Utilization of Coal Ash for Preparation of Seedbed in Disturbed Land in Indonesian Open Cut Coal Mine

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Abstract

The amount of coal ash disposed as industrial wastes is increasing with increasing coal demands all over the world. Although coal ash is generally disposed by landfill, the demand of effective utilization of them is increasing because of the limitation of the disposal site. Moreover, in Indonesia, most of soil is classified as acrisol which is acid and clay-rich soil. As the plant growth is inhibited under the acid and low permeability, the utilization of coal ash is expected in order to improve physical and chemical conditions of seedbed in the revegetation area.

In this paper, the utilization of coal ash for preparation of seedbed in disturbed land in Indonesian open cut coal mine is discussed by means of several laboratory tests, column leaching test, and laboratory vegetation test by using Acacia mangium. *Considering the obtained results, it was suggested that the coal ash can be utilized to improve the physical and chemical conditions of seedbed and the growth rate of* Acacia mangium *by incorporated into soil with proper mixture rate.*

Keywords: Acacia mangium*, coal ash, column leaching test, laboratory vegetation test, rehabilitation*

Introduction

Indonesia is the largest coal exporter in the world in 2012. The amount of coal production and exported coal are drastically increasing: these are growing at an annual average rate of more than 10% since 2000. Due to this situation, Indonesian coal companies are increasing coal production and redeveloping coal mines in order to accommodate the heavy coal demands all over the world. Moreover, it is estimated that coal production increases continually and it also reaches 361 million tons in 2020, and 430 million tons in 2030 respectively. Furthermore, it is also predicted that the domestic demand of energy in Indonesia increases with a high rate of economic growth. In order to meet these demands, Indonesian government regards coal as an important source of energy supply in domestic, and they are constructing new coal-fired power plants. Therefore, it is predicted that domestic coal demand mainly for generation of electricity increases rapidly and exceeds the amount of export in 2022 (New energy and industrial technology development organization, 2011).

However, vast amount of coal ash is produced as the industrial wastes in a coal-fired power plant and it is expected that the amount of industrial wastes also increase with construction of additional power plants (Shimada et al. 2010). Although coal ash is generally disposed by landfill, the demand of effective utilization of them is increasing because of the limitation of the disposal site. 80% of coal ash is utilized such as a material for cements though less of them are disposed by landfill. Considering the preparation of landfill area and environmental issues, it is very meaningful to discuss the utilization of coal ash except a cement usage. Besides, most of soil is classified as acrisol which is acid and clay-rich soil in Indonesia. As the plant growth is inhibited under the acid and low permeability, the utilization of coal ash is expected in order to improve physical and chemical conditions of seedbed in the revegetation area (Park, 2014).

Therefore, this paper discusses the applicability of coal ash as a seedbed in the rehabilitation area by means of multiple laboratory experiments.

Kaltim Prima Coal (KPC) Mine

KPC mine is the biggest open cut coal mine in Indonesia located in East Kalimantan (Figure 1). The mine site belongs to tropical rainforest climate: the average annual precipitation shows 2,000~4,000 mm and the average temperature varies from 26 to 32ºC (Hamanaka et al., 2011). Mining area of KPC is 90,938 ha and it is divided into two parts which are called Bengalon and Sangatta, respectively.

This mine commenced coal production in 1991 and annual production reached about 41 million tons in 2011. Moreover, bituminous coal has been produced and exported to overseas, however, it is expected that the domestic coal demand increases

