A chronosequence study of soil properties and microclimate in the reclamation area of Batu Hijau Mine, West Sumbawa

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Abstract. The objective of this study was to characterize soil physical and chemical properties, development of soil and microclimate condition according to the time sequence of revegetation. Sampling and observation were conducted in revegetation areas aged 2 to 8 years old and in the natural forest for comparison. Disturbed soil samples were taken from three depths while undisturbed soil samples were taken from two depths. Light intensity, air temperature, humidity and soil temperature were measured for microclimate analysis. The results showed that the soil had clay loam and loam texture with relatively high density and low permeability. Natural forest soil had lower density and higher permeability. Low soil fertility was indicated by low organic-C, total-N, available P and exchangeable K. Exchangeable-Ca and -Mg and cation exchange capacity of the soil in revegetation area were higher than in the natural forest soil. Only the content of organic-C and total-N in the first 5 cm layer of the soil increased along with the increasing revegetation age, while other parameters of soil properties showed no differences. Falcataaria moluccana, Anthocephalus cadamba and Melochia umbelata were the dominant vegetation found in sapling, pole and tree. Light intensity, air temperature and soil temperature tended to decrease, while humidity increased with the increasing age of revegetation.

1. Introduction
Reclamation of ex-open pit mined land is intended to carry out revegetation on mine spoils that have been arranged. Reclamation is important in shortening the time period of succession because naturally plant succession to a stable community may take from tens to hundreds of years [1]. Much of mine spoils are physically and chemically not suitable for growing medium, therefore mine spoil need to be covered with “top soil” before planting process. These topsoils are salvaged during land clearing activity before mining process begins. According to [2] this is the first step for a successful and built a sustainable mine soil system. The topsoils are a mixture of soil material from the A and B horizons.
and sometimes also include the C horizon when the soil materials from C horizon are considered to have a capability to act as growing medium. As a result, the mixed of the "top soil" has a lower soil fertility level compared to soil material from the original A horizon, indicated by very low organic-C content and nutrients. Nevertheless, top soil usually has a better quality than mine spoil as a plant growth medium due to the presence of plant propagules, higher soil organic matter (SOM) content and presence of microorganisms. However, if top soil is stored for a long period prior to application, much of the potential for rapid microbial recovery will be lost[1].

Soils developing on reclaimed sites are highly modified, as compared to native soils, in terms of their physical, chemical, and biological properties and their vertical arrangement into distinct horizons [2,3]. Chronosequence studies of the effect of revegetation on the properties of soil on ex-mining land have been carried out [4,5,6,7,8,9,10]. Over time, revegetation plants grow and develop, and produce litter that decompose to SOM. This increase in SOM levels can further improve soil structure, porosity, cation exchange capacity (CEC), nutrient availability and microbiological activity. According to[11] mine soils can show signs of pedogenesis after only 10 years and can develop weak B horizons. In addition, [12] shows an increase in the soil aggregate stability index from unstable on 0-year-old reclaimed land to stable on 13-year-old reclamation land.

The study of the effect of mined land revegetation on microclimate conditions have been carried out, for examples by [13,14,15,16] and others. Microclimate is a crucial determinant of ecological patterns, directly influencing ecological processes, changes in ecosystem function, and landscape structure[13]. Tree canopy is a significant component that can contribute to local microclimate modification because it can attenuate solar radiation and control wind speed[17]. Trees with larger canopies tend to cast more shade and deliver greater thermal comfort than smaller ornamental species. A large and dense canopy structure could enhance the cooling capacity of plant via increasing transpiration capacity and synergic physical properties[18].

The objectives of this study were to characterize the soil physical and chemical properties and to investigate the development of mine soil and microclimate condition according to the time sequence of revegetation age in ex-mined land of copper and gold in Batu Hijau Mine.

