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Soil chemical properties of opencast coal mining site in Indonesia and its effect on plant growth

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ABSTRACT

Opencast coal mining causes severe ecosystem disturbances, such as soil degradation, excessive waste production, overburden formation, and possibly reforestation inhibition. In this study, we assessed the effect of opencast coal mining on soil chemical properties and plant growth in soil from natural forests and post coal mining sites (a 16-year-old coal mining site in Lati and a 5-year-old coal mining site in Sambarata) in Berau Regency, East Kalimantan, Indonesia. Soil pH, total carbon, total nitrogen, available phosphate, exchangeable cations, and cation exchange capacity were measured. Plant growth and shoot phosphorus, potassium, calcium, magnesium, and iron concentrations were determined as well. Soil from the post coal mining sites had lower pH, total carbon, total nitrogen, available phosphate, potassium, sodium, calcium, magnesium, and cation exchange capacity than soil from the natural forests. Reduction of shoot nutrient content and plant biomass was observed in *Sorghum bicolor* grown in soil from both Lati and Sambarata post coal mining sites. By calculating the correlation between soil chemical properties and plant growth, it was found that all the soil chemical properties are limiting factors of plant growth in Lati. The results revealed that opencast coal mining reduced soil fertility and inhibited plant growth, which hinders successful reforestation. Thus, monitoring, evaluation, and restoration of post coal mining area is recommended to prevent more severe environmental damage.

***Key words**: Opencast coal mining, Soil degradation, Restoration, Growth limitation, Kalimantan*

Introduction

Coal mining is one of the most important industries in Indonesia (Suryantoro and Manaf, 2002). According to US Energy Information Administration (www.eia.gov), Indonesia ranks 5th among the world's coal producers, with total production reaching approximately 414 million tons in 2011. The mining industry, including coal mining, accounts for approximately 4-5% of Indonesia's gross domestic product (GDP). Among the minerals produced in Indonesia, coal has the highest production, and its price is second only to that of gold (Directorate General of Minerals and Coal, 2012). Coal mining is widespread in the six main islands of Indonesia, namely, Sumatra, Kalimantan, Java, Sulawesi, Maluku, and Irian Jaya (Syahrial *et al.*, 2012).

Coal mining is known to contribute to environmental degradation. Opencast mining is conducted in Indonesia because coal is mostly located close to the surface and under natural forest areas (Resosudarmo *et al*., 2009). The process of opencast coal mining, which involves logging trees, stripping topsoil, removing overburden, and exploiting minerals (Ghose and Majee, 1998), leads to deforestation and severely damages both local and global ecosystems (Resosudarmo *et al*., 2009). The impact of opencast coal mining is greater than that of underground coal mining as there is no aboveground disturbance by underground mining. In addition to deforestation, opencast coal mining results in excessive waste production (Bian *et al*., 2010), overburden (Dowarah *et al*., 2009), increased soil erosion (Braghina *et al*., 2010), and reduction of soil essential nutrients (Sheoran *et al*., 2010), all of which further deteriorate soil fertility (Ghose, 2004). Finally, opencast coal mining may alter soil physical, chemical, and biological properties, leading to extensive soil degradation (Juwarkar and Jambhulkar, 2008).

Soil degradation by opencast mining decreases plant species richness, inhibits plant development (Burger and Zipper, 2002), damages aboveground flora (Monjezi *et al*., 2009), and destroys native vegetation (Chen *et al*., 1998). This adverse impact of soil degradation on aboveground vegetation has direct negative consequences on the habitat and biota of fauna (Monjezi *et al*., 2009), wildlife, community, and finally, the ecosystem (Peplow and Edmonds, 2005). Opencast mining also causes heavy metal contamination of the adjacent land (Kien *et al*., 2010).

