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Testing of Bituminous Coal and its Impurity Layers as *in situ* Ameliorant of Physico-chemical Soil Reclamation Properties of Coal Mine

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ABSTRACT

Background: Coal mined reclaimed soil is prone to losing organic carbon content, increased soil acidity, soil structural damage and compact. This degradation of soil properties can be reduced and improved by applying coal and coal impurities as potential ameliorants. This research was aimed at knowing the potential of coal and coal impurity (partings) to improve the physicochemical properties of coal mine reclaimed soil.

Methods: The research was conducted using the randomized block design (RBD) with 3 types of treatment and was in a pot experiment. The tried treatments, among others, are 1) Control (K0), 2) Coal ameliorant (C) and 3) Coal impurity (partings) ameliorant (B). Coal and coal impurity (partings) were both tested with 5 doses, which respectively consisted of 5, 10, 15, 20 and 25 tons ha^{-1}.

Result: The results showed that the application of bituminous coal ameliorant and coal impurity significantly affected on physicochemical soil reclamation properties of coal mines. Both types of ameliorants had an effect on increasing pH and decreasing Al-dd contents but were only significantly different from the control (K0). Amelioration significantly affected the increase in the C-organic, Humic acid and N total content with doses of the applications bituminous coal C5, while coal impurity doses of C4.

Key words: Ameliorant, Bituminous coal, Coal impurity (Partings), Coal mine reclamation, Soil properties.

INTRODUCTION

The degradation of the quality of the physical and chemical properties of soil coal mine reclamation fundamentally includes structural damage, loss of organic carbon, increased acidity and increased bulk density of the soil (Shrestha and Lal, 2011). Damage to the structure of the coal mine reclamation soil occurs due to compaction during the rebuilding of the mine soil body. Post compaction, there is an increase in the value of bulk density (Ajidirman *et al.*, 2019). The increase in acidity of coal mine soil reclamation is caused by exposed parent material as a source of soil acidity to the surface layer (Ajidirman *et al.*, 2019; Gitt and Dollhopf, 1991). Loss of organic matter occurs because the topsoil layer is degraded and lost when it is stripped, stored and backfilled (Hu, 1997).

Soil properties, identiûed as indicators of soil quality, include soil organic matter, total organic nitrogen, total organic carbon, nutrient availability, pH, *etc* (Courtney *et al.*, 2009).

Soil pH is a parameter of soil acidity and is the indicator of mine soil quality (Wei *et al.*, 2014). However, most critical is the accumulation of organic matter in the surface layers because this results in positive changes in physical and chemical soil properties (Sourková *et al.*, 2005). Increasing soil organic carbon is an attempt to change and improve a large number of soil properties resulting in measurable improvements in soil quality and fertility (Bhogal *et al.*, 2009). One of the natural *in situ* carbon resources found in the land coal mine reclamation is coal itself and its impurities (parting). The application of organic carbon-based ameliorants in addition to increasing the organic carbon content in the reclaimed coal mine soil (Akala and Lal, 2000), also reduces bulk density and soil density (Pritchett *et al.*, 2011). The high C-organic content of bituminous coal and coal impurities (parting), makes it a potential ameliorant. Kwiatkowska *et al.* (2008) state that the highest C contents are detected in the soil amended with the highest dose of brow coal. The application of coal ameliorant into the soil has a good effect on increasing the humic acid concentration and increasing the Exchange cation capacity (CEC) of the soil (Giannouli *et al.*, 2009). The carboxylic and phenolic functional groups of humic substances provide reactive sites for cation exchange and form complex compound bonds with metal cations, resulting in an increase in soil pH (Turgay *et al.*, 2011).

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This study aims to determine the potential of bituminous coal and coal impurity (parting) to improve the physicochemical properties of coal mine reclamation soil.