Fig. 1. Location of Kaltim Prima Coal mine

Rys. 1. Lokalizacja kopalni węgla Kaltim Prima

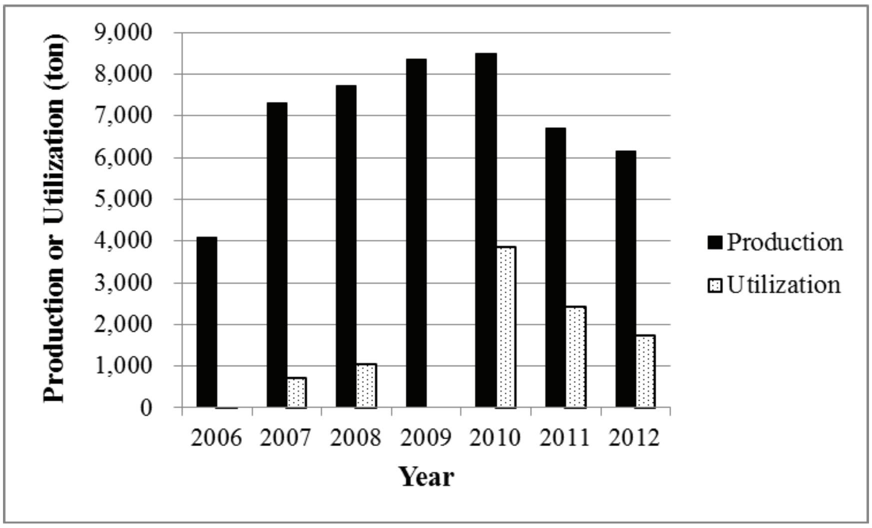


Fig. 2. Coal ash production in KPC

Rys. 2. Produkcja popiołu węglowego w KPC

from now on. Furthermore, the demand of revegetation as a process of reclamation is drastically increasing because this mine has a plan to finish the mining operation in 2021.

Coal Ash

Classification of Coal Ash

Coal ash is a residue after coal combustion in a pulverized coal-fired boiler and is equivalent of ash content of coal. In coal-fired power plant, finely-milled coals are burned at 1,200 to 1,600ºC. Almost all of carbon and hydrogen are burned during combustion process, and then combustion ash which mainly composes SiO_2 and Al_2O_3 is produced with combustion gas. Combustion ash produced inside of a boiler sometimes adheres on the surface of inside wall and falls on the bottom of boiler, however most of them move to a downstream of a gas duct with a combustion gas. Coal ash which falls on the bottom is called bottom ash and it is collected at the bottom of a boiler. On the other hand, coal ash which is collected with a combustion gas at the electric precipitation is called fly ash. Fly ash accounts for about 90% of coal ash and bottom ash accounts for about 10% of them.

Coal Ash in KPC Mine

Bituminous coal is applied at a coal-fired power plant in KPC mine and calorific value of it is about 6,000 kcal/kg. Coal ash production is about 17 m^3/day, and fly ash and bottom ash account for about 12 m^3/day and 5 m^3/day, respectively. Coal ash production is decreasing since 2011. However, it is expected to increase the production of coal

Tab. 1. Soil conditions

Tab. 1. Warunki glebowe

	Topsoil in KPC	**Simulated topsoil**
Soil pH	3.4~5.7	4.8
Texture	CL, LiC, SiC	LiC

Classification	Code
Sand	S
Loamy sand	LS
Sandy loam	SL
Loam	L
Silt loam	SiL
Sandy clay loam	SCL
Clay loam	CL
Silty clay loam	SiCL
Sandy clay	SC
Light clay	LiC
Silty clay	SiC
Heavy clay	HC

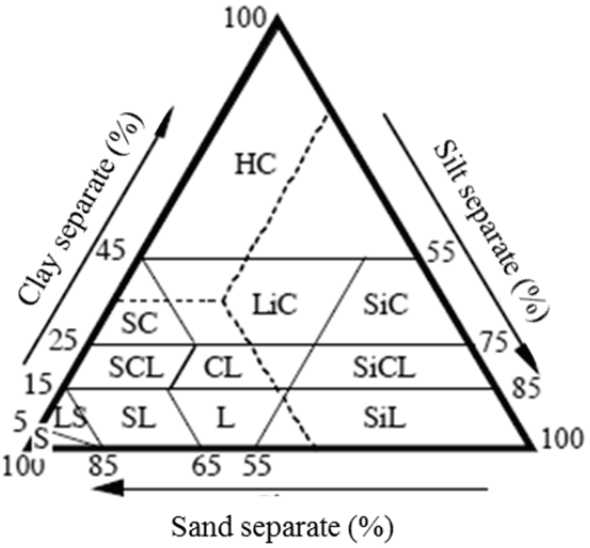


Fig. 3. Soil texture

Rys. 3. Tekstura gleby

ash because new power plants are under construction. Moreover, fly ash has been utilized as a road base since 2006 though bottom ash has not utilized. However, considering the increase of coal ash production, it is important to discuss the effective utilization except a road base usage.