Clearly, the restoration of opencast mining areas is a must. Natural forest recovery occurs very slowly (Jha and Singh, 1991) and it is estimated that approximately 200 years is required to reach the level of native forests (Srivastava *et al.,* 1989). Revegetation is usually adopted for soil and environment stabilization in areas degraded by opencast mining (Wong, 2003). However, most revegetation attempts are inhibited by problems concerning soil chemical or physical properties. The restoration of degraded land in opencast mining areas can be achieved by the determination of soil chemical, physical, and biological properties (Sheoran *et al*., 2010).

The evaluation of soil chemical properties in opencast coal mining areas is important. The removal of topsoil, the erosion of exposed areas (Carrol and Tucker, 2000), low soil organic matter, and the lack of nutrients create problems for revegetation on degraded mine spoils (Makineci *et al*. 2011). Few studies have investigated the impact of opencast coal mining on soil chemical properties in Indonesia. This is a serious concern in Kalimantan because this area is the second largest coal producer in Indonesia (Syahrial *et al.,* 2012) and suffers from the highest rate of deforestation (FAO, 2009).

In this study, we focused on the impact of opencast coal mining on soil chemical properties and the potential limiting factors of reforestation in Berau Regency, East Kalimantan, Indonesia. We compared soil chemical properties and plant growth using soil from post coal mining sites and natural forests. As bio-indicator, we used *Sorghum bicolor* to evaluate the limiting factors of plant growth in post coal mining site, because this plant is able to grow in a short time and adapts well to wide ranges of soil pH, high Al stress, and low-fertility soil, such as ultisol soil (Flores *et al*., 1988; Flores *et al*., 1991). We investigated the relationships among opencast mining, soil chemical properties, and plant growth. In particular, we addressed the following questions: (1) Does opencast mining change soil chemical properties? (2) Does the soil chemical property in post mining site effect on plant growth?

Materials and Methods

Study site and soil sampling

The study site was located in PT. Berau Coal and lies between the longitude (01°52'26.74" - 02°25'09.78" N; 117°07'44.52" - 117°38'26.46" E), Berau Regency East Kalimantan Indonesia. PT Berau Coal is the first contractor of coal mining in the country to operate a concession area in Berau approximately 121.804 ha. The climate is of tropic-type with a mean annual rainfall of 3132 mm yr^{-1}. A mean daily minimum temperature is range of 22 °C and a mean daily maximum of 35 °C. A mean daily minimum velocity is range of 5.8 knot and a mean daily maximum of 11.42 knot. A mean of daily humidity is 87% and a mean of daily sunshine duration is 44%. This region is located in tropical rain forest zone with Dipterocarpacea forest as its typical vegetation. Two areas of two ages of mining were selected which encompassed two post coal mining sites and their respective natural forests (pre-mining site): a 16-year-old post coal mining site (02°15'N; 117°35'E) and its natural forest (02°15'N; 117°34'E) at Lati, and a 5-year-old post coal mining site (02°10'N; 117°24'E) and its natural forest (02°10'N; 117°24'E) at Sambarata, in Berau Regency, East Kalimantan, Indonesia. Both natural forests were dominated by *Anisoptera costata* (Dipterocarpaceae), whereas there was no vegetation covering the post coal mining sites. Lati mine is the biggest mine site at PT Berau Coal and laid 35 km from the East of Tanjung Redeb, a capital city of Berau Regency. Lati mine started the operation in 1993 with a production capacity of 15 Mt of coal per year and more than 120 x 10^6 m^3 of overburden movement annually. While in Sambarata mine, coal operation was started in 2001. The coal deposits are mined using open pit mining method involves the complete removal of vegetation, top soil, and underlying gravel layer. After the removal of vegetation, the top soil and underlying gravel layer or overburden were collected and used as backfilling in post coal mining site.

Soils were ultisol and collected representatively in uniform field in a simple random pattern across the field. Field had flat slope, dry, no erosion, and without fertilizer or manure application history. The top soil (0-10 cm) and under layer gravel (10-30 cm) were collected, weighed approximately 0.5 kg, and composited. Soils were collected in approximately 90 x 90 m^2 of wide sampling area with 30 m distance between soil sampling. Five replications of soil samples were collected at each site. In Lathi area, soil texture in natural forest was silty clay loam, and soil texture in post coal mining site was clay loam. While in Sambarata area, soil texture in natural forest and post coal mining site was loam.