2. General description of location

Batu Hijau Mine is copper and gold mine that located in West Sumbawa District, West Nusa Tenggara. The condition of the Batu Hijau reclamation area is mostly in the waste dump area which is dominated by hilly to mountainous morphological forms with homogeneous slope classes ranging from 25-40%. Arrangement of reclamation area is conducted by forming slopes that have an incline of 2H:1V or 26.6°, the spread soil material as thick as 2.75 m, from 25 cm topsoil before compaction.

Revegetation begins with hydroseeding throughout the soil surface using mixed seeds of Stylosanthes sp., Oryza sativa and Sesbania grandiflora. Coconet is installed in certain places as an erosion control blanket and to slow down run off and to provide an additional anchorage matrix in the application of hydroseeding.

Furthermore, the reclamation areas are planted with fast growing plants, and are tolerant to semi tolerant plants such as Sengon (Falcata moluccana), Jabon (Anchocephalus cadamba), Pulai (Alstonia scholaris), Kayu Batu (Alstonia stipulata), Bentengu (Melochia umbelata), Bungur (Lagerstroemia speciosa), Majaq (Syzygium polyathum), Kesambi (Syzygium so), Gelumpang (Sterculia foetida), Besira (Albezzia chinensis), Kelanur (Albizzia procera), Binong (Tetrameles nudiflora), Suren (Toona sureni) and in the second or third years are planted an interplanting intolerant/climax species plants, such as Gaharu (Aquilaria malaccensis), Serenti (Shorea sp), Dao (Dracontomelon dao), Monar (Garcinia celebica), Ipil (Intsia bijuga), Sao (Pouteria obovata), Tempoak (Eugenia subglauc), Salam (Artocarpus sericicarpus), Sentul (Sandoricum koetjape), Mentangir (Calophyllum soulattri), Kesambi (Sleichera oleosa), and Ajan Kelicung (Diospyros macrophylla).

3. Materials and Methods
This study was conducted in April to May 2016 in Tongoloka block, Kanloka and East Dump, Batu Hijau Mine. Soil sampling and microclimate observations were carried out in the revegetation area of 2 to 8 years (2008 to 2014 planted year). Each revegetation area was dominated by certain groups of plants, such as the sapling, pole or tree level (table 1). For comparison, soil sampling and microclimate observations in natural forests around the East Dump block were also carried out.

Table 1. The dominant plants in the revegetation area of Batu Hijau Mine

| Planted year | Location | Level               |
|--------------|----------|---------------------|
|              |          | Sapling             |
| 2014         | Tongoloka| Jabon (*Anthocephalus cadamba*) |
| 2013         | Tongoloka| Kayu batu (*Alstonia stipulata*) Bentenu (*Melochia umbelata*) |
| 2012         | Kanloka  | Jabon (*Anthocephalus cadamba*) Bentenu (*Melochia umbelata*) Jabon (*Anthocephalus cadamba*) |
| 2011         | Kanloka  | Jabon (*Anthocephalus cadamba*) Jabon (*Anthocephalus cadamba*) Bentenu (*Melochia umbelata*) |
| 2010         | East Dump| Bungur (*Lagerstroemia speciosa*) Sengon (*Falcataria moluccana*) Jabon (*Anthocephalus cadamba*) |
| 2008         | East Dump| Sengon (*Falcataria moluccana*) Sengon (*Falcataria moluccana*) Sengon (*Falcataria moluccana*) |
|              | Natural Forest | Kayu pola (*Pseuduvaria reticulata*) Rapat bewe (*Drypetes longifolia*) Rapat bewe (*Drypetes longifolia*) |

3.1. Soil sampling and analysis
Soil sampling was carried out in the form of undisturbed soil samples for measurement of bulk density and permeability as well as disturbed soil samples for analysis of soil chemical properties and textures. Samples of undisturbed soil were taken at depths of 0-30 cm and 30-60 cm, while disturbed soil samples were carried out on soil profiles at a depth of 0-5 cm, 5-10 cm, and 10-15 cm to determine the development of mine soil as a function of time and vegetation growth. With increasing age of revegetation, the development of the soil would be seen from the formation of certain layers or in the certain parameters of the physical chemical properties of the soil.