In general, characteristics of coal ash differ depending on the coal type and specification of power plants, therefore characteristics of it must be investigated in order to discuss the effective utilization of coal ash. Thus, physical and chemical characteristics of coal ash obtained at the power plant in KPC mine was investigated by means of several analyses. Furthermore, the utilization of coal ash for preparation of seedbed in disturbed land in Indonesian open cut coal mine is discussed by means of several laboratory tests, column leaching test, and laboratory vegetation test.

Materials and methods

Assessment of Application of Coal Ash as a Seedbed in Disturbed Land

The utilization of coal ash for preparation of seedbed is one of solutions to improve physical and chemical properties in the disturbed land in Indonesian open cut coal mine because most of soil is classified as acrisol which is acid and clay-rich soil in Indonesia. However, the characteristics of coal ash have to be investigated because the characteristics of coal ash differ depending on the coal type and specification of power plants. Therefore, several analyses such as elemental composition analysis, particle size analysis, and SEM were conducted to understand the characteristics of coal ash. Moreover, assessment of application of coal ash as a seedbed is discussed by using simulated topsoil in Indonesia which was prepared in laboratory based on topsoil data in KPC (Table 1). In order to assess the application of coal ash as a seedbed, soil pH and EC test by using the solution sample mixed with soil : water = 1 : 5 in terms of mass ratio, and permeability test based on ASTM D5084-10 standard were conducted for 9 types of samples which were prepared by changing the

Tab. 2. Elemental composition

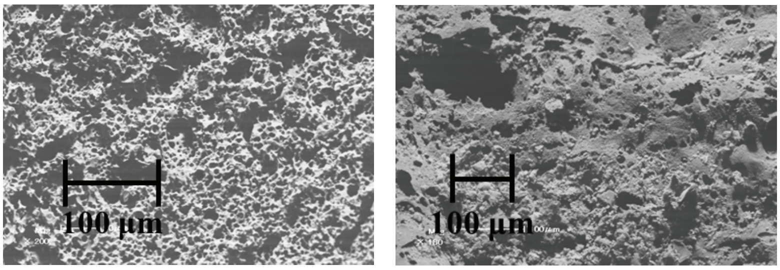
Tab. 2. Skład pierwiastkowy

	SiO_2 (%)	Al_2O_3 (%)	FeO (%)	CaO (%)	MgO (%)	K_2O (%)	Ig. Loss (%)
Topsoil in KPC	66.1	19.3	4.02	0.02	0.97	1.56	7.00
FA	30.9	13.3	5.93	1.82	2.24	1.54	41.0
BA	44.6	16.4	7.59	2.34	2.72	1.69	22.3

Tab. 3. The distribution of particle size

Tab. 3. Rozkład wielkości ziaren

	Sand (%)	Silt (%)	Clay (%)	Classification	D_{50} (mm)
FA	84.9	10.4	4.7	LS	0.33
BA	94.2	1.8	0.8	S	1.70



(a) FA (b) BA

Fig. 4. Surface conditions of the coal ash

Rys. 4. Warunki powierzchniowe popiołu węglowego

mixture rate of simulated topsoil and coal ash. Besides, column leaching test was conducted assuming the Indonesian climate in order to clarify the transition behaviour of pH and EC of elute, and discuss the effect of harmful elements contained in elute after the elapse of certain period of time. Assuming a half-year precipitation, flushing was conducted every day by using de-ionized water of 100 mL and continues 10 cycles. Moreover, the room temperature was kept at 30ºC.

