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Nutrient Cycling Index in Relation to Organic Matter and Soil Respiration of Rehabilitated Mine Sites in Kelian, East Kalimantan

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ABSTRACT

Degraded soils at mine sites are often associated with decreased soil fertility. However, soil nutrient status might be improved through biomass recovery primarily from re-vegetation. This paper relates nutrient cycling index (NCI) derived from Landscape Function Analysis (LFA) to soil respiration and soil organic matter as a measure of improving soil condition after rehabilitation. Fieldwork was conducted at Kelian Equatorial Mining, East Kalimantan in June 2001. Four sites were selected representing rehabilitation work in 1994 (7 year), 2000 (1 year) and 2001 (3 month), and a reference site of undisturbed primary forest. The NCI value was calculated from scores of basal/canopy cover, litter (abundance, origin and degree of incorporation), cryptogam cover and surface roughness. Soil respiration was measured using the inverted-box method. In general, the NCI values increased with age of rehabilitation (12 to 56 %) showing a significant increase compared with the values of reference site (80%). Soil respiration varied greatly and the values were equally high (200-800 mg CO_2 m^{-2} hr^{2}) across all sites. Tropical soils like those of Kelian might be inherently rich of soil organism as shown by high value of soil respiration. Nevertheless, the NCI values were not systematically related to soil respiration. We found that increased organic matter may be used as early sign of functioning soil resources in degraded land.

Keywords: Gold mining, nutrient cycling, organic matter, respiration

INTRODUCTION

Mine site rehabilitation is essential to restore soil fertility after disturbance. Methods used for soil restoration may include geo-technical measures, vegetative, or in combination with other techniques depending upon stages of mining operation. Mining operation in a tropical area may be exposed to severe erosion due to much higher rainfall than in a temperate region. Therefore, land rehabilitation aims to reduce soil and erosion in the early stage. In addition, rehabilitation also improves both soil fertility and soil organism.

High precipitation in the tropical areas, on the other hand, may act as a trigger (pulse) for rapid plant growth (Ludwig *et al*. 1997). As a result, high stand plant community may be achieved more rapidly. Likewise, litter and soil carbon turnover may be high under a tropical condition. Litter accumulation is the first visible sign of soil recovery. A congruent development of soil microbes may also occur which is able to promote nutrient release of decomposing organic matter.

To assess this progress, there should be a set of soil indicators that can be applied as simple, rapid but reliable in the field. There is a wide range of methods available for this purpose, for example a method that was eveloped by Andersen and Sparling (1997). In particular, the landscape function analysis (LFA) which was developed by Tongway and Hindley (1995). Originally this method was developed for tropical grasslands in Australia. However, it has been adapted for mine sites (Tongway *et al*. 1997; Setyawan *et al*. 2002). The LFA method provides a simple, repetitive procedure for assessing soil surface conditions. Potential soil fertility is estimated by nutrient cycling index (NCI) under this protocol (Tongway *et al*. 2003). It is estimated that soils with high NCI values will correspond with more functioning soil resources. Activity of soil organism can be approached by measuring soil respiration.

This paper describes relationship between nutrient cycling index, soil respiration and soil carbon at rehabilitated mine sites in a tropical area.

MATERIALS AND METHODS

Study site

Fieldwork was conducted at the Kelian Equatorial Mining (KEM) site which is about 180 km north-west of Samarinda, the capital city of East Kalimantan Province. It is about 3 km south of the Equator (approximately 0°05¢S, 115°30¢E). Mining operation is focused at the Prampus hill prospect near the Kelian River. Altitude is around 250 m above sea level. The area has a typically tropical environment with rainfall in excess of 3,500 mm yr^{-1} distributed mostly in September-March. Rainfall has caused a high variability in flow rate of the Kelian River ranged from 2 to 400 m^3 s^{-1}. Local relief is deeply dissected sloping areas with steep-sided ridges and valleys and riverbed on flat lands (Eaglen *et al*. 1998).

LFA Procedure and Soil Sampling

Four sites were selected representing locations which were rehabilitated in 1994 (7 year), 2000 (1 year) and 2001 (3 month), and a reference site of primary forest uphill of the Namuk dam (Setyawan 2004). At every site the soil surface conditions were assessed and sampling points were located along a down-slope transect. The number of sampling points differed between sites and in total there were 26 sampling points. From each sampling point, soil samples were collected from four depths (0-1, 1-3, 3-5 and 5-10 cm) that had a total number of 104 samples.

