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by Mulyadi Makrawie

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Research Article

Morphological characteristics of top soiling in the reclamation areas of post-coal mining at Kutai Kartanegara and Kutai Timur Regencies

Mulyadi*, Makhrawie

Faculty of Agriculture, Mulawarman University, Gedung C-8, Jalan Pasir Balengkong Kampus Gunung Kelua Samarinda East Kalimantan, Indonesia

*corresponding author: mulyadi_srm@yahoo.com

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Abstract

This study aimed to obtain information about the impact of different morphological characteristics and genesis at some reclamation sites after coal-mining activities. Two coal sites were chosen as study areas, i.e. the Separi site, which is located in Kutai Kartanegara regency and the Bengalon site, located in Kutai Timur Regency. A descriptive research method was used to identify the morphological characteristics of reclamation sites at different times (chronosequence). The results showed that in-situ weathering, indicated by soil leaching caused by rainwater infiltration, led to the formation of the Ah horizon more than two years after the reclamation activity. The process of material removal and disposal (cutting, filling, transporting and levelling) from coal mining operations tends to accelerate the decomposition of parent soil material and promote the formation of pre-cambic horizons. The soils used (A, B, and C horizons) for the topsoil of the reclamation site were initially Typic Hapludults and Typic Dystropepts, although Typic Tropaquents and sandy parent materials were also used. Due to the impermeable layers of overburdening where water channels in the soil profile and deeper layers have not yet formed as human-made soil and landscape (artificial) cause rainwater to fail to infiltrate deeper layers so that with less heavy rain, the groundwater level will rise to the surface and the land will become waterlogged/flooded.

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Introduction

Almost all coal-mining activities in East Kalimantan use an open-pit mining system. The process starts with land clearing, removing the surface layer of topsoil and subsoils, moving the overburden, and extracting the coal (Noviyanto et al., 2017). In general, an open-mine process involves forest-logging, eroding soil layers (Zulkarnain et al., 2014), the formation of sinkholes (dredging), and backfilling, and that process can cause severe environmental damage, which ultimately harms the fertility of the soil as the natural medium for plant growth (Sopialena et al., 2017). The natural landscape has been disturbed and damaged, along with the destruction of biodiversity within ecosystems through the removal of natural soils, plants, animals, microbes, etc. (Hapsari et al., 2020). The damage caused by activity such as digging and transporting stripped materials spreads to the dumping area, either a former mine (in a pit) or steep valleys (external pit), to form a planned topography and elevation (landscape). The bedrock (overburden materials) located above the coal seam is removed using heavy equipment (excavators) to be used as overburden material. The placement of overburdened materials according to their geochemical characteristics is one of the most important activities in this landscaping process (Pratiwi et al., 2021). Using topsoil and subsoil or changing the position of parent materials and bedrock on the surface on a large scale has an impact on the deterioration of soil quality (Khaidir et al., 2019), and overburden materials are structureless, with high bulk density, due to the movement of heavy machinery that obtains, contains and elevates the concentration of trace metals (Pratiwi et al., 2021); their characteristics hamper water circulation, limiting their capability to support the growth of plant roots.

The body of reclamation soil in parent materials and bedrock, which differs between layers, has fluctuating properties based on the age of reclamation (Khaidir et al., 2019). The rate of land degradation can be measured through the morphological characteristics of the soil and landscape (Aji et al., 2020). Aditya et al. (2020) stated that information on soil characteristics and morphological properties could be determined by observing soil profiles. A soil profile is a historical record of all the soil-forming factors and processes which form a snapshot of soil development.

The study aimed to identify the effect of soil layering of the disposal area over time on soil morphology and its characteristics according to land reclamation. The results of this study serve as basic information for the optimal use of revegetation as a conservation strategy and rehabilitation. The restricted result recommendation is to conduct an anticipation program given the dangers of the impact that occurs due to erosion and sedimentation on water quality and soil (Nasrudin, 2021), such as a study of soil morphological characteristics.