Some parameters of soil properties were analysis in the laboratory, including pH (pH-meter), organic-C (Black and Walkley method), total-N (Kjeldahl method), potential P and K (extracted with HCl 25%/spectrophotometry), available P (Olsen/spectrophotometry), CEC and exchangeable bases K, Na, Ca, Mg (extracted with NH₄OAc 1 N pH 7), texture (pipette and gravimetry), bulk density (gravimetry) and permeability (constant head permeability test). Results of the soil chemical analysis were evaluated according to Criteria for Assessment of Soil Chemical Properties[19].

3.2. Observation of microclimate condition
Light intensity, air and soil temperatures and relative humidity were measured to evaluate the microclimate condition. Light intensity was measured with fluxmeter, air and soil temperatures with a thermometer and relative humidity with a hygrometer. Measurements in each monitoring location were carried out for 6 consecutive days in the morning (7 to 9 am), during the day (12 to 02 pm) and in the afternoon (04-06 pm) and each measurement was repeated 3 times. Air temperature and humidity were measured at 1.5 m above ground level. Soil temperature was measured at three soil depth, i.e. 0-5 cm, 5-10 cm and 10-15 cm using soil thermometer with metal casing.

4. Result and discussion

4.1. Morphological properties of mine soils
Morphologically the soil profiles in the Batu Hijau Mine revegetation area had not shown any clear horizonization as a result of the pedogenesis process, except for a surface layer about 5 cm thick. The
surface layers of the soils in the revegetation area for the years of planting from 2008 to 2014 were darker in color (dark brown to very dark brown), granular structure, slightly friable to friable consistency and penetrability around 0-2 kg/cm². These properties are related to high levels of soil organic-C in the upper layer. Figure 1 shows the accumulation of organic matter in the 5 cm thick topsoil. Organic C levels decreased with depth, but in the surface layer the level of organic-C relatively increased with increasing age of the plants. Soil organic carbon is the main component of soil organic matter, which is critical for the soil structure, fertility and colour[20,21].

The soils under the surface layers had a red-yellowish to brown color, massive structure, slightly firm to firm consistency and penetrability of 1.0-4.5 kg/cm². Thus, it was seen that the subsoil was more compact than the soil in the upper layer. This condition is in accordance with the opinion of[11] that mine soils have at least two horizons: a distinguishable surface horizon containing some organic matter and high percentage of fine earth material, and a lower horizon having poor structure and various sizes of rock fragments. [10]named the topsoil as an organo-mineral horizon, i.e. the horizon which is affected by vegetation cover as a source of organic matter and soil biota.

4.2. Physical and chemical properties of mine soils
The soils in the study area had clayey loam and loam textures (table 2) with bulk densities of surface layer were quite high (1.29-1.52 g/cm³) and the permeability was classified as moderate (4.55 cm/hour on average). This shows that the mine soils in the revegetation area were quite compact. Compaction occurs due to the use of heavy equipment during dumping spoils and top soil materials. Natural forest soil had better physical properties, as reflected by lower bulk density (1.22 g/cm³) and higher permeability of surface layer, which was 10.58 cm/hour. The two parameters of physical properties appear to be closely related to other soil morphological properties, namely structure. Natural forest soil had a granular structure, while the mine soil had a more massive structure. Top soil on reclaimed land in addition to functioning as a plant growth medium, if necessary, it must also function as acid rock coating material so that it is not oxidized and produces acid mine drainage. For this purpose top soil must be able to inhibit the contact of oxygen and water from the soil surface with these acidic rocks. The bulk density and permeability values of top soil at the study site have been adjusted to the technical specifications applied to function properly also as capping materials.