Soil chemical analysis

Soil was air-dried and passed through a < 2 mm sieve. The passed dried soil was used for analysis of pH (H_2O) and pH (KCl). Available phosphate (P) (Truog 1930) was extracted with 0.001 M sulfuric acid solutions and analyzed by the ammonium molybdate method (Olsen and Sommers 1982). Total carbon (TC) and total nitrogen (TN) were determined by a C:N analyzer (Sumigraph NC-220F, Tokyo). Exchangeable potassium (K), sodium (Na), magnesium (Mg), and calcium (Ca) were extracted with 1M (pH 7) ammonium acetate solution and their concentrations were determined using an atomic absorption spectrophotometer (Hitachi model Z-5000 series Polarized Zeeman, Tokyo). After removing excess NH_4^+, the sample was extracted with 100 g L^{-1} KCl solution and the supernatant was used to determine cation exchange capacity (CEC) using the semi-micro Schöllenberger method. Base saturation (BS) was calculated by dividing the sum of exchangeable cations (K, Na, Mg, Ca) by CEC and multiplying the result by 100%.

Plant growth

Owing to the limiting number of soil samples and the short time of plant cultivation (3 months), a fifty ml cylindrical pot (3 cm diameter x 11 cm height) was used and enough to grow *Sorghum bicolor* (CV) New sorgo No.2 in one hundred grams of fresh soil sample. Five seeds of *Sorghum bicolor* (CV) New sorgo No.2 were sown. Seedlings were thinned to three in each pot after germination and grown under greenhouse conditions at Yamagata University, Tsuruoka, Japan (38°44'N, 139°50'E) for 90 days. Five replications were made. The seedlings in the 50 ml cylinder pots were placed randomly in the greenhouse and approximately 15 mL of tap water was applied once every two days. No fertilizer was applied. In three months after sowing, shoots and roots were harvested, washed with tap water and deionized water, separated, and oven-dried at 70 °C for 72 hours before weighing. The dried shoots were ground and digested with a solution of nitric acid (HNO_3), perchloric acid ($HClO_4$), and sulfuric acid (H_2SO_4) (5 : 2 : 1 volume). P concentration in the digestion solution was determined colorimetrically with the vanadomolybdate-yellow assay (Olsen and Sommers, 1982) by employing a spectrophotometer (Hitachi U-2900, Tokyo) with the absorbance set at 880 nm. Shoot K, Mg, Fe, and Ca concentrations in the digestion solution were determined with atomic absorption spectrophotometer (Hitachi 170–50, Tokyo) using hollow cathode lamps. Shoot P, K, Mg, Fe, and Ca contents were calculated by multiplying shoot P, K, Mg, Fe, and Ca concentrations by shoot dry weights.

Statistical analysis

Statistical significance was analyzed using Kaleida Graph 4.1 software (Synergy Software 2012, USA) and means of groups were compared using the student t-test ($P < 0.05$).

Results

Chemical properties of soil from natural forests and post coal mining sites

Marked degradation of the chemical properties of soil from Lathi and Sambarata post coal mining sites was noted (Table 1). TC concentration and CEC were lower in soil from the post coal mining sites than in soil from the natural forests in both Lati and Sambarata. The reduction of soil TC concentration was approximately 89% in Sambarata and 92% in Lati. CEC was decreased by approximately 31% and 37% in soil from Lati and Sambarata post coal mining sites, respectively (Table 3).

Large reductions of TN, available P, and exchangeable K, Mg, Ca, and Na concentrations were observed in soil from the post coal mining sites in both Lathi and Sambarata (Table 1). TN concentration was decreased by approximately 49% and 65% in soil from the post coal mining sites in Sambarata and Lati, respectively (Table 3). Available P was decreased to approximately 67% and 57% in soil from the post coal mining sites in Lati and Sambarata, respectively (Table 3). Soil K, Ca, and Mg concentrations were decreased by approximately 61%, 95%, and 91%, respectively, in Lati.