MATERIALS AND METHODS

Coal mine reclamation soil that is used as the object of research comes from PT Bukit Tambi in Batanghari Regency, Jambi Province, Indonesia Republic. This research was conducted from April to November 2020. Soil material is taken and collected from the expanse of coal reclaimed land by peeling regularly to a depth of 20 cm from the surface. The expanse of reclaimed land was stripped of its soil per plot with a plot size of 2×3 meters. The plots were divided into 3 groups with each group consisting of 11 plots. The distance between the plots of taking land is 10 meters systematically. The reclaimed soil that has been collected is prepared in the form of crushing chunks of soil and sifting, then mixed and stirred evenly to obtain homogeneity. The prepared soil was put into each experimental pot as much as 12.5 kg. Bituminous coal and coal impurity (partings) that are used as ameliorants are crushed with a Stone Crusher with a fineness of 2 mm. Ameliorant that has been mashed and sieved with a 2 mm sieve is put into an experimental pot that has been filled with soil according to a predetermined dose. The ameliorant was mixed and stirred in a pot to a depth of 20 cm. Determination of the lowest dose of ameliorant is based on the general dosage of organic carbon-based amelioration. Analysis of the chemical properties of the ameliorant used includes the Organic-C (Curmies method and Spectrophotometer); Total-N (Kjeldahl method), C/N ratio, Humic and fulvic acid content (NaOH extraction and Calorimeter), pH H_2O (pH meter), CaO and MgO total (Total extraction of perchlorate and AAS), P_2O_5 (Total perchlorate extraction and Spectrophotometer), K_2O-total (Total extraction of HCl and Flamephotometer), S-total (Total extraction of perchlorate and AAS), Fe-total (total extraction of perchlorate and AAS) and Al-total (Total perchlorate extraction and Spectrophotometer). Soil samples and ameliorants were analyzed at the Integrated Testing Laboratory of the Vegetable Crops Research Institute, Lembang Bandung, Indonesia and the Chemistry-Soil Fertility Laboratory, Faculty of Agriculture, Jambi University, Indonesia.

The research was carried out in the form of a pot experiment with a randomized block design (RBD) which was placed in an open field garden of the Faculty of Agriculture, Jambi University. The tried treatments, among others, are 1) Control (K0); 2) coal ameliorant and 3) coal impurities (parting) ameliorant. Coal and coal impurity (partings) were both tested with 5 doses, which respectively consisted of 5, 10, 15, 20 and 25 tons/ha. Specific codes according to treatment dose for coal are C1, C2, C3, C4, C5 and Meanwhile, Coal impurities are B1, B2, B3, B4 and B5. Each treatment level was replicated 3 times in the group. The number of trial units is 33 main pots. All main experimental pots (33 pots) were duplicated 3 × 33 pots for each treatment for the validity of the research results. The placement of each experimental pot in the field used the distance between group and rows, which was 30 cm x 25 cm. The physicochemical variables of reclaimed coal soil observed after being treated include bulk density (gravimetric method), C-organic (Curmies method and Spectropho to meter), pH H_2O (pH meter), Al-dd (KCl extraction), N-total (Kjeldahl), C/N ratio, humic and fulvic acid (NaOH extraction and Calorimeter). The effect of treatment on the physicochemical properties of reclaimed coal mine soil was analyzed using analysis of variance (ANOVA) at a significance level of 5 per cent (β = 0.05) and 1 per cent (β= 0.01) with the statistical software SPSS Version 26. Significant differences between treatments on the observed variables were tested using the DMRT (Duncan's multiple range test) with a confidence interval of 95-99%.

RESULTS AND DISCUSSION

Characteristics of bituminous coal ameliorant and coal impurities (Parting)

nalysis shows that the bituminous coal ameliorant sample contained higher total organic C than coal impurities (parting), which was 29.46% versus 19.51%. Content humic and fulvic acid of coal were 0.13 and 2.31%, while coal impurities were 0.10 and 3.41% (Table 1). Zao *et al*. (2020) reported that in coal is 79.83% average total carbon, while in parting is 46.97%. According to (Giannouli *et al*., 2009), the key properties for the assessment of coal as a soil amendment are determined by the content of C-organic and humic substances and mineral materials contained therein. The total mineral element content of CaO, Fe and S is higher in Bituminous coal compared to Parting, respectively 0.98%, 14674 ppm and 0.24% versus 0.81%, 9729 ppm and 0.18% (Table 1). Zao *et al*. (2020) also found that the total mineral content of CaO, Fe and S was higher in coal than in Parting.

Bulk density (BD) of coal mine reclamation soil before and after amelioration

The bulk density of reclaimed coal mine soil in field conditions is 1.50 g cm^{-3} (A0) and very dense (Table 2). According to DeLong *et al*. (2012), the native forest soil showed an average bulk density of 1.05 g cm^{-3}, while the mine soils ranged from 1.70 to 1.84 g cm^{-3}.