Laboratory Vegetation Test

In order to discuss the effect on soil properties which are prepared by using coal ash to plant growth, laboratory vegetation test was conducted under the soil conditions which assess as a seedbed in previous section. *Acacia mangium* was selected as a plant species to conduct the laboratory vegetation test. Usually, this species is applied in the early stage of revegetation in open cut coal mine in Indonesia due to its extremely vigorous growth rate, and tolerance of highly acidic and low nutrient soils. Therefore, the applicability of coal ash as a seedbed in Indonesian open cut coal mines is discussed by using *Acacia mangium*.

The seedlings of *Acacia mangium* were planted to pots one by one filled soil mixed with simulated topsoil and coal ash artificially. This vegetation test continued for 2 month and measured the height and soil moisture content every a week. The diameter of seedlings was measured at the end of this test. All pots were supplied with 500 mL water every 3~4 days, while liquid fertilizer HYPONeX○,R (N-P-K = 6-10-5) at the concentrate of 2 mL per liter of water was applied weekly. The experiment was carried out in constant temperature and humidity room, which was controlled temperature and humidity at 30°C and 70%, respectively.

Results and discussion

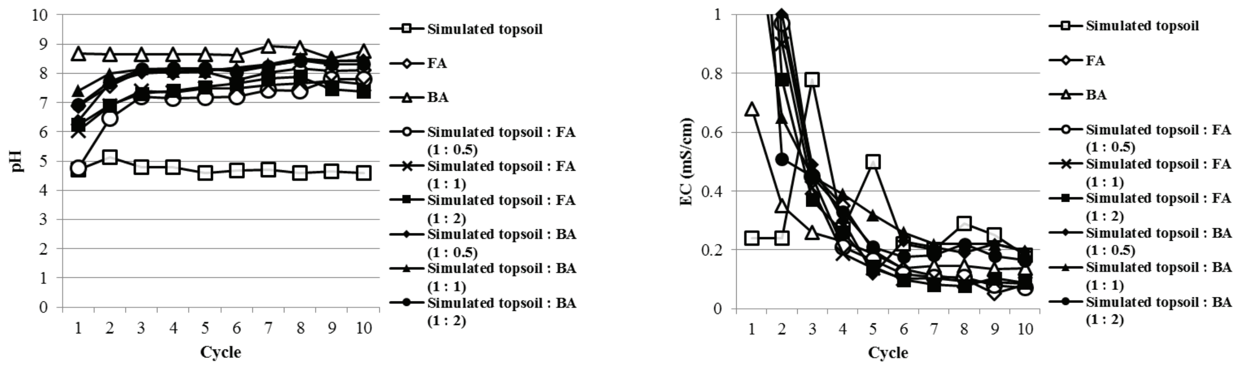
Applicability of Coal Ash for Preparation of Seedbed in Disturbed Land

Table 2 shows the result of elemental composition analysis. From these results, major elemental composition of coal ash is roughly equal to that

Tab. 4. Soil conditions

Tab. 4. Warunki glebowe

	Soil pH	Soil EC (mS/cm)	Permeability (cm/sec)
Simulated topsoil	4.81	0.650	$<1.00\times10^{-7}$
FA	7.35	1.21	9.52×10^{-3}
BA	9.18	0.260	1.42×10^{-2}
Simulated topsoil : FA (1 : 0.5)	5.66	0.870	2.19×10^{-5}
Simulated topsoil : FA (1 : 1)	5.81	0.890	1.61×10^{-4}
Simulated topsoil : FA (1 : 2)	5.90	0.920	9.97×10^{-4}
Simulated topsoil : BA (1 : 0.5)	5.77	0.570	1.09×10^{-3}
Simulated topsoil : BA (1 : 1)	6.28	0.440	1.15×10^{-3}
Simulated topsoil : BA (1 : 2)	6.67	0.370	1.73×10^{-3}