The pH (H_2O) and pH (KCl) were decreased in soil from the post coal mining sites in both Lati and Sambarata (Table 1). The high acidity is due to the small amount of exchangeable cations. Mining decreased soil pH (H_2O) by 10% in both Lati and Sambarata, whereas it decreased soil pH (KCl) by approximately 23% in Lati and 11% in Sambarata.

The relatively large decline of TC, available P, and exchangeable K, Ca, Mg, and Na concentrations was mostly recorded in soil from the 16-year-old mining site in Lati than in soil from the 5-year-old mining site in Sambarata.

Plant growth, shoot nutrient concentration, and shoot nutrient content

To gain a better understanding of mining effects on soils and plants, growth and biomass response of *S. bicolor* were monitored and the results of which are expected to reveal the limiting factors of plant growth. Shoot dry weight of *S. bicolor* grown in soil from the post coal mining sites was lower than that grown in soil from the natural forests in both Lati and Sambarata (Fig. 1).

Shoot nutrient concentrations of *S. bicolor* grown in soil from the post coal mining sites and the natural forests in Lati and Sambarata are shown in Table 2. Use of soil from Lati post coal mining site resulted in the significant reduction of shoot nutrient contents: P was reduced by 41%; K, by 73%; Ca, by 72%; Mg, by 59%; and Fe, by 54%. Meanwhile, use of soil from Sambarata post coal mining site resulted in the

Table 1. Chemical properties of soil from natural forests and post coal mining sites in Lati and Sambarata, East Kalimantan, Indonesia

Area	pH		Total Carbon	Total Nitrogen (%)	C:N ratio	Avail. P (mg P_2O_5 kg^{-1})	Exchangeable cation				CEC ($cmol_c$ kg^{-1})	BS (%)
	H_2O	KCl					K	Na	Ca	Mg		
							($cmol_c$ kg^{-1})					
Lati												
Natural forest	5.08 a	5.04 a	2.23 a	0.20 a	11.09 a	10.10 a	0.64 a	0.10 a	2.80 a	2.30 a	11.60 a	76.67 a
	(0.07)	(0.08)	(0.36)	(0.008)	(1.94)	(0.08)	(0.16)	(0.005)	(0.91)	(0.34)	(1.01)	(4.58)
Post coal mining	4.60 b	3.88 b	0.19 b	0.07 b	2.72 b	3.30 b	0.25 b	0.07 b	0.14 b	0.22 b	7.30 b	9.70 b
	(0.11)	(0.03)	(0.02)	(0.005)	(0.33)	(0.06)	(0.02)	(0.004)	(0.01)	(0.09)	(0.59)	(2.34)
Sambarata												
Natural forest	4.61 a	3.83 a	2.84 a	0.27 a	10.44 a	9.60 a	0.41 a	0.09 a	0.32 a	0.95 a	12.88a	38.37 a
	(0.11)	(0.03)	(0.27)	(0.006)	(0.92)	(0.20)	(0.04)	(0.006)	(0.05)	(0.19)	(0.95)	(5.66)
Post coal mining	4.16 b	3.44 b	0.31 b	0.14 b	2.25 b	4.10 b	0.21 b	0.07 b	0.09 b	0.10 b	8.88 b	5.64 b
	(0.08)	(0.02)	(0.03)	(0.005)	(0.18)	(0.13)	(0.02)	(0.007)	(0.01)	(0.06)	(0.78)	(1.44)

H_2O, water; KCl, potassium chloride; C:N, carbon-to-nitrogen ratio; Avail. P, available phosphate; K, potassium; Na, sodium; Ca, calcium; Mg, magnesium; CEC, cation exchange capacity; BS, base saturation. Values in parentheses are means of five replicates standard error (SE). Different letters in the same column within the same area indicate a statistically significant difference between post coal mining site and natural forest (P<0.05) according to student t-test (n=5).

