in the Modified Ajkwa Depositional Area (ModADA), in Mimika, Papua. According to PTFI (2000; 2003; 2006; 2007), tailings are deposited at the rate of about 230,000 tons/day. The main sulfide minerals of the ore are chalcopyrite, covellite, bornite, and digenite (PTFI 1997) and some of these minerals are present in the tailings which are treated with lime to combat the acid sulfate reaction. The tailings in ModADA are deficient in some macro nutrients, while base cations and some micro nutrients are abundant. Deposition of tailings in ModADA will take place until the year 2040. A study of the soil fertility of tailings is required in order to determine the ability of vegetation to grow on the inactive tailings area. Amelioration requirements for a considerable area of tailings that will require revegetation need to be determined to optimise land use. The objectives of this research were: 1) to study vegetation cover and soil characteristics on inactive tailings in ModADA; 2) to identify the capacity of the tailings areas to support agricultural crops and natural reforestation based on soil properties.

Methods

Study area

The research was done on tailings ModADA in Timika, Papua (Figure 1). The tailings area is located in the lowlands of Timika and has a high rainfall from 3,500 - 4,000 mm/year, temperature from 25- 27 ^{o}C, and humidity > 90%. On the west side of the west levee of the tailings deposition area, there are about 1500 ha of the tailings that are inactive (8 - 20 years). There are two approaches adopted by PTFI to rehabilitate the tailings area, these are: 1) enable the natural succession of local vegetation to develop, and 2) develop the deposit area with agriculture, forest plants, and animal livestock. The first area with a natural succession has a depth to ground water < 50 cm, and is known as the Succession Area. The second area is used both for agriculture and forestry with a depth to ground water ≥ 100 cm, and is known as the Reclamation Area. The representative location for soil sampling was chosen based on differences in existing vegetation and particle size distribution (coarse - medium - fine) of tailings from north to south on the inactive tailing area, ModADA.

Plant identification for the natural succession and reclamation areas
Plant species were identified for the natural succession and reclaimed areas from Mile 24-28 covering a transect from south to north. Transects were established and plant species were identified by standard methods (LIPI 2004). The vegetation in the reclaimed area was not identified by transects but by observation during soil sampling. The data collected were used to study the distribution of each plant species and to identify plant species suitable for use in the tailings area.

Soil sampling
Soil samples from the reclaimed and natural succession sites from each distinct layer to a depth of 50 cm, were taken for analysis of pH, organic C, base cations, CEC, macro and micro nutrients, and texture.

Results
Vegetation in the inactive tailings area, ModADA
1. Succession area
Vegetation in the natural succession area was predominantly *Phragmites karka* (seedling) with an importance value > 80%, followed by *Ficus adenosperma, Ficus armiti, Nauclea papuana, Glochidion macrophila, Macaranga aleoritoides* (level trees); *Adina nerifolia, Pandanus* sp., *Casuarina equistifolia, Glochidion macrophila, Camnosperma berpetiolata, Ficus damaropsis,* and *Sterculia* sp. (young trees). *Phragmites karka* is the dominant species in the natural succession area. *P.karka* is a robust, erect, perennial grass (reed) up to 4 m tall with an extensive, creeping, branching rhizome or stolon up to 20 m long. It spreads by its creeping rhizomes (underground) or stolon (above ground) (PROSEA 2003) and grows in standing water and is tolerant to flooding. The ability of *P.karka* to dominate the inactive tailings deposition area creates a better soil microclimate and rapidly increases soil organic carbon compared to the other vegetation. Most successions contain a number of stages that can be recognized by the collection of species that dominate at that point in the succession. Succession stages are closely tied to the tolerance of plant species for soil conditions. Succession stops when species composition no longer changes with time, and this community is said to be a climax community. Climax represents a relatively stable plant community which has a dominant plant population suited to the environment. Stages of succession in general are as follows: Grasses-Forbs → Shrub-Seedlings → Sapling-Pole → Young → Mature → Climax (Martin and Gower 1996). A general succession of plant species based on the research work in the ModADA is illustrated in Figure 2.

2. Reclamation area
Reclamation activities since 2000/2001 have been implemented by planting with various native forest and agricultural plants. Native plants including *Metroxylon sago*, *Pometia pinata*, and *Casuarina equisetifolia* show good plant growth comparable to growth on adjacent non-tailings soil. Most of the reclamation area is dominated by *C.equisetifolia* which also occurs in the natural succession area. *Calopogonium muconoides* occurs in this area and is well adapted as a cover crop in the reclamation area. The South to North (Mile 26-28) area is planted in blocks with the followed of species 1). *C .equisetifolia*, *Metroxylon sago*, with *C.muconoides* as cover crop; 2). *Pometia pinata*, *C.equisetifolia*, with *Paraserianthes falcataria* as a border plant and *C.muconoides* as a cover crop; 3). Alley Cropping (*Paraserianthes falcataria, Leucaena leucocephala*, *Gliricidae sapium*, *Caliandra surinamensis*, *Sesbania grandifolia)*, *C.equisetifolia*, *Coconut nucifera*; 4). *Pennisetum purpuphoides*, *C.equisetifolia*; 5). *C.equisetifolia, C.muconoides*; and 6). *C.equisetifolia, C.muconoides, P.karka, Dryapteris* sp. Although the tailing area on the north side is dominated by sandy materials, crops grow and adapt readily to the soil material. Based on Management Report and Environmental Monitoring of PTFI (2004) using routine monitoring of the growth of crops in the reclamation area occupied by *P.pinata* and Alley Cropping, the rate of growth increased each month.