(a) pH (b) EC

Fig. 5. pH and Electrical Conductivity of Leachate

Rys. 5. pH i przewodność elektryczna odcieku

of soil though ignition loss of coal ash is much higher than that of topsoil due to unburned carbon. Therefore, it can be supposed that coal ash can be applied as a planting soil. The coal ash produced in KPC mine has sandy characteristics because the most of the particle size of FA and BA are classified as sand (Table 3). Usually, coal ash has the higher water holding capacity due to the macro- and micro-pores in their body (Haynes, 2009). According to the results of Scanning Electron Microscope (SEM) shown in Figure 4, FA has the higher water holding capacity that of BA because there were a lot of macro- and micro-pores in their surface.

Table 4 shows the results of soil pH, soil EC, and permeability. Soil pH shows alkaline both of FA and BA used in the present experiment. The pH range of coal ash varies from 4.5 to 12.0, but most of the coal ash which are produced around the world are alkaline (Park, 2014). Therefore, it can be expected that coal ash has potential to neutralize the acidity of soil by applying with proper mixture rate. Soil EC increases with an increase of mixture rate of FA whereas soil EC decreases with an increase of mixture rate of BA. These results are attributed to the particle size. It was reported that EC of the solution obtained from dissolution test increases with decreasing in the particle size due to the increase of reactivity of coal ash caused by the increase of a specific surface (Inoue, 2014). Therefore, adding FA has higher fertilizer effects than that of BA. Permeability of the samples increases by mixing coal ash with simulated topsoil. As low permeability of the seedbed is the one of critical reasons to inhibit plant growth (Phelps and Holland, 1987), it is useful to apply coal ash produced in KPC in order to improve the permeability of seedbed.

Figure 5 (a), (b) shows the results of behaviour of pH and EC transition about column leaching test. According to the results of Figure 4, FA and BA control columns produce leachate with high pH values, whereas the simulated topsoil column has the lowest pH values. However, the pH of the column mixed with simulated topsoil and FA or BA lays in high pH values after several flushing

Tab. 5. Results of leachate in 7th cycle

Tab. 5. Wyniki odcieku w 7-ym cyklu

	Cr (ppm)	As (ppm)	Se (ppm)	Cd (ppm)	Pb (ppm)
Simulated topsoil	N.D	0.002	N.D	0.031	N.D
FA	N.D	0.036	N.D	0.031	N.D
BA	N.D	0.060	N.D	0.032	N.D
Simulated topsoil : FA (1 : 0.5)	N.D	N.D	N.D	0.160	N.D
Simulated topsoil : FA (1 : 1)	N.D	0.027	N.D	0.032	N.D
Simulated topsoil : FA (1 : 2)	N.D	0.052	N.D	0.032	N.D
Simulated topsoil : BA (1 : 0.5)	N.D	0.052	N.D	0.032	N.D
Simulated topsoil : BA (1 : 1)	N.D	N.D	N.D	0.032	N.D
Simulated topsoil : BA (1 : 2)	N.D	0.063	N.D	0.033	N.D

Tab. 6. Contained amount in the planting

Tab. 6. Zawartości w sadzonkach

Heavy metal	Cr (ppm)	As (ppm)	Se (ppm)	Cd (ppm)	Pb (ppm)
Contained amount	0.2~1.0	0.1~5	0.02~2.0	0.2~0.8	0.1~1.0

due to their alkaline to neutralize the acid. Furthermore, it can be considered that FA and BA sustain the effect as fertilizer because EC shows a certain value even in the case column leaching test assuming a half-year precipitation is finished. Thus, it is conjectured that coal ash has quite continual effects as a neutralizer of acidic soil and a fertilizer for plant growth.

Table 5 shows the results of elute analysis for heavy metals after 7th cycle of elution. From these results, the impact of harmful materials eluted from coal ash is considered to be very little because the concentration of the metal contents in 7th cycle are very low compared to the contained amount in the planting shown Table 6.