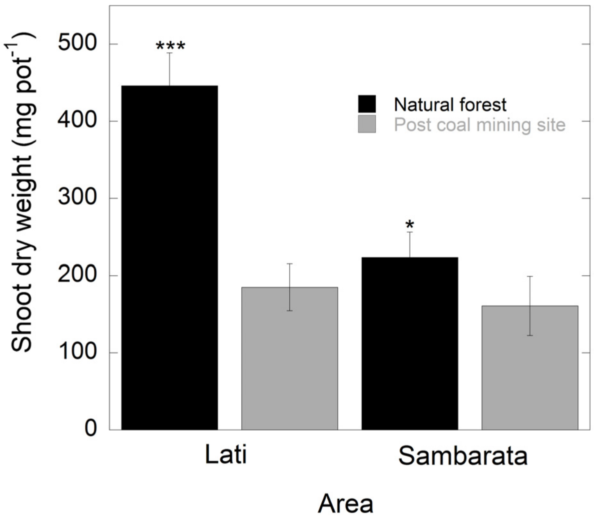

Fig. 1. Shoot dry weight of *Sorghum bicolor* grown in soil from 5-year-old (Sambarata) and 16-year-old (Lati) post coal mining sites in East Kalimantan, Indonesia. * 5% level of significance; *** 0.1% level of significance by the Tukey HSD test (n=5). *Vertical bars* are standard errors of means (SE)

significant reduction of only Mg content by 75%.

Shoot K concentration was decreased by 34% in *S. bicolor* grown in soil from the post coal mining site in Lati (Table 2). Similarly, shoot Mg concentration was decreased by 63% in *S. bicolor* grown in soil from the post coal mining site in Sambarata.

Discussion

Impact of coal mining on soil chemical properties

Coal mining significantly decreased the soil chemical properties. The decrease was extensive due to the excavation process adopted by opencast coal mining, which involved the removal of cover trees, topsoil, and litter. The reduction of soil TC concentration in Sambarata and in Lati is much higher about 25% – 40% than the reduction of TC in India (Singh *et al.*, 2012) and Ohio, USA (Shrestha and Lal, 2011), respectively. The decrease in TC concentration in soil from the post coal mining site also lowered CEC. Furthermore, mixing of the lower soil horizon during opencast mining might have lowered CEC. Those values are within the range observed in a previous study that reported a CEC reduction of approximately 26-37% in soil from a coal mining site in India (Sadhu *et al.*, 2012).

Large depletion of TN, available P, and ex-

Table 2. Shoot nutrient concentrations and contents of *Sorghum bicolor* grown in soil from natural forests and post coal mining sites in Lati and Sambarata in East Kalimantan, Indonesia

Area	Shoot nutrient concentration					Shoot nutrient content				
	P† (mg g-1)	K	Ca	Mg	Fe	P	K	Ca (mg pot-1)	Mg	Fe
Lati:										
Natural forest	0.38 b	14.21 a	4.61 a	7.48 a	0.15 a	0.17 a	6.25 a	2.10 a	4.60 a	0.063 a
	(0.03)	(1.09)	(0.90)	(1.97)	(0.02)	(0.01)	(0.58)	(0.45)	(0.44)	(0.006)
Post coal mining	0.58 a	9.48 b	3.58 a	4.50 a	0.18 a	0.10 b	1.66 b	0.58 b	1.90 b	0.029 b
	(0.05)	(1.15)	(0.96)	(1.05)	(0.05)	(0.01)	(0.17)	(0.03)	(0.31)	(0.001)
Sambarata:										
Natural forest	0.32 b	8.37 a	2.48 a	10.24 a	0.49 a	0.09 a	2.28 a	0.72 a	3.02 a	0.133 a
	(0.03)	(1.33)	(0.49)	(0.69)	(0.21)	(0.01)	(0.32)	(0.16)	(0.57)	(0.054)
Post coal mining	0.85 a	8.06 a	4.28 a	3.76 b	0.22 a	0.12 a	1.30 a	0.60 a	0.75 b	0.028 a
	(0.13)	(0.28)	(0.76)	(1.12)	(0.05)	(0.02)	(0.32)	(0.11)	(0.33)	(0.004)