Materials and Methods

This study was carried out on reclamation areas of post-coal mining with different ages of reclaimed plants (<2 years, 2-5 years and >5 years). The area is located in Separi Site Kutai Kartanegara Regency (geographical position at $117^{0}12'53"$ EL and $0^{0}13'21"$ SL for reclaimed plants <2 years; $117^{0}13'46"$ EL and $0^{0}12'8"$ SL for reclaimed plants 2-5 years, and $117^{0}08'12"$ EL and $0^{0}17'42"$ SL for reclaimed plants >5 years) and Bengalon Site Kutai Timur Regency (geographical position at $117^{0}36'15"$ EL and $0^{0}48'37"$NL for reclaimed plants <2 years, $117^{0}35'05"$ EL and $0^{0}49'02"$ NL for reclaimed plants 2-5 years, and $117^{0}34'59"$ EL and $0^{0}50'5"$ NL for reclaimed plants >5 years) as shown Figures 1 and 2.

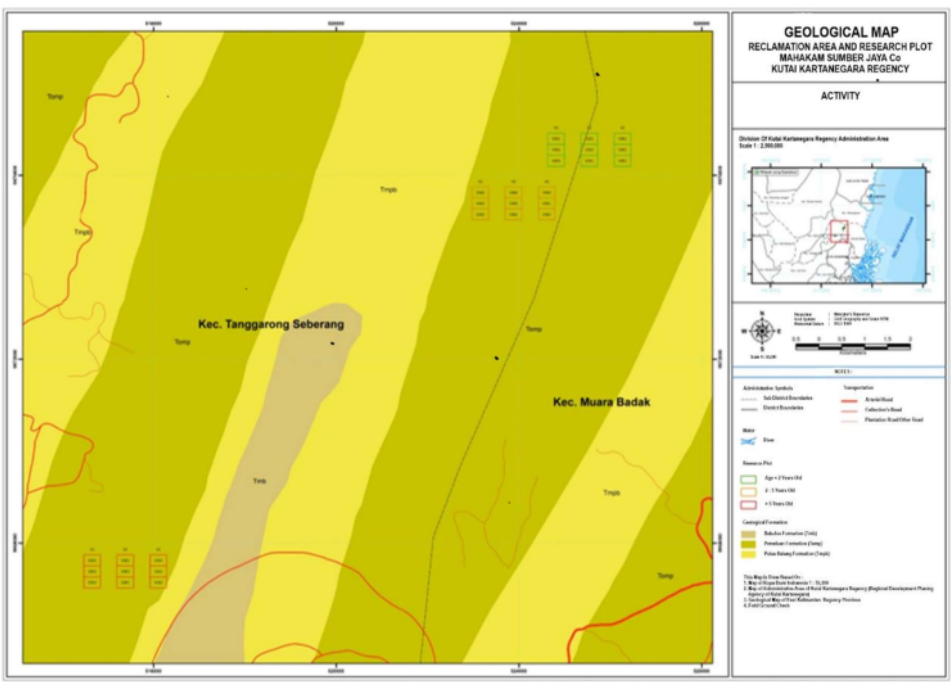

Figure 1. Research location of Separi site showing the geology of coal mining.

Representatives soil profiles or mini-pit for each reclamation area with different plant ages were located in an area of 400 m^2 (20 m x 20 m). Such soil profiles or mini-pits were made at a depth of ≥30 cm or up to the limit of the depth of reclaimed landfills, followed by drilling the soil to a depth of 140 cm. Observations and descriptions of existing soil profiles or mini pits and horizons were established using a Manual Field Book for Describing and Sampling Soils Ver. 3 (USDA-NRCS, 2012). Soil samples were taken on each identifiable soil horizon up to the overburden (OB) layer and then analyzed using the Soil Survey Laboratory Information Manual (Soil Survey Staff, 2011).