Laboratory Vegetation Test

Figure 6 shows the results of laboratory vegetation test; height of seedlings and diameter of seedlings. The different alphabets in these figures show a significant difference obtained by Tukey-kramer method (Nagata and Yoshida, 2001). This method is one of the statistical tests to show the clear differences among the each result.

According to results, the growth of *Acacia mangium* is promoted by mixing simulated topsoil and coal ash compared with the height and diameter in simulated soil. Considering that the permeability of simulated soil is much lower than that of mixed soil, this is due to improvement of permeability by mixing coal ash. Besides, the height of *Acacia mangium* in mixed soil with FA is larger than that of BA. This is the reason why FA has bigger fertilizer effects than BA because EC of FA is higher than that of BA as shown Table 4. However, excess mixing of FA inhibit the plant growth because the height of FA is much lower than mixed soil with simulated topsoil and FA while excess mixing of BA is not effected to plant growth. As the impact of harmful materials eluted from coal ash is considered to be very little according to the results of Table 5, this is due to water holding capacity of soil. FA has higher water holding capacity than that of BA due to their macro- and micro-pores as shown Figure 4. The height of seedlings, shown Figure 7, increases up to a certain volume water content and then it decreases rapidly. In usual, high water holding capacity has favour effects for plant growth because the available water in soil is increased. However, the plant growth is inhibited under the high moisture content in soil due to lack of oxygen for root propagation (Bartholomeus, 2008). Therefore, it can be suggested to apply FA as a seedbed considering the water holding capacity.

To sum up, it can be said that the coal ash used in this study has high applicability as a seedbed. However, it should be considered the proper mixture rate to incorporate into soil because excessive use of coal ash inhibits the plant growth.

Conclusion

In this study, the applicability of coal ash produced from KPC mine as a seedbed in the rehabil-