P, phosphorus; K, potassium; Ca, calcium; Mg, magnesium; Fe, iron. Values in parentheses are means of five replicates standard error (SE). Different letters in the same column within the same area indicate a statistically significant difference between natural forest and post coal mining site ($P<0.05$) according to student-t test (n=5).

changeable K, Mg, Ca, and Na concentrations in both Lathi and Sambarata area is due to the removal of topsoil, vegetation, and litter that plays a prominent role in supplying organic matter and nutrients to soil during opencast coal mining. As it is reported that litter from a tropical forest in Kalimantan contributes approximately 0.4-1% N (Vernimmen *et al*. 2007). However, the reduction of TN is smaller about 10% - 20% in comparison to N reduction in soil from a post coal mining site in India (Singh *et al*. 2012), and in Ohio, USA (Shrestha and Lal, 2011). This may be explained by the low denitrification rate (Vernimmen *et al*. (2007), low nitrification from 0 to 35% (Ohta and Effendi, 1992) and low mineralization of N in Kalimantan (Vernimmen *et al*., 2007) in the tropical forests of Kalimantan. Furthermore, the high rainfall (3132 mm yr^{-1}) in Tanjung Redeb (Station of Meteorology of Tanjung Redeb, Berau Regency 2008), may explain the low N (Santiago *et al*., 2005; Alvarez-Clare and Mack, 2011). The low C:N ratio in soil from the post coal mining site is due to mineralization of soil organic matter that results from the loss of C and N due to mining.

The impact of opencast coal mining on the reduction of available P in Lathi and Sambarata area is much higher about 30% - 40% than reduction of available P in opencast coal mining in India (Ghose 2004). The low available P in this study can be explained by the high soil acidity (pH< 5), which greatly reduces availability of P (Hazelton and Murphy, 2007). Together, these findings indicate that the high soil acidity and the low soil organic matter are the limiting factors of available P.

The reduction of soil chemical properties was also found for K, Ca, and Mg in both post coal mining in Lathi and Sambarata area. Those reductions are much higher in this study than the K reduction of 28-46% (Ghose, 2004), Ca reduction of 7-46%, and Mg reduction of 9-43% in opencast coal mining in India (Sadhu *et al*., 2012).

Coal mining activity increased the soil acidity in Lathi and Sambarata area. The high acidity is due to

Table 3. Changes of soil chemical properties due to mining activities in countries having tropical climate and temperate climate, in comparison to soil from post coal mining sites in Lati and Sambarata, Indonesia

Soil chemical property	Place	Ratio (%) post mining: pre mining	Mining type	Reference
C	Lati	9	Coal	Present study
	Sambarata	11	Coal	Present study
	Ohio	14-44	Coal	Shrestha and Lal (2011)
	India	33	Coal	Singh *et al*. (2012)
CEC	Lati	69	Coal	Present study
	Sambarata	63	Coal	Present study
	India	63-74	Coal	Sadhu *et al*. (2012)
N	Lati	35	Coal	Present study
	Sambarata	51	Coal	Present study
	Ohio	20-47	Coal	Shrestha and Lal (2011)
	India	47	Coal	Singh *et al*. (2012)
P	Lati	33	Coal	Present study
	Sambarata	43	Coal	Present study
	India	65-77	Coal	Ghose (2004)
K	Lati	39	Coal	Present study
	Sambarata	51	Coal	Present study
	India	54-72	Coal	Ghose (2004)
Ca	Lati	5	Coal	Present study
	Sambarata	28	Coal	Present study
	India	54-93	Coal	Sadhu *et al*. (2012)
Mg	Lati	9	Coal	Present study
	Sambarata	10	Coal	Present study
	India	57-91	Coal	Sadhu *et al*. (2012)

C, carbon; CEC, cation exchange capacity; N, nitrogen; P, phosphate; K, potassium; Ca, calcium; Mg, magnesium; Co, copper; Pb, lead; Zn, zinc; As, arsenic; Mn, manganese.

the small amount of exchangeable cations. The changes of soil acidity in this study are much higher than the pH reduction of approximately 2% to 4% in a dry deciduous forest in India (Sadhu *et al*., 2012).