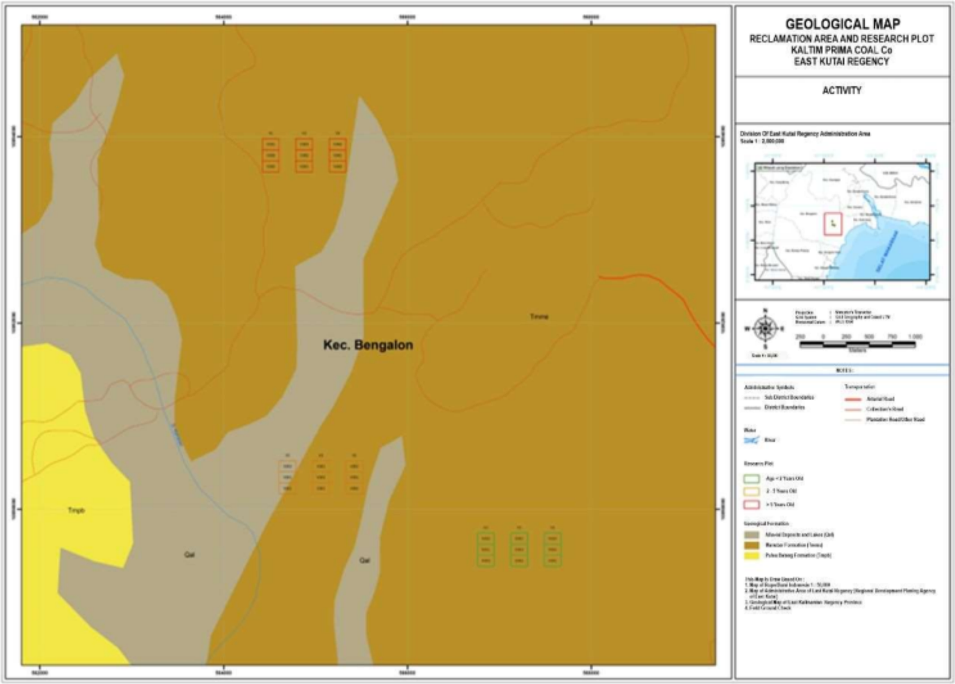

Figure 2. Research location of Bengalon site showing the geology of coal mining.

Soil parameters analyzed were as follows: (1) texture (clay, silt and sand content, pipette), (2) two coarse fragments (fraction >2 mm, sieving), (3) soil reaction (pH H_2O and pH KCl, digital pH meter), (4) organic carbon (Walkley and Black), (5) total nitrogen (Kjeldahl), (6) available P and K (Bray I), (7) base cations and cation exchange capacity (1 M NH_4OAc, pH 7), (8) exchangeable aluminium (1 N KCl extraction), and (9) base saturation and aluminium saturation (calculation). The profile development of the soil is based on the presence of a soil horizon (horizontal differentiation), physical and chemical compositions ranging from the upper soil layer, the lower soil layer to the parent material layer or OB layer, development of colour, soil structure and consistency, effective soil depth and groundwater depth or soil drainage class.

Results and Discussion

Coal mining is carried out using an open-pit mining system that involves dredging the topsoil and subsoil; then, coal material is taken. Biophysical damage sightings on ex-coal mine land in two sites (Separi and Bengalon) of two regencies in East Kalimantan Province as a result of coal-mining land-clearing activities.

Soil morphological characteristics of land reclamation area (Separi site)

Morphological characteristics <2 years

The slope class of the land reclamation area <2 years after planting is classified as wavy, which is between 5-7% and 6-10%, with soil colour from yellowish-brown or grey-brown to grey with an angular to the massive structure. Soil generally comes from the parent material of a mudstone/shale type, where the properties of the parent material are still commonly found in the soil profile in the form of grey mudstone fragments. Genetic characteristics such as colour, texture, and the soil structure identified are pedogenetic properties of the original soil from where the soil is taken, especially in B and C soil horizons. The layers of horizons found in the soil profile are generally A–C, BC–C, A–BC, and A–OB–BC. The weathering process of ex-mine land in this area is mainly physical and biological. A mechanical process causes the disintegration of consolidated massive rock into similar pieces and is a change brought about by living agents, which are mainly controlled by the prevailing environment and are responsible for both physical and chemical changes (Boul et al., 2011). The characteristics of soil horizons show that the parent material layer is very dominant in the soil, even up to the soil surface. The OB layer in subplot U1K1/II dominates from the surface layer to a thickness of 100 cm, and in subplot U1K1/III, after the A horizon, it is covered by an OB layer and another soil horizon (BC1 and BC2). Shale is a sedimentary rock, a fine-grained detrital rock made up of clay and silt-sized particles (Singh and Chandran, 2015), that forms from the compaction of silt and clay-size mineral particles, commonly called mudstone.