Soil surface assessment was conducted using landscape function analysis (LFA) as described by Tongway and Hindley (1995). For this presentation, only nutrient cycling index (NCI) in used. Scores for calculation of this index were derived from 1) basal cover of perennial grass or canopy density of trees and shrubs (score 1-4), 2) litter cover, origin and decomposition (score 1-30) 3) cryptogam cover (score 1-4), and 4) surface roughness (score 1-5). The NCI was the obtained score divided by total score (43).

Figure 1. Instrument for soil respiration measurement consists of Perspex lid, metal ring and dish containing 0.5 M KOH. (Photo courtesy of Tongway and Ludwig, 1996).

Soil Respiration Measurement

Soil respiration estimates soil microbe activity through entrapment of produced carbon dioxide (CO_2) during metabolism. It can be conducted in the field using a simple apparatu (*i.e.* inverted box, Figure 1) which retains evolving gas in a close system. The released CO_2 was reacted with an alkali solution (0.5 *M* KOH) (Hartigan 1980; Tongway and Ludwig 1996).

The rate of soil respiration is estimated by measuring electrical conductivity (EC) of alkali solution and the EC reading is fitted into a calibration curve of fresh and saturated KOH. For a 20-cm diameter ring and 20 ml of 0.5 *M* KOH, soil respiration can be calculated with the formula as follows:

$$\text{Respiration} = \frac{220(x_2 - x)}{x_2 - x_1} \times \frac{10000}{314} \times \frac{1}{t}$$

where:
respiration is expressed as mg CO_2 m^{-2} hr^{-1}
x = sample EC (mS cm^{-1})
x_1 = EC of saturated KOH (45.74 mS cm^{-1})
x_2 = EC of fresh KOH (vary slightly, approx. 114.6 mS cm^{-1})
t = time required for measurement (hour).

Soil Analysis

Potentially available (mineralizable) nitrogen was determined following the modified chemical procedure of Gianello and Bremner (1986). This chemical procedure is quite rapid for measuring available N for routine analysis. It was found that eventhough the average concentration of ammonium-N obtained by the chemical method is only about 32% of the N concentration produced by incubation of soil at 40°C for 7 days, both methods are closely related (r = 0.95). Published work also shows close relationships for ammonium-N obtained by the chemical extraction and incubation methods (Zhang *et al*. 2002; Picone *et al*. 2002). For this analysis, a batch of 3 grams of 2-mm sieved soil was mixed with 20 ml of 2 M KCl in a digestion tube. The mixture was transferred into AIM500 block digester and heated for 16 hours at 95°C. An aliquot was filtered through Whatman 42 filter paper (pre-moistened with Milli-Q water). Ammonium-N was measured with a SKALAR autoanalyser. Another set of samples was simultaneously prepared for 'cold' extraction to measure mineral-N in which the soil mixture was shaken occasionally and kept at room temperature for 16 hours. Potentially mineralisable-N was calculated as the difference between values for the hot extraction (*i.e.* mineral plus mineralizable N) and the cold extraction (mineral N).

The LECO CHN1000 combustion method was used to measure total carbon (Nelson and Sommers 1982).

RESULTS AND DISCUSSION

Nutrient cycling index (NCI) varied widely with age of rehabilitation and as compared to the values of analogue sites which ranged from 10-20% in the 3 month sites to about 50% in the 7 year site. The nutrient cycling index is by far the most sensitive index for the success of rehabilitation as it is often non-existent in the early years of rehabilitation (Tongway *et al*. 1998). Figure 2 shows that rehabilitated landforms attained favorably values for the nutrient cycling index than those of the natural 'analogue' site. With regard to the Kelian sites, the NCI values were likely to increase most rapidly after first years rehabilitation.

The NCI was moderately related to mineralizable nitrogen (SMN) for the topsoil (0-1 cm). The prediction is weaker with increasing soil depth (Figure 2). The lower correlation was partly due to results of the 7 year site which was a little variation in the NCI value despite a wide range of SMN values. If the regression is fitted to the average value of the 7 year sites, this correlation is improved (r^2 = 0.59).