Table 2 shows that soil samples in the revegetation area of Batu Hijau Mine had an acid to slightly acid in soil reaction (pH 5.1-5.8) with organic-C and total-N content classified as very low, i.e. 0.43-0.80% and 0.04-0.08 % respectively. The organic-C (figure 1) and total-N levels decreased with the soil depth. Even though it looks higher, organic-C content in surface layer of natural forests soil were low, which was 1.30%. The accumulation of organic matter in the top layer of the mine soil would begin to improve the physical chemical properties of the soil. According to[2] the plant-soil interaction initiates nutrient cycling and the development of soil biota, and it improves infiltration and soil water-holding capacity.
Potential P\textsubscript{2}O\textsubscript{5} content (25% HCl extract) was classified as high to very high (45-73 mg/100g), but its availability for plant growth (Olsen P\textsubscript{2}O\textsubscript{5} extract) was very low to low (3-9 ppm). Potential K content (25% HCl extract) was classified as low to moderate (10-25 mg/100g), except in natural forests soil that were classified as moderate to high (29-42 mg/100g). There was no significant difference between potential P content and available P in the revegetation area with potential P content (25% HCl extract) was classified as low to moderate.

Table 2. Texture and chemical properties of soil in the revegetation area of Batu Hijau Mine

| Planted year | Soil depth cm | Texture | pH | Organic Matter C-org | HCl 25% P\textsubscript{2}O\textsubscript{5} | Olsen P\textsubscript{2}O\textsubscript{5} | Exch. Cations (%NH\textsubscript{4}-Acetat 1N, pH7) Ca | Mg | K | Na | CEC* | BS* |
|--------------|---------------|---------|----|----------------------|------------------------|----------------|----------------|----|---|---|------|----|
| 2008         | 0-5           | 33      | 50 | 60                   | 80                     | 100            | 120            | 140 | 160| 180| 200  | 220 |
| 5-10         | 35            | 55      | 65 | 70                   | 85                     | 100            | 120            | 140 | 160| 180| 200  | 220 |
| 2010         | 0-5           | 45      | 50 | 60                   | 80                     | 100            | 120            | 140 | 160| 180| 200  | 220 |
| 5-10         | 50            | 55      | 65 | 70                   | 85                     | 100            | 120            | 140 | 160| 180| 200  | 220 |
| 2011         | 0-5           | 40      | 50 | 60                   | 80                     | 100            | 120            | 140 | 160| 180| 200  | 220 |
| 5-10         | 45            | 55      | 65 | 70                   | 85                     | 100            | 120            | 140 | 160| 180| 200  | 220 |
| 2012         | 0-5           | 50      | 50 | 60                   | 80                     | 100            | 120            | 140 | 160| 180| 200  | 220 |
| 5-10         | 55            | 55      | 65 | 70                   | 85                     | 100            | 120            | 140 | 160| 180| 200  | 220 |
| 2013         | 0-5           | 60      | 50 | 60                   | 80                     | 100            | 120            | 140 | 160| 180| 200  | 220 |
| 5-10         | 65            | 55      | 65 | 70                   | 85                     | 100            | 120            | 140 | 160| 180| 200  | 220 |
| 2014         | 0-5           | 70      | 50 | 60                   | 80                     | 100            | 120            | 140 | 160| 180| 200  | 220 |
| 5-10         | 75            | 55      | 65 | 70                   | 85                     | 100            | 120            | 140 | 160| 180| 200  | 220 |
| Natural forest | 0-5        | 80      | 50 | 60                   | 80                     | 100            | 120            | 140 | 160| 180| 200  | 220 |
| 5-17         | 85            | 55      | 65 | 70                   | 85                     | 100            | 120            | 140 | 160| 180| 200  | 220 |

*) CEC=cation exchange capacity; BS=base saturation

Exchangeable bases content for Ca were classified as moderate to high, Mg were high to very high and K were very low to low. Cation exchange capacity (CEC) varied from low to high with the percentage of base saturation classified as very high, in line with the pH of the soil which was
generally more than 5. There were no significant differences between these properties of soil in the revegetation area and that in natural forest soil. Except of organic-C content in the upper layers, the other chemical properties of the soil in the revegetation area did not differ significantly with increasing age of the plants. The oldest revegetation age at the study site, which was 8 years old, was still unable to influence soil chemical properties, such as CEC or available P.