The soil layer, which was taken from the swamp (U1K1/I) forms a yellowish-brown to grey A–C layer with brown mottles of about 30-60% and crackers (Figures 1 and 2) that formed due to the oxidization of swamp/wetland soils (Figures 3 and 4), as represented in the soil profile <2 years old. Marshland soils can be identified using soil morphological indicators, such as the accumulation of organic matter, greyed soil colours, soil mottling, iron or mangan segregations, oxidizing root channels, and soil pore-lining sand reduction of sulfur and carbon. The OB layer is generally massive and compact/sticky, which is the cause of water locking so that it cannot be penetrated by water (Figure 5). According to Arisnawan (2015), changes in the water content of clay shale from air-dry to saturated conditions have a significant range of changes in physical, mechanical, and dynamic parameter values after the clay shale changes. It is suspected that this causes the OB layer to become compact so that an impermeable layer is formed. Soil reaction (pH H_2O) at a depth of <10 cm, 10-30 cm, and >30 cm soil samples composited at less than 2 years old is classified as acid, with very low to low organic matter content (<2 years old) at 0-30 cm soil thickness and low at more than 30 cm of soil thickness. Cation exchange capacity (CEC) was low (<2 years old), and classed from the surface to more than 30 cm of soil thickness.

Figure 3. Topsoil from marshland and crack formation (solum, <2 years old).

Figure 4. Topsoil from marshland and crack formation (crack formation, <2 years old).

In more detail, the morphological characteristics of the land in this reclamation area are presented in Table 1. Reclamation soils (<2 years) are formed from different soil materials and not arranged sequentially as topsoil, subsoil, parent material, and bedrock. The different colours (change) from grey to yellowish-red do not indicate the occurrence of epipedon because wet-dry fluctuations in rainfall do not migrate soil particles which decreases soil materials (Khaidir et al., 2019). Munawar (1999) reported that the topsoil of open-pit coal mining is very heterogenous and has high fill weight, low total pores, low N and P content, high Ca and Mg reserves and a low soil-microbial population, compared to forest land surrounding it. The application of compost to ex-mineral sand mine land was unable to improve the soil structure after reclamation had been carried out for two years (Schroeder et al., 2010).

Figure 5. The OB layer is impermeable to water and roots develop in fractures (groundwater table (impermeable) 2–5 years old).

Morphological characteristics at 2-5 years

The slope class at 2-5 years old in the Separi mine land reclamation area is relatively gentle when compared to <2 years old (Table 2). Soil colour is from yellowish-brown to brownish-yellow, with angular to massive soil structure. The colour and structure of the soil are properties of the original soil (BC and C horizons).

Table 1. Morphological characteristics of reclamation area of Separi site (<2 years).

Sample	Slope (%)	Characteristics of Dumping Area			Morphological Characteristics		Chemical Properties*		
		Origin	Thick (cm)	Horizon	Colour	Structure	pH (H_2O)	OM (%)	CEC (meq/100g)
U1K1/I	5-7	In situ process	3	A	10YR 6/4	S-blocky			
		Swamp clay	3-115	C	7.5YR 5/6	S-blocky			
		OB layer	>115	-	Mottling	Massive			
U1K2/I	5-7	Soil + gravelly	0-30	BC1	10YR 7/4	Massive	5.08	0.36	14.45
		Soil + gravelly	30-120	BC-C	10YR 5/4	Massive	(U1K1)	(U1K1)	(U1K1)
		OB layer	>120	-	-				
U1K3/I	5-7	BC layer	0-25	BC1	10YR 5/4	S-blocky			
		BC layer	25-135	BC2	10YR 7/6	S-blocky			
		OB layer	>135	BC3	-	Massive			
U1K1/II	7-10	OB layer	0-100	-	-	-			
U1K2/II	6-10	In situ process	0-6	A	10YR 7/4	S-blocky			
		BC layer	6-150	BC	10YR 6/6	Massive	5.24	2.54	17.28
		OB layer	>150		10YR 6/1	Massive	(U1K2)	(U1K2)	(U1K2)
U1K3(II)	5-8	In situ process	0-2	-	10YR 5/2	S-blocky			
		BC layer	2-140	A	10YR 6/6	S-blocky			
		OB layer	>140	BC	10YR 6/1	Massive			
U1K1/III	6-10	In situ process	3/10	-	10YR 6[illegible]	S-blocky			
		BC/OB layer	3/10-60	A	5YR 5/2	Massive			
		OB layer	>60	BC/OB	10YR 6/1	Massive			
U1K2/III	5-8	In situ process	0-9	-	10YR 6/2	S-blocky	5.38	3.01	19.35
		BC layer	9-113	A	10YR 6/6	S-blocky	(U1K3)	(U1K3)	(U1K3)
		OB layer	>113	BC	10YR 6/1	Massive			
U1K3/III	8-10	In situ process	0-4	-	10YR 7/3	S-blocky			
		BC layer	4-70	A	10YR 7/6	S-blocky			
		OB layer	>70	BC	10YR 6/1	Massive			

