The potency of *Cassia siamea* as phytostabilization in post-mining land reclamation

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Abstract. Revegetation for reclamation is a strategic effort to overcome the negative impacts of coal mining. The growth of reclaimed vegetation has a positive impact in reducing soil density so that it is suitable for the growth of food plants, and also can increase the content of soil organic matter. One of the efforts to restore the function of post-mining land is by planting legumes, one of the species is *Cassia siamea* (*C. siamea*). The method used is a literature study. Literature searches were using the Google Scholar, Research Gate, and Science Direct databases. From the results of a literature search, *C. siamea* can accumulate heavy metals as phytostabilization by reduces the mobility and presence of pollutants in the soil by accumulating the metallic trace elements (MTE) into the roots. These plants produce proline, a substance that is produced when drought occurs so that the inside of the plant does not suffer from differences in water concentrations. *C. siamea* can restore and improve the physical and chemical properties of the soil to become more fertile and rich in nutrients with Legume-Rhizobia Symbiosis and also has a high RMSI (> 0.500), this value is preferable for reclamation of post-mining land.

1. Introduction
The development of Indonesian coal production in 2009-2018 increased significantly with the production of 557 million tons in 2018. From the total production, the percentage of coal export reached 357 million tons (63%) which were mostly exported to meet the demand in China and India. The high percentage of Indonesia’s coal export has made Indonesia one of the biggest coal exporters in the world besides Australia [1]. Coal mining leads to the removal of vegetation cover and topsoil, material dumping, mine fires, etc. These mining activities bring about dramatic physical changes and disruptions of local ecosystems. In post-mining land, there is a decrease in the quality of the topsoil, which is
characterized by damage to the soil structure, accelerated erosion, excessive washing, soil compaction, decrease in soil pH, accumulation of heavy metals in the soil, depletion of organic matter, decreased plant nutrients, reduction cation exchange capacity, decreased microbial activity [2,3]. In addition to severe land degradation, coal mining harms biodiversity [4].

Fortunately, in contrast to different industries, mining is a brief consumer of land, and right reclamation can repair the productiveness of land and may bring a better landscape [5]. In the context of mining, reclamation often refers to a general process in which mined land is returned to some form of useful use [6]. The growth of reclaimed vegetation has a positive impact in reducing soil density so that is suitable for the growth of food plants, besides it can also increase the content of soil organic matter [7-10]. One of the efforts to restore the function of post-mining land is by planting legumes [11]. C. siamea is a species of legume that is widely used for revegetation in the reclamation of post-mining land [4].

C. siamea is also known as Senna siamea, kassod tree and johar is a type of plant native to Southeast Asia which spread from Indonesia to Sri Lanka [12]. Siamea refers to the land of origin namely Siam or Thailand. The clinical research and assessment articles on C. species recommended a full-size organic ability of those plants. C. siamea can survive in extreme conditions in post-mining land and can accumulate heavy metals in post-mining areas [13]. Many compounds inclusive of anthraquinone glycosides, naphthopyrone glycosides, phenolic compounds, flavonoids were stated from different species of this genus [8, 14, 15].

C. siamea has a high Reclaimed Mine Soil Index (RMSI) value. RMSI reflects the contribution of tree species to reclamation rates [4]. In Indonesia, the reclamation and revegetation of post-mining areas with C. siamea is carried out by PT. Kaltim Prima Coal (PT. KPC) was started from 1996 to 2009 with an area of more than 5000 ha. Revegetated plants in the post-mining area of PT. KPC has now formed a forest ecosystem and has been able to provide forest functions [16]. The purpose of this study is to know C. siamea can become a tree species for post-mining land reclamation.

2. Method
The type of data used by the author in this study is secondary data obtained from journals, documentation books, and other references related to the study of revegetation plant selection for the success of reclamation of post-mining land. The data that has been obtained is then analyzed using descriptive analysis methods. The descriptive analysis method is a research method that is carried out by describing the facts that are later followed by analysis and providing adequate understanding and explanation. The research data is then presented in a systematic order, beginning with the introduction of C. siamea, the ability to survive in post-mining land and to accumulate heavy metals, Legume-Rhizobia symbiosis, and Reclaimed Mine Soil Index (RMSI) of C. siamea.

3. Results and discussion

3.1. C. siamea can survive in post-mining land and the ability to accumulate heavy metals
C. siamea is a fast-growing annual tree, 10-20m tall. The trunk is round, erect, woody, with rough skin, branching, and dirty white. The tips and bases of the leaves are rounded, flat edges, with 3 7.5 cm long leaves and 1-2.5cm wide. These plants can grow in a wide range of climates with an average temperature of 20-31 °C and with a dry season of 4-8 months. C. siamea can grow in rainfall ranges of 500-2800 mm. This means it is resistant to areas with low rainfall (< 1000 mm/year) [17].