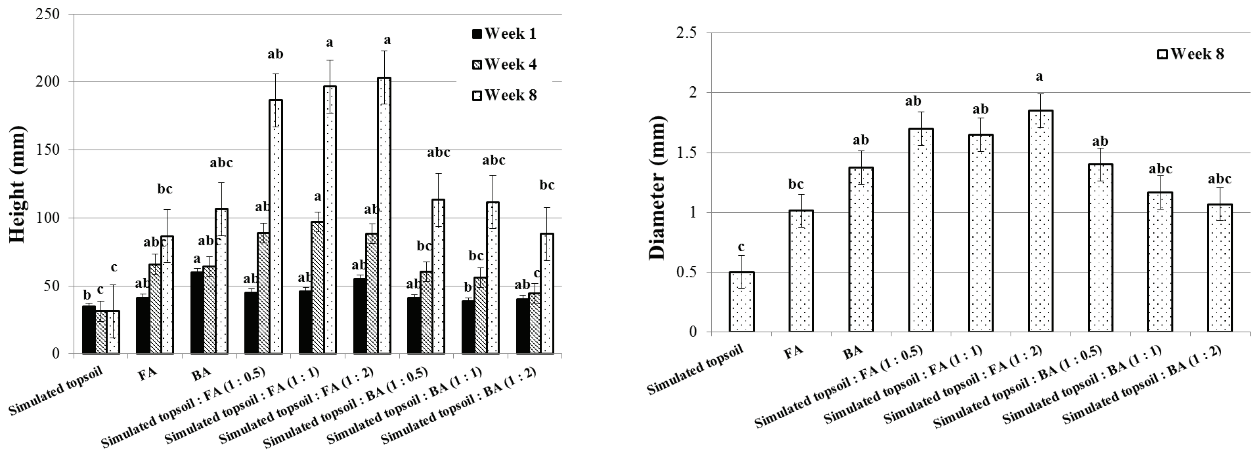


Fig. 6. The results of laboratory vegetation test

Rys. 6. Wyniki laboratoryjnych testów wegetacji

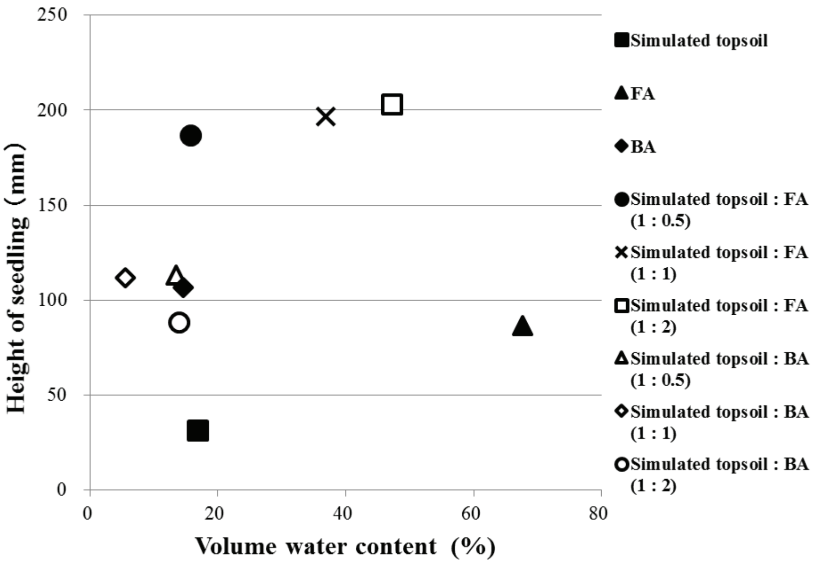


Fig. 7. The relationship between the volume water content and the height of seedlings

Rys. 7. Zależność pomiędzy objętościową zawartością wody oraz wysokością plonów

itation area is discussed by multiple experiments. As a result, it was proved that the physical and chemical conditions of seedbed in the revegetation area which most of soil is classified as acrisol such as Indonesia is improved by the application of coal ash due to their high permeability and alkaline. Furthermore, the plant growth of *Acacia mangium* can be improved by incorporating coal ash into soil with the proper mixture rate though the excessive use of coal ash inhibit the plant growth. As *Acacia mangium* is a common species to apply in the early stage of revegetation in open cut coal mine in Indonesia, it can be said that the results obtained in this study are very useful when the revegetation in Indonesian open cut coal mine is discussed. However, it is necessary to study by using various types of coal ash produced from other power plants because the characteristics of coal ash differ depending on the coal type and specification of power plants.

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Zastosowanie popiołu węglowego do przygotowania podłoża na ziemiach zlokalizowanych w rejonie indonezyjskiej odkrywkowej kopalni węgla

Ilość popiołu węglowego składowanego jako odpady przemysłowe narasta wraz ze wzrostem zapotrzebowania na węgiel w świecie. Mimo tego, że popiół węglowy jest zazwyczaj deponowany na składowiskach wzrasta zapotrzebowanie na jego efektywną utylizację ze względu na ograniczoność miejsc przeznaczonych na jego składowanie. Ponadto, w Indonezji większość gleb jest klasyfikowana jako akrisol, który jest glebą kwaśną i bogatą w ił. Wzrost roślin jest hamowany przez zakwaszenie i niską przepuszczalność i z tego powodu oczekuje się, że popiół węglowy spowoduje poprawę warunków fizycznych i chemicznych podłoża w rejonie wegetacji.
W artykule przedstawiono zastosowanie popiołów węglowych do przygotowania podłoża w rejonie indonezyjskiej kopalni odkrywkowej węgla za pomocą wielu testów laboratoryjnych, testów ługowania kolumnowego oraz testów wegetacji w warunkach laboratoryjnych przeprowadzonych za pomocą Acacia mangium. Ze względu na otrzymane wyniki, sugeruje się, że popiół węglowy może być zastosowany w celu poprawy warunków fizycznych i chemicznych podłoża oraz powoduje poprawę wzrostu Acacia mangium przy odpowiednim jego dozowaniu.

Słowa klucze: Acacia mangium, *popiół węglowy, test ługowania kolumnowego, test wegetacji w warunkach laboratoryjnych, rekultywacja*