Notes: *OM = organic matter, CEC = cation exchange capacity.

Table 2. Morphological characteristics of the reclamation area of Separi site (2-5 years old, U2).

Sample	Slope (%)	Characteristics of dumping area			Morphological Characteristics		Chemical Properties*		
		Origin	Thick (cm)	Horizon	Colour	Structure	pH (H_2O)	OM (%)	CEC (meq/100)
U2K1 (I)	2-3	In situ process	5	A	10YR 5/4	S-blocky			
		BC layer	5-83	BC	10YR 6/6	S-blocky			
		OB layer	>83	-	-	Massive			
U2K2 (I)	0-2	In situ	4/23	Ah	YR 3/3	S-blocky	6.61	1.51	12.19
		BC layer	4/23-85	BC	10YR 5/2	S-blocky	(U2K1)	(U3K1)	(U2K1)
		OB layer	>85	-	10YR 6/1	Massive			
U2K3 (I)	0-2	In situ process	0-6	Ah	10YR 6/3	S-blocky			
		BC layer	6-18/120	Bw/BC	10YR 6/6	S-blocky			
		OB layer	>120	-	10YR 6/1	Massive			
U2K1 (II)	2-5	C layer	0-18	C	YR 3/3	Massive			
		C layer	18-100	C	10YR 4/1	Massive			
U2K2 (II)	2-5	In situ process	0-2	A	10YR 5/3	S-blocky	5.17	1.68	12.69
		BC stone	2-41/100	BC	10YR 5/4	S-blocky	(U2K2)	(U3K2)	(U2K2)
		OB layer	>100	-	10YR 6/1	Massive			
U2K3 (II)	5-8	In situ process	0-5	A	5YR 5/6	S-blocky			
		BC layer	5-21/60	BC	10YR 5/6	S-blocky			
		OB layer	>60	C	YR 6/1	Crumb			
U2K1 (III)	2-3	In situ process	0-5	A	10YR 5/6	S-blocky			
		BC layer	5-21/83	BC	10YR 6/6	S-blocky			
U2K2 (III)		OB layer	>83	-	10YR 6/1	Massive	5.04	1.45	17.47
	0-2	In situ process	0-4	Ah	10YR 3/3	S-blocky	(U2K3)	(U3K3)	(U2K3)
		BC layer	4-23/85	BC	10YR 5/2	S-blocky			
U2K3 (III)	0-2	OB layer	>83	-	10YR 6/1	Massive			
		In situ process	0-6	A	10YR 4/3	Crumb			
		BC layer	6-18/120	Bw/BC	10YR 6/3	S-blocky			
		OB layer	>120	-	10YR 6/1	Massive			

Notes: *OM = organic matter, CEC = cation exchange capacity.

The formation of a precambic horizon was identified, especially in subplots U2K3 (I) and U2K3 (III). The subsoil in the B, BC, and C horizons is partially mixed with the parent material so that in the same soil horizon, there is parent material and soil. The thickness of the topsoil is quite thick, around 60 cm, but in subplot U2K1 (II) there is no soil layer. The OB layer is generally massive and only partially soft, with the characteristic of being relatively easy to hoe (Figure 6). In the upper part of the overburden layers, roots can penetrate because of the fractures in the parent rock. A massive OB layer formed because the water could not penetrate deeper (Figure 3). Chaubery et al. (2012) showed that the state of soil organic C on ex-mining reclamation land is influenced by the condition of the vegetation planted after land reclamation so that the land-surface condition will be filled with leaf litter from planted vegetation. Soil formation of soil is influenced by climate, parent materials, vegetation, topography, and time (Buol et al., 2011).

Figure 6. The OB layer is impermeable to water and roots develop in fractures (root growth in cracked, 2-5 years old).