The action of crushing chunks and sifting of coal mine reclamation soil caused a decrease in the bulk density from 1.50 g cm^{-3} in field conditions to (1.14-1.19 g cm^{-3}) in each experimental pot before treatment application (Table 2). The application of bituminous coal and coal impurities ameliorant did not significantly affect the soil bulk density. Although it had no significant effect, the application of both types of ameliorants prevented an increase in the bulk density of the soil (Bulk density is still around 1.14-1.20 g cm^{-3}). Kolodziej *et al*. (2016) reported that post-mining land rehabilitated with lignite experienced a very significant decrease in bulk density from 1.53 to 1.17 g cm^{-3}. Troeh and Thompson (1993) suggest that the lighter volume of organic C and the ability to increase the stability of soil aggregates can decrease the bulk density.

Total C-organic of coal mine reclamation soil before and after amelioration

Analysis of variance showed that the application of ameliorant significantly affected the total C-organic of the soil. In the initial conditions before amelioration, the total C-organic soil in each experimental pot ranged from 0.87 to 1.17% (Table 2). There was an increase in total soil organic C after amelioration so the average was 1.14 to 2.07% (Table 2). In the treatments of bituminous coal ameliorants with doses of C5, the effects were significantly different with all of the doses that were applied, including control, with compared total C-organic soil is 2.07% versus 1.01 to 1.69% (Table 2). In each of the types of same ameliorants, the best treatment effect of coal impurities on total C-organic soil is with a dose of B4 (1.69%), while for coal is with a dose of C5 (2.07%).

Table 1: Characteristics of bituminous coal ameliorants and coal impurities (parting) used as a treatment.

Characteristics	Ameliorant type	
	Bituminous coal	Coal impurities (parting)
C-Organic total (%)	29.46	19.51
N-total (%)	0.55	0.42
C/N ratio	54.00	46.00
Humic acid (%)	0.13	0.10
Fulvic acid (%)	2.31	3.41
pH	3.90	4.40
P_2O_5-total (%)	0.02	0.02
K_2O-total (%)	0.01	0.06
CaO-total (%)	0.98	0.81
MgO-total (%)	0.06	0.07
S-total (%)	0.24	0.18
Fe-total (ppm)	14674.00	9729.00
Al-total (ppm)	7060.00	41395.00

There is a tendency that the higher the dose of each type of ameliorant applied, the higher the increase in total soil organic C (Table 2). Sklodowski *et al*. (2006) stated that the Application Rekulter origin of brown coal significantly increases the organic carbon content of Haplic Luvisols.

Soil acidity (pH) of coal mine reclamation soil before and after amelioration

The pH value of the reclaimed coal mine soils in each experimental pot before being treated varied from pH 4.34 to 4.57 (Table 2). This soil is strongly acidic. Mukhopadhyay and Maiti (2011) stated that the cause of soil acidity in coal mining is the placement of acidic overburden material in the soil surface layer. Soils with a pH<5 are classified as strongly acidic (Tan, 2011). The application of bituminous coal ameliorant and coal impurity had a significant effect only on increasing the soil pH compared with control (K0), which is pH 4.97 to 5.05 versus pH 4.80. The highest effect on the pH value of the soil occurred at a dose of 20 tons/ha (C4 and B4 treatments).

The increase in soil pH that was not significantly different between the two ameliorants and doses was probably because both were acidic due to the presence of Sulfur, iron and aluminum they contained. However, the application of both ameliorants has resulted in an increase in soil pH. The application of ameliorant originating brown coal significantly increased the pH value of acidic haplic luvisol soils from 4.6 to 6.0 (Sklodowski *et al*., (2006) and contaminated soil with heavy metals from 5.88 to 6.11 (Push, 2007).

Exchangeable aluminium (Al-dd) of coal mine reclamation soil before and after amelioration

The total aluminum is the the sum of exchangeable aluminum (Al-dd) and non-exchangeable aluminum. The Al-dd content of the reclaimed coal mine soil in each experimental pot before being treated ranged from 5.97-

Table 2: The average physicochemical properties of coal mine reclamation soil before and after treatment application in field conditions and pot experiments.