One of the characteristics of plants that can adapt to dry conditions is the ability of plants to produce proline. Proline is a substance that is produced when drought occurs to prevent dryness of the plant body. It has been reported in Hendrati and Hidayati (2014) that the resistance of C. siamea plants in dry conditions is shown in the ability to produce proline at 20 days of drought. The C. siamea test results have been carried out in dry conditions both under controlled conditions and in three field conditions when compared to control plants (watered normally) C. siamea has only decreased in advanced drought conditions, namely 20-30 days of drought without water at all (soil moisture content is 20%). This is
shown in various characters including growth, leaves, roots, and transpiration (water evaporation). This means that *C. siamea* responds to the pressure of the drought. Different seed sources will generally respond differently. This is due to the adaptability that these plants have developed to their original conditions so that they can survive and it is estimated that the plants have developed adaptations to dry conditions for generations [18].

*C. siamea* can accumulate metals in post-mining areas in a stable manner. *C. siamea* has adequate heavy metal tolerance mechanisms (hyperactive antioxidant enzymes, accumulation of non-protein thiols (metal detoxification peptide index-phytocrelation), and accumulation of cellular antioxidants) [19]. Heavy metal transfer or decontamination from the environment through plants occurs by several mechanisms, namely rhizodegradation, phytostabilization, phytodegradation, phytoaccumulation/phytoextraction, and phytovolatilization. *C. siamea* is suitable for phytostabilization, this phytostabilization/phytoimmobilization mechanism uses certain plants to stabilize contaminants in a polluted land. This mechanism reduces the mobility and bioavailability of environmental pollutants and thus prevents their transfer to groundwater or the food chain [20].

*C. siamea* bind contaminated soil which results in the immobilization of toxic contamination. Planting *C. siamea* attempts to reduce the mobility and presence of pollutants in the soil by accumulating the MTE (metallic trace elements) into the plants’ roots. MTE is bound to various soil constituents and exists in various chemical forms. MTE is primarily retained in the soil's solid phase, where they are distributed in the various organic and mineral fractions. They are found in clays and organic matter in exchangeable form (phytodisponible), as complexes, or associated with organic molecules. The main criterion that influences MTE mobility and interactions with soil compounds is their chemical speciation. The bioavailability and speciation of MTE must be assessed to determine the environmental impact of contaminated soils. They are controlled by soil physicochemical parameters such as pH, redox potential, texture, organic matter content, and biological parameters (plants and microorganisms) [21].

As an adaptive mechanism, the plant accumulates a large number of nitrogenous compounds such as proline or polyamines to protect itself from the harmful effects of heavy metals [22, 23]. Other than preventing dryness, proline can protect plants from the harmful effects of heavy metals. Proline also plays a key role as an osmolyte, electron sink, radical scavenger, component of the cell wall, and stabilizer of macromolecules [24]. Generally, under heavy metal stress, proline accumulation increases, thus improving stress tolerance in plants. According to Gupta (2011) the proline concentrations in *C. siamea* near the industrial area were significantly higher (p < 0.01, 0.05) than in control plants [25]. Proline's higher accumulation and role in stress reduction can be explained in part by its distinct chemical properties when compared to other amino acids, proline being a water-soluble amino acid exists as in a zwitterion state having both positive charge and weak negative charge in N groups and a carboxylic acid, respectively [23].

SEM studies confirm that leaf morphology (epidermis, trichomes, and stomata) of *C. siamea* helps accumulate toxic metals from deposited particulate matter (PM) and entrap PM in respirable suspended particulate matter (RSPM) range (in both fine and coarse fractions) [26]. The other studies showed that 30 (µg/g) Cd metal was found in *C. siamea* leaf; another study also showed the adsorption capacity of Cd (II) ions in *C. siamea* increased from 2.48 to 9.81 mg/g at pH 7 in aqueous solutions, in addition to Cd, accumulation of Cr content found in the leaf and stem of *C. siamea*, as much as 1225 ppm Cr was found in the leaf, and 796 ppm Cr was found in stems, the results of this study confirmed that *C. siamea* can accumulate heavy metals [27-29].

3.2. *Legume-Rhizobia symbiosis in C. siamea*

*C. siamea* is a species of legume that is widely used for revegetation in the reclamation of post-mining areas [4]. Legumes are plants that have root nodules that function as nitrogen suppliers. In the root nodules, there is rhizobium bacteria carry out symbiosis with legume plants. The 3 bacteria reside, reproduce, and carry out nitrogen fixation activities free of air [30–33]. The symbiotic nitrogen fixation model of legumes by rhizobia is shown in figure 1.
Rhizobium bacteria enter into symbiotic associations with leguminous plants, producing differentiated bacteria enclosed in intracellular compartments called symbioses within nodules on roots (Figure 1). The nodules and associated symbioses are structured for efficient nitrogen fixation. While this interaction is beneficial to both partners, it occurs with rigid rules that are strictly enforced by the factory. Entering the root, cells need proper recognition of signaling molecules. Rhizobium factor nodules and this recognition trigger a cascade of events, including polarized root-hair tip growth, invagination associated with infectious bacteria, and cell division in the cortex, which leads to meristem nodules. The enforcement of terminal differentiation of bacteria in the nodules of some legumes has highlighted the installation order of the infectious process [8]. This can result in loss of bacterial viability while enabling effective nitrogen fixation. Therefore, legume plants can restore and improve the physical and chemical properties of the soil to become more fertile and can make the soil rich in nutrients.