Morphological characteristics at >5 years

The slope classes of land reclamation areas more than 5 years old are relatively flat (0-7%). Most of the Ah layer forms as a result of mixing organic matter and soil minerals with dark brown soil colour. The layers found in this land reclamation area generally derive from the weathering of the parent material of mudstone and sandstone but have pedogenesis at their place of origin (ex situ) with brown to yellow-brown colours and subangular structures to crumbs. The layers formed in this land reclamation area are Ah–BC–C, A–BC, and Ah–Bw–BC. The formation of the cambic horizon (U3K2/III) is a pedogenetic process that occurs as a result of local processes that may be due to the soil being used as topsoiling, which is soil that has weathered in its original place (ex situ). The cambic horizon is a horizon formed due to physical alteration, transformation, chemical transfer, or a combination of two or more processes (Soil Survey Staff, 2014a).

The thickness of topsoil is quite thick due to the weathering of sandstone and mudstone parent materials. The soil texture in several subplots tends to be coarse sand with a crumb structure because the spread soil material comes from a weathered sandstone parent material or has physically changed from compact to cracking due to mechanical activity (excavated). The formation of the cambic horizon (U3K2/III) is a pedogenetic process that occurs as a result of local processes that may be due to the soil being used topsoiling, which is soil that has weathered in its original place (ex situ). The thickness of the top soiling applied is quite thick, and the soil texture in several subplots tends to be coarse sand with a crumb structure.

The OB layer is generally massive and causes a water lock, so it is difficult for water to penetrate this layer, and when it rains, lateral water movement is more dominant (Figures 7 and 8). The identified pedogenetic characteristics of the local process (in situ) are the formation of a thin Ah layer and a cambic horizon. Soil reaction (pH H_2O) is acid to slightly acid, organic matter content is very low, and cation exchange capacity in the upper part (<10 cm thick) tends to become moderate (18.20 meq/100 g soil). The morphological characteristics of a reclamation area more than 5 years old can be seen in Table 3.

Looking at the values of the chemical characteristics, these indicate that the soil has been mixed in a state of a landfill, and it is poor as a result of washing and reversing the original position that occurred during the dredging and landfilling process (Kartawisastra and Gani, 2020). Hartati (2018) reported that the high bulk density facilitates roots penetrating the soil due to the availability of sufficient pores, either macro or micro. All soil's physical and chemical variables rise to a level suitable for food crops after being reclaimed for 12 years (Hermawan, 2011).

Figure 7. Top soiling was taken from soft sandstone OB impermeable layers (Piece of sandstone, uncrushed, >5 years).

Table 3. Morphological characteristic of a reclamation area of Separi site (>5 years old, U3).

Sample	Slope (%)	Characteristics of dumping area			Morphological Characteristics		Chemical Properties*		
		Origin	Thick (cm)	Horizon	Colour	Structure	pH (H_2O)	OM (%)	CEC (meq/100g)
U3K1/I	0-7	In situ process	0-7	Ah	10YR 4/1	S-blocky			
		BC layer	7-57/100	BC	10YR 4/2	Crumb			
		OB layer	>100	-	-	Massive			
U3K2/I	0-3	In situ process	0-7	Ah	10YR 3/3	S-blocky	5.66	1.10	18.20
		BC layer	7/25-104	BC	10YR 6/6	S-blocky	(U2K1)	(U3K1)	(U2K1)
		OB layer	>104	-	10YR 6/1	Massive			
U3K3/I	0-2	In situ process	0-5	Ah	10YR 4/1	Crumb			
		BC layer	5-32/100	BC	10YR 3/2	Crumb			
		OB layer	>100	-	10YR 6/1	Massive			
U3K1/II	0-2	In situ process	0-3/5	Ah	10YR 5/3	S-blocky			
		OB layer	3/5-70	BC	10YR 6/6	S-blocky			
		OB layer	>70	-	10YR 6/1	Massive			
U3K2/II	0-2	In situ process	0-3	A	10YR 5/6	S-blocky	5.08	0.75	16.11
		BG layer	3-30/66	BC	10YR 6/6	S-blocky	(U2K2)	(U3K2)	(U2K2)
		OB layer	>66	-	10YR 6/1	Massive			
U3K3/II	0-2	In situ process	0-3/6	A	10YR 3/3	S-blocky			
		BC stone	3/6-60	BC	10YR 5/6	S-blocky			
U3K1/III	0-2	In situ process	0-10	A	10YR 5/6	Crumb			
		BC layer	10-100	BC	10YR 6/3	S-blocky			
		OB layer	>100	-	10YR 6/1	Massive			
U3K2/III	0-2	In situ process	0-5	Ah	10YR 3/3	S-blocky	5.47	0.72	14.03
		BC layer	5-15/140	Bw/BC	10YR 6/2	S-blocky	(U2K3)	(U3K3)	(U2K3)
		OB layer	>140	-	10YR 6/1	Massive			
U3K3/III	0-2	In situ process	0-6	A	10YR 5/6	S- blocky			
		BC layer	6-28/5	BC	10YR 6/6	S- blocky			