4.3. Microclimate condition
Revegetation activities on ex-mined land caused the soil surface is covered again by plant canopy. In general, the density of plant canopy increased with increasing age of revegetation plants. The increase in plant canopy density caused a decrease in light intensity from 2378-2954 lux in the revegetation area of 2-3 years to 629 lux in the 8-year-old revegetation area. However, that light intensity still did not match with the light intensity in natural forests of 339 lux (figure 2).

![Figure 2](image-url)

**Figure 2.** Relationship between light intensity and planted year in the revegetation area of Batu Hijau Mine

The range of air temperature as a result of measurement in the morning, afternoon, and evening on in both revegetated land and natural forest land was classified as slightly hot. The range of air temperature in the revegetation area (26.4-27.6 °C) was higher than the air temperature in natural forest (26.0 °C). The air temperature tended to decrease with increasing age of revegetation (figure 3).

![Figure 3](image-url)

**Figure 3.** Relationship between air temperature and year of planted in the revegetation area of Batu Hijau Mine
Revegetation age also significantly affected air humidity. Figure 4 shows that air humidity increased with increasing revegetation age. Air humidity values in the revegetation area of 2-3 years were 75.3-77.3% and increased to 84.7% in the 8-year revegetation area. Meanwhile, the air humidity in natural forest was 83.6%.

![Figure 4. Relationship between relative humidity and the planted year in the revegetation area of Batu Hijau Mine](image1.png)

In general, the microclimate-elements values exponentially decreased after the peak values (figure 2, 3, and 5). The relative humidity exhibited the opposite relationship with soil and air temperatures, and light intensity during the study period. All equation functioned well in simulating the microclimate elements patterns, with $R^2$ ranging from 0.8209 to 0.9269.

The data above are in line with the results of [13] which states that average soil and air temperatures were significantly lower, while relative humidity was significantly higher in revegetated areas of a surface mine dumpsite. [14] also obtained the same results for light intensity, i.e. solar radiation was
higher in open space than that under forest cover. [15] observe the largest differences between temperature at the soil surface and in the ground; however, temperature and relative humidity values at a high of 2 m did not differ very much in the study localities. They concluded, that, it is important that technical reclamations be followed as soon as possible by biological reclamations, by the fastest possible development of vegetation in the newly forming surface. This will lead to improvements in other parameters, such areas, both biotic and abiotic.

5. Conclusion

Until the age of the 8-year revegetation plant, the profile of the mine soils still does not show clear horizonization other than the 5 cm dark brown top layer due to the accumulation of organic matter. Except of organic-C content in the upper layers, the other chemical properties of the mine soil in the revegetation area did not differ significantly with increasing age of the plants. Bulk densities of surface layer of the mine soils were quite high (1.29-1.52 g/cm$^3$) and the permeability was classified as moderate (4.55 cm/hour on average). Natural forest soil had better physical properties, as reflected by lower bulk density (1.22 g/cm$^3$) and higher permeability of surface layer (10.58 cm/hour). The bulk density and permeability values are in accordance with the technical specifications applied to ensure the soil functions properly as a capping material for acid rocks by inhibiting the contact of oxygen and water from the soil surface.

The condition of the microclimate at the location of this study seems to be improving towards the direction of natural forest conditions with the aging of the revegetation age. Light intensity is the primary factor that influences other microclimate parameters such as air temperature, humidity and soil temperature. Therefore, variations in light intensity will cause variations in other climate parameters with more or less the same tendency. The intensity of light decreases as the plant canopy grows along with the increasing age of revegetation. The development of plant canopy is also inseparable from the role of soil in providing plant nutrients, such as calcium and magnesium, and also organic-C and total-N especially in the upper layers.

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