Generally, mining adversely affects soil chemical properties, reducing them to extremely low levels that possibly inhibit plant growth. Comparison with other opencast mining sites in countries with different climates revealed the severity of soil degradation due to opencast mining in East Kalimantan, Indonesia (Table 3). The high rainfall in Kalimantan possibly causes the high runoff that lead to the marked degradation of soil chemical properties. Rainfall in Tanjung Redeb, Berau Regency East Kalimantan measures approximately 3132 mm yr^{-1} (Station of Meteorology of Tanjung Redeb, Berau Regency, 2008), which is much higher than rainfall in dry tropical India, which is approximately 1240-1500 mm y^{-1} (Sadhu *et al*., 2012). Santiago *et al*. (2005) reported that soil P, K, Ca, and Mg concentrations decreased with increasing precipitation gradients of 1800, 2300, 3100, and 3500 mm yr^{-1} in a lowland tropical forest in Panama.

The relatively large decline of TC, available P, and exchangeable K, Ca, Mg, and Na concentrations was mostly recorded in soil from the 16-year-old mining site in Lati than in soil from the 5-year-old mining site in Sambarata. This implied that mining, particularly long-term mining, severely lowered soil quality. Consistent with our results, Ghose (2002) reported reductions of CEC and C, N, P, K, Ca, Mg, and Na concentrations with increasing age of overburden from 1-10 years due to erosion in mined soil dump. On the other hand, Maharana and Patel (2013) reported increases in soil C, N, and P concentrations with increasing age of overburden from 0-10 years. The gradual establishment of vegetation cover on the overburden accounted for those results. Our results underscored the urgent need for rehabilitation to improve soil chemical properties at the post coal mining sites in East Kalimantan, Indonesia.

Impact of coal mining on plant growth, shoot nutrient concentration, and shoot nutrient content

Soil from post coal mining significantly showed the plant growth inhibition as expected. However, we found no symptoms linked to toxic metals, such as necrosis, bronze spotting, or chlorosis, in leaves. To clarify the reasons for plant growth inhibition, shoot nutrient concentrations were measured. The depletion of K and Mg concentrations in soil from the post coal mining sites could have resulted in the decreases in shoot K and Mg concentrations. By contrast, shoot P concentration was higher in *S. bicolor* grown in soil from the post coal mining site than in that grown in soil from the natural forest in both Lati and Sambarata. This could be explained by the dilution effects of high shoot dry weight production. As shown in Fig. 1, shoot dry weight was lower in *S. bicolor* grown in soil from the post coal mining site than in soil from the natural forest. Low shoot N, P, and K concentrations with high biomass were previously observed in lodgepole pine at an oil shale post mining site (Kuznetsova *et al*., 2011). High shoot Mg, K, and Ca concentrations with low biomass were also observed in *Pinus sylvestris* grown at a brown coal mining site (Baumann *et al*. 2006). Based on the classification of sorghum nutrient concentration (Reuter and Robinson, 1986), shoot P concentration in this study is categorized as deficient as this value is <20 $mgP.g^{-1}$ in *S. bicolor* grown in soil from both natural forest and post coal mining sites in Lathi and Sambarata. In contrast, shoot K, Ca, Mg, and Fe concentrations are categorized as adequate. Our results indicate that P is the major plant growth limiting factor. Low shoot N, P, K, Ca, and Mg concentrations were also observed in grass grown in coal spoils in the Lusatian region, Germany (Nada *et al*., 2011).