The nutrient cycling index showes a strong relationship with soil total carbon (Figure 3). The prediction is consistent with increasing soil depth. The NCI value was attributed largely (70%) to litter component (*i.e.* abundance, origin and degree of incorporation) and lesser extent to perennial basal or canopy cover, cryptogam cover and soil surface roughness. Hence, this index is related to nutrient pool size in soils. However, it should be noted here that the non-linear trend results in two regions. For the 0-1 cm depth, the NCI increased rapidly with increasing soil carbon up to 25 g kg^{-1}. Beyond this point, any changes in NCI could happen (*i.e.* plateau area).

Soil respiration was measured at the same sites as an assessment of soil nutrient cycling rate and a measure of biological fertility. The respiration

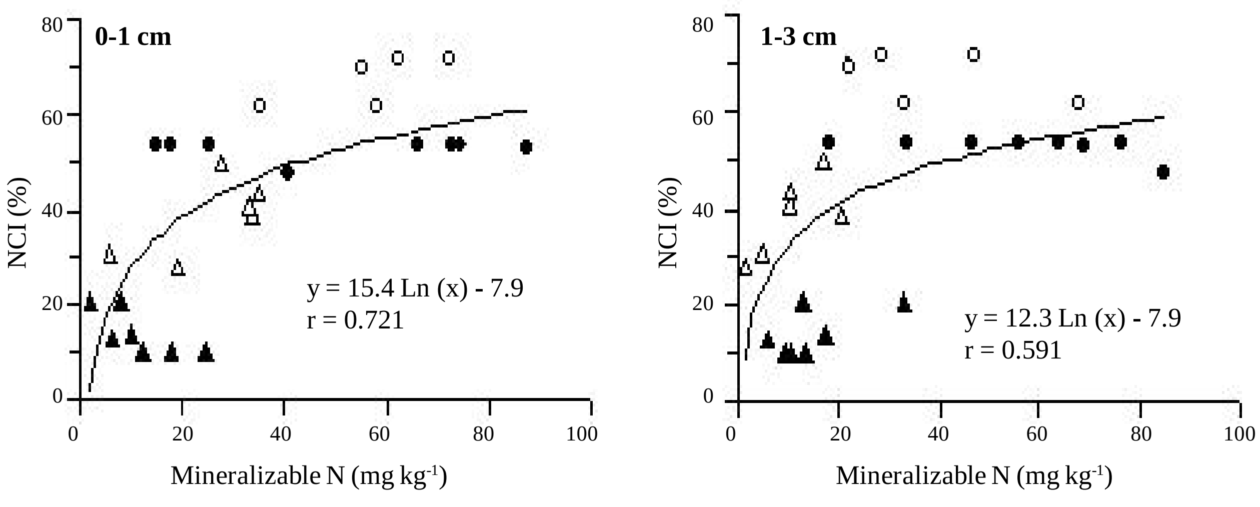

Figure 2. Nutrient cycling index (NCI) is moderately related to soil mineralizable nitrogen for the 0-3 cm depth. Note the wide range of mineralizable N values for the 7 year sites despite a similar NCI value. ○ = analogue, ● = 7 year, △ = 1 year, and ▲ = 3 month.