Here, we review the plant mechanisms that allow bacterial infection and promote nodule formation, as well as details on how this intimate relationship plays out in nodule cells where the complex exchange of regulatory metabolites and peptides forces the bacteria into a nitrogen-fixing organelle to facilitate the rehabilitation process as shown in Figure 2. The nitrogenase system can break the strong triple bond in the dinitrogen molecule. It is estimated that at least eight moles of electrons and sixteen moles of ATP hydrolysis are required to reduce one mole of dinitrogen as seen in Equation 1 [35-36]. The formula of nitrogenase reaction reveals that for one mole of dinitrogen reduced, one mole of hydrogen gas is evolved:

$$\text{N}_2 + 8e^- + 8 \text{H}^+ + 16 \text{ATP} \rightarrow 2\text{NH}_3 + \text{H}_2 + 16 \text{ADP} + 16\text{Pi}$$ [37]

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Molecular nitrogen is reduced in multiple electron transfer reactions during biological nitrogen fixation, resulting in the synthesis of ammonia and the release of hydrogen. Following that, ammonium is used in the next synthesis of biomolecules. This reduction of molecular nitrogen to ammonium is catalyzed by the nitrogenase enzyme complex in all nitrogen-fixing organisms in an ATP-dependent, high-energy-consuming reaction (Figure 2) [39]. Electrons are transferred from reduced ferredoxin (or flavodoxin) to molybdoferrredoxin via azoferrredoxin. Every mole of fixed nitrogen needs 16 moles of ATP hydrolyzed by the NifH protein. The NH₃ produced is utilized in the synthesis of glutamine or glutamate, respectively, for N-metabolism. NifJ is pyruvate flavodoxin/ferrodoxin oxidoreductase, NifF(Flavodoxin/Ferredoxin) [38].

3.3. Reclaimed mine soil index (RMSI) C. siamea

Trees are the major C sink in the secondary forest and can account for up to 75% of the total ecosystem C pool [40]. Therefore, an accurate estimate of tree biomass is important to quantify the C collection capacity of tree species. The development of a deep roots system can transfer C into the deeper layer and may have significant impacts on the biogeochemical C cycle [10].

Any reclamation program aims to maintain a good substrate for better plant establishment and growth. The success of reclamation can be evaluated with Reclaimed Mine Soil Index (RMSI) as this index is highly correlated with plant performance data. Principal component analysis (PCA) was used to obtain the RMSI which was used for ranking the suitability of the species. By using PCA it was found that soil CO₂ flux, dehydrogenase activity, organic carbon, coarse grain content, and soil moisture are the most important characteristics controlling the soil condition of the reclaimed coal mine soil. The above characteristic observations were converted to scores (0 to 1.00) without units and the scores were integrated into RMSI. The RMSI value was validated by regression analysis using plant growth parameters (aerial height, diameter at breast height, and canopy cover) for each species. RMSI using an equation that refers to the value of soil parameters, soil microbial properties, the average value of each parameter according to the age of different reclaimed coal mine dumps, the value of the slope of the equation soil parameters value. The higher the index score, the better the soil quality or functionality [4].

Tree species with higher RMSI values could be recommended for revegetation of degraded coal mining areas [41]. C. siamea has a high RMSI (>0.500), this value is preferable for reclamation of post-coal mining areas. Principle component analysis of soil properties under different tree species growing in reclaimed sites reveals that soil CO₂ flux, coarse fraction, dehydrogenase activity, and organic carbon are the major factors that influence the overall development of soil health. Overall, these physicochemical and biological properties can be considered biomarkers of the reclamation status and quality of soil [4].

4. Conclusions

C. siamea has potency as phytostabilization in post-mining land reclamation with the ability to survive in post-mining land and to accumulate heavy metals by reduces the mobility and presence of pollutants in the soil by accumulating the metallic trace elements (MTE) into the roots. These C. plants produce proline, a substance that is produced when drought occurs so that the inside of the plant does not suffer from differences in water heavy metals from the environment. With Legume-Rhizobia Symbiosis in C. siamea can restore and improve the physical and chemical properties of the soil to become more fertile, and also has a high RMSI (> 0.500) which is preferable for reclamation post-mining land of ex-coal mining areas.

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