Soil fertility of the reclaimed area
The land cover in the Double Levee ModADA area is mostly natural vegetation, and species depend on soil characteristics. So far, the soils developed on the tailings in these areas are still relatively young and consequently their structure ranges from loose to massive reflecting the presence of predominantly sandy to silty materials, and a low content of OM (< 1%). Only one area with particle size of silty coarse sand has an OM > 1% in the surface soil. The pH ranged from neutral to alkaline. Only a few samples had an acid pH for the surface soil. All of the soil samples with a sand texture have a range of pH from 7-8 in each layer. Whereas, soils with a texture of loamy coarse and silty coarse sand have a tendency to be acid in the surface soil and alkaline in the subsoil.

Soil pH affects the solubility and availability of most nutrients. The availability to plants of most metals decreases with increasing pH. Values of CEC were < 10 cmol/kg and OM ≤ 1%. Most CEC values are very low except for several surface soils. Total N is very low (< 0.02 %) in the reclaimed area with sandy soils. Total N tends to increase (≥ 1%) for the surface soil on both loamy coarse sand and silty coarse sand in the reclamation area. To increase the fertility of tailings soils, an application of OM would be beneficial with the goal of increasing CEC, organic C, and N. Observations of the macro- and micronutrient contents including metals in the reclaimed area indicate that N, K, and organic C contents tend to be low. Available micronutrient contents (Fe, Mn, Cu, Zn) tend to be high contents of other nutrient elements, relatively low to very low. The concentration of available Cu ranges from 100 to ≥ 300 mg/kg and varies between layers. The higher available Cu in sandy soils is caused by the low pH due to the impact of oxidation of sulfides and the high OM content especially for the horizon surface. Available Fe, Mn, Zn levels are lower than Cu. Tisdale *et al*. (2005) show that the availability of micro nutrients is usually low on soils of alkaline pH.

Soil fertility in the natural succession area

The average OM value of surface soil increases from north (maximum sand) to south (maximum silt) i.e.: 0.21, 2.29, and 2.32 % respectively. Organic C is most abundant in this area as a result of of *P. karka* biomass accumulation. It is evident that formation of an OM layer on the tailings via natural plant growth takes a long time (Jacob and Otte 2004). The increase in OM has an effect on available Cu because of the low pH. Cu tends to increase because of the oxidation of sulfide minerals due to the root of *P. karka* providing O_2 to submerged subsoil. Available Cu has a tendency to increase to a very high concentration (≥ 500 mg/kg) in each layer of the loamy coarse sand. Total S increases in sub soil horizons > 1% for both silty coarse sand and loamy coarse sand. Wang *et al.* (2006) show that fine particles with a high specific area increase adsorption of nutrients and metals. Acosta *et al.* (2009) also noted the tendency of metals to accumulate on fine particles.

Micro elements in plants

Plants utilise nutrients for their development if the nutrient is in available form in soil solution. Commonly the availability of a nutrient in soil is indicated by the plant nutrient status. The analysis of As, Cu, Hg, Pb, and Zn in the plants indicated that metal uptake from the tailings materials is minimal and levels of metals in the plants are below the maximum values stipulated in the National Food and Drug Administration Decree No.03725/B/SK/ B/VII/SK. Microelements such as Cu can be easily changed in solubility due to reaction with inorganic or organic materials with their solubility varying with pH (Pais and Jones 1997). Although the concentration of some micronutrients in tailings soils is relatively high the alkaline pH has limited metal uptake by the plants.

Conclusion

Clearly many plant species have the ability to grow and adapt to the soil conditions in the tailings area of ModADA. Characteristics of tailings are not optimum for growing plants, because of deficiencies of N, low organic C, high base cations (Ca, Mg) and available metals (Cu, Fe), and CEC values are low. pH values of the tailing soils are maintained at neutral to alkaline values by liming to limit metals uptake by plants.

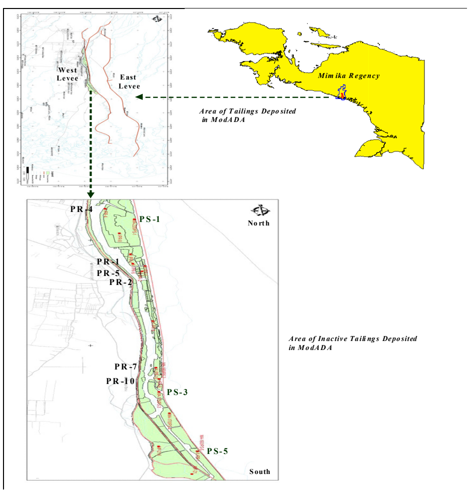

Figure 1. Area of Inactive Tailings in ModADA.

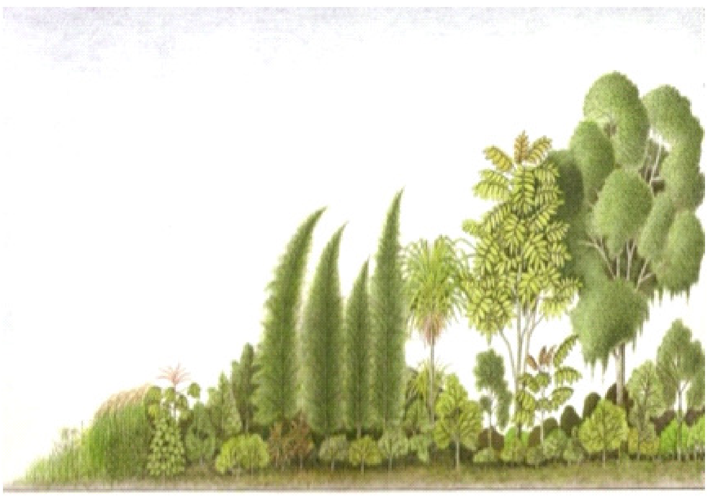

Figure 2. Pattern of Plant Succession on Tailings Deposition Areas, ModADA.

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