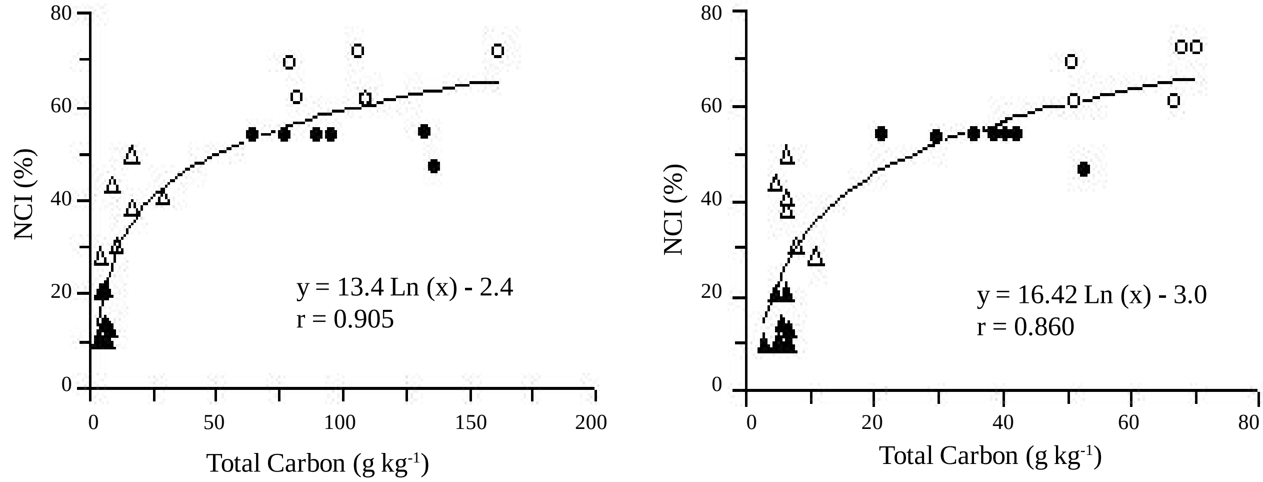

Figure 3. Nutrient cycling index (NCI) is strongly related to soil total carbon for the top 0-3 cm depths. ○ = analogue, ● = 7 year, △ = 1 year, and ▲ = 3 month.

values varied widely despite a narrow range in the corresponding NCI values. The values ranged from 200 to 800 mg CO_2 m^{-2} hr^{-1}. Soil micro-organisms were considered equally active in rehabilitation and analogue sites. This result was much higher than respiration in mulga soils of New South Wales with mean values ranging from 128 to 221 mg CO_2 m^{-2} hr^{-1} for different treatments of bare soil rehabilitation (Tongway and Ludwig 1996). For Kelian data, the NCI values increased with age. However, there is not systematic relationship between nutrient cycling index and soil respiration (Figure 4). There was a tendency that higher NCI values might be expected as soil respiration increased.

Measuring soil respiration in the wet tropics area has exposed some technical problems. This is due to the complex plant litter/root system above the mineral soil horizons. In this situation, one needs to remove most of the litter to secure the respiration chamber in place. As a consequence, the measurement might have been under-sampled and hence under-estimated the complex, layered litter conditions which is typical of the wet tropics.

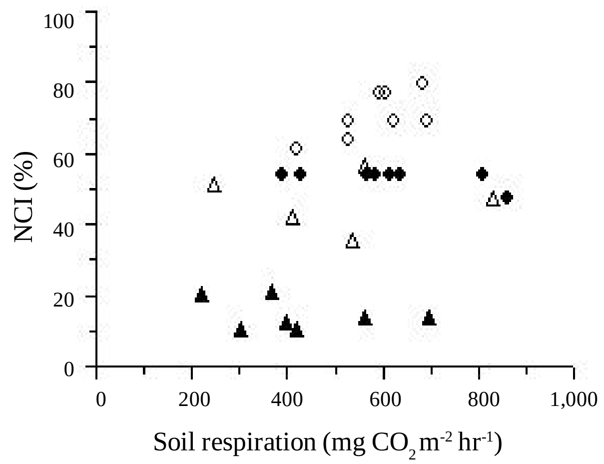

Figure 4. Nutrient cycling index (NCI) in relation to soil respiration for Kelian soils. ○ = analogue, ● = 7 year, △ = 1 year, and ▲ = 3 month.

Increased organic matter in rehabilitated mine soils in the long-term was indication the improving of nutrient pool. This was noticed particularly for the 7-year rehabilitated sites where residual direct effects of previously applied fertilizers might have been reduced or even became negligible. Long-term effects of organic amendments significantly improved mine soil quality in addition to the increase in soil organic matter (Schwenke *et al.* 2000). Mineralizable nitrogen, extractable phosphorus and aggregate stability also commonly increased (Bendfeldt *et al.* 2001). Under natural systems, this improvement mostly happens through plant production as appears to be the case at Kelian. A question to be resolved is whether the current vegetation at rehabilitated sites is functioning optimally and is sustainable in the long-term, as occurs in the primary forest?. Vegetation monitoring is necessary to ensure the that rehabilitation is progressing satisfactory and whether additional amelioration is necessary.

CONCLUSIONS

Soil recovery after disturbance occurs relatively fast in the tropical mine site of Kelian, East Kalimantan. Organic matter turnover from re-established vegetation provided soil Nutrient cycling index derived from the LFA procedure was not correlate linearly to nutrient pool size (soil carbon and nitrogen). This might indicated a highly dynamic soil system in tropical condition.

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