Shoot dry weight had significant positive correlations with soil chemical properties in both Lati and Sambarata (Table 4). The very low N, P, K, Ca, Mg, and TC concentrations in soil from the post coal mining site decreased plant growth. Positive correlations between shoot dry weight and all the soil chemical properties were observed in plants grown in soil from Lati post coal mining site. The lower soil chemical properties in post coal mining site resulted in lower shoot dry weight of *S. bicolor* in comparison to this plant grown in soil from natural forest. It indicates that all the soil chemical properties are the limiting factors of plant growth at Lati post coal mining site. In contrast, only TN, TC, Mg, and Ca concentrations were positively correlated with shoot dry weight in plants grown in soil from Sambarata post coal mining site. The fact that the mining site in Sambarata area is only five years old may explain the low impact of mining, as shown by the lack of significant correlation of some soil chemical properties with shoot dry weight. However, as available P and K showed positive correlations with shoot dry weight, they are the potential limiting factors of plant growth in long-term mining. The results imply that low soil fertility, which is reflected by the low nutrient availability in soil from the post coal mining site, is influenced by mining period. The low soil nutrient availability suppresses nutrient uptake, thereby limiting plant growth. Consistent with our results, positive correlations between soil N and P and total biomass were observed in *Alnus sinuata* and *Anaphalis margaritacea* grown in copper mine tailings (Kramer *et al.*, 2000). It is reported that the application of P improved growth of *Oryza sativa*, *Triticum aestivum*, and *Brassica chinensis* in a reclaimed coal mine in China (Chen *et al.*, 1998), and the application of N, P, and K improved growth of 13 tropical tree species in coal mine spoils in India (Jha, 1992). The reduction of soil Ca, Mg, and K concentrations was also reported limited plant growth in lignite mine soil in Spain (Monterroso *et al.*, 1998).

To summarize, it was clarified that the inhibition of *S. bicolor* growth in soil from post coal mining sites is caused by multiple nutrient deficiencies. Generally, the low availability of soil nutrients inhibited nutrient uptake by and growth of plants grown in soil from the post coal mining sites in both Lati and Sambarata. This plant growth inhibition was more pronounced in soil from the 16-year-old mining site in Lati than in soil from the 5-year-old mining site in Sambarata (Tables 4). This result indicates potential reforestation problems at post coal mining sites due to the reduction of soil fertility.

In conclusion, our results show that coal mining changes the soil chemical properties into under limit and exhibit the plant growth inhibition. This study also shows that the duration of ecosystem disturbance by coal mining is related to soil fertility. This is the main reason for the inhibition of plant growth in soil from the post coal mining sites in humid tropical Indonesia. Nevertheless, the present results do not represent the diverse site conditions in Indonesia, but illustrate the relationship between plant growth and soil under mining impact. To overcome this soil degradation problem at post coal mining sites, rehabilitation is urgently needed. Application of soil organic amendment, K, Ca, Mg, P, and plant growth-promoting microorganisms may improve nutrient supply and soil fertility for reforestation.

Table 4. Correlations between shoot dry weight of *Sorghum bicolor* and chemical properties of soil from natural forest and post coal mining site in Lati and Sambarata areas, East Kalimantan, Indonesia

Area	Total Nitrogen (%)	Avail. P† (mg P_2O_5 kg^{-1})	Total Carbon (%)	Exchangeable cation K	Ca (cmol$_c$ kg^{-1})	Mg	CEC (cmol$_c$ kg^{-1})
Lati:							
Shoot dry weight (mg pot^{-1})	+0.821**	+0.841***	+0.799**	+0.727**	+0.738**	+0.954***	+0.823***
Sambarata:							
Shoot dry weight (mg pot^{-1})	+0.644*	+0.521ns	+0.679*	+0.536ns	+0.655*	+0.622*	+0.479ns

†Avail. P, available phosphate; K, potassium; Ca, calcium; Mg, magnesium; CEC, cation exchange capacity. * 5% level of significance; ** 1% level of significance; *** 0.1% level of significance; ns: not significant.

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