Treatment code	Before treatment application				After treatment application			
	BD (g cm^{-3})	C-org total %	pH	Al-ddcmol (+)kg^{-1}	BD (g cm^{-3})	C-org total%	pH	Al-ddcmol (+)kg^{-1}
A0	1.50	-	-	-	-	-	-	-
K0	1.17	0.91	4.49	6.39	1.18a	1.01f	4.80b	5.55ab
B1	1.17	1.00	4.42	6.20	1.18a	1.14ef	4.97a	4.75bc
B2	1.14	1.17	4.60	5.98	1.15a	1.30de	5.03a	5.45abc
B3	1.18	0.87	4.36	5.96	1.14a	1.43cd	5.01a	4.76bc
B4	1.18	1.10	4.44	6.22	1.16a	1.69b	5.04a	4.84abc
B5	1.19	1.03	4.39	6.22	1.16a	1.59bc	4.99a	5.32abc
C1	1.18	0.96	4.57	6.25	1.18a	1.20ef	4.96a	5.70a
C2	1.16	1.01	4.65	6.49	1.15a	1.54bc	5.00a	5.00abc
C3	1.14	1.04	4.34	5.97	1.13a	1.47cd	5.04a	4.61c
C4	1.15	1.00	4.53	5.99	1.20a	1.55bc	5.05a	5.30abc
C5	1.19	1.07	4.57	5.97	1.15a	2.07a	4.98a	4.80abc

A0 = Condition of field reclamation; the numbers followed by the same letter in the same column are not significantly different according to the DMRT test with a 5% confidence level.

Table 3: The average content of total-N, C/N ratio, humic acid and hulvic acid on coal mine reclamation soil after application of treatment.

Treatment code	N-total %	C/N ratio	Humic acid (%)	Fulvic acid (%)
K0	0.05d	20.13de	0.07e	0.33a
B1	0.06bcd	18.94e	0.15cde	0.28a
B2	0.06bcd	21.61cde	0.18bcde	0.25a
B3	0.06bcd	23.89bc	0.28abc	0.23a
B4	0.07abc	25.53ab	0.44a	0.17a
B5	0.06abc	25.02abc	0.27abc	0.25a
C1	0.06cd	21.33cde	0.10de	0.29a
C2	0.07abc	23.02bcd	0.21bcde	0.31a
C3	0.07abc	22.43bcde	0.25bcd	0.19a
C4	0.07ab	22.10bcde	0.34ab	0.20a
C5	0.07a	28.26a	0.35ab	0.23a

The numbers followed by the same letter in the same column are not significantly different according to the DMRT test with a 5% confidence level.

6.39 cmol (+) kg^{-1} (Table 2). Application of all doses of ameliorants, only one dose significantly affected the decrease in Al-dd content is C3. Bituminous coal of ameliorant at a dose of 15 tons ha^{-1} (C3) gave the best effect in reducing Al-dd content from 5.97 to 4.1 cmol (+) kg^{-1} and was significantly different from C1 and K0 (Table 2).

The effect of treatment in reducing the Al-dd content is highly suspected dependent on the Al-dd content in each experimental pot before being given treatment. The Al-dd content of the coal mine reclamation soil is still very high after being treated, although there has been a decrease compared to before. The decrease in Al-dd content with the addition of bituminous coal ameliorants and coal impurities illustrates that there has been the complexation of Al by organic C. Berggren and Mulder (1995) stated that at pH<4.1 complexation reactions with soil organic matter seemed to control Al^{+3} activity. The solubility of Al^{3+} in the soil will decrease drastically starting from pH > 5.5-7.0. Slightly acidic soil with a pH of 5.5-5.7 contains very little Al-dd, *i.e.* 0.06-0.66 cmol(+)/kg (Yerima *et al.*, 2020).

Humic substance and total-N of coal mine reclamation soil after amelioration

Table 3 shows that the humic acid content of the reclaimed coal mine soil increased with increasing the dose of ameliorant applied, except for B5. The application of ameliorant significantly affected the increase in humic acid content, but not the fulvic acid content. In each of the same types of ameliorants, the best effect of coal impurity treatment on soil humic acid content was with a dose of B4 (0.44%), while in the treatment of coal with a dose of C5 (0.35%). Dosage of C5 of bituminous coal ameliorant has a significant effect in increasing the total N and is in line with the increase in C-organic and humic acid.

The increase in humic acid content comes from the decomposition of bituminous coal and given coal impurities. Changes in the value of the C/N ratio indicate that weathering has occurred. Humic acid can be obtained from any source of organic matter, among them peat and coal at different maturation degrees. Coal contains up to 50 % humic substances (HS), the majority of which is humic acid (Krumins *et al*., 2017).

CONCLUSION

Ameliorant origin of bituminous coal and material coal impurity layer (parting) can improve some physicochemical properties of coal mine reclamation soil. The application of bituminous coal ameliorant and material from coal impurity can reduce bulk density, acidity, exchangeable aluminum content and increase organic carbon, humic acid and N-total in coal mine reclamation soil. Improvement of the physicochemical properties of the coal mine reclamation soil after amelioration, in turn, creates a favorable growing environment for plants.

Conflict of interest: None.

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