Notes: *OM = organic matter, CEC = cation exchange capacity.

Figure 8. Top soiling was taken from soft sandstone OB impermeable layers (groundwater table in sandy material, >5 years).

In the post-coal mining soil reclamation area, the physical characteristics of the reclaiming materials were the limiting factors in the revegetation process Materials taken from a swamp area cause high soil compaction, so plant roots find it difficult to penetrate the soil, but it is easier to penetrate sandy materials, as shown in Figures 7 and 8. The results showed that the high bulk density in the whole of the researched Separi area was followed by soil porosity descent. In the <2 years old soil reclamation area, the soil had the highest bulk density (1.44 g/cm^3), more than 2-5 years old (1.36 g/cm^3) and more than 5 years old (1.35 g/cm^3). Bulk density decreases with the increasing age of land reclamation (Mukhopadhyay et al., 2014). Thomas et al. (2020) state that the growth of a root system and the addition of biomass to 15-20-year-old post-coal mining land reclamation can rebuild soil porosity.

Morphological condition and reclamation of Bengalon mining land area

Morphological characteristics of a reclamation area <2 years old

The slope class of the land reclamation area <2 years old is quite gentle, namely between 0-2% and 3-5%, with soil colour from yellowish-brown or pale brown to brownish-yellow with an angular to a massive structure that characterizes pedogenetic processes such as oxidation-reduction, transportation, translocation and transformation of parent material, especially the type of mudstone that occurs in the original soil, and the properties of the parent material are still found in the soil solum in the form of grey mudstone fragments in the land reclamation area. The genetic characteristics such as soil colour, texture, and soil structure that are identified are the pedogenetic properties of the original soil taken (ex situ), especially in A/B, B, and C soil horizons (Figure 9). The horizon layers found in the topsoiling are generally O–A/B –C, A/B–BC, A–Bw–BC, and A–BC. The formation of the O and A horizons located on the surface was caused more by the decomposition of topsoiling material and the organic matter that had not been weathered. The soil-horizon layer shows that the parent material layer is quite dominant. The number of fractures produces macropores that help soil-oxygen circulation and water infiltration, so that roots and living things can develop. The OB layer is generally massive and compact/sticky, but the presence of crackers results in unidentified inundation. Probably, a little downshifting process in the lower layers of the soil can cause cracks in and even damage to the horizon surface (Noviyanti et al., 2020). Soil reaction is very acidic, with little organic matter and low cation exchange capacity. In more detail, the morphological characteristics of the soil in this land reclamation area can be seen in Table 4.

Figure 9. Representation of the soil profile (<2 years).

Morphological characteristics of reclamation area >2-5 years old

The slope classes between 2-5 years old at the reclamation area of the KPC mine are quite gentle, namely 0.2% to 5-8%. The colour of the soil is from brownish yellow to brown; it is angular stocky to massive, and crumbly, which indicates that the soil has undergone a decomposition process so that a B cambic layer has formed (Figure 10).

Figure 10. Representation of the soil profile (2-5 years).

Table 4. Morphological characteristics of a reclamation area of Bengalon site (<2 years old, U1).

Sample	Slope (%)	Characteristics of dumping area			Morphological Characteristics		Chemical Properties*		
		Origin	Thick (cm)	Horizon	Colour	Structure	pH (H_2O)	OM (%)	CEC (meq/100g)
U1K1 (I)	0-2	Litter	1	O	-	-			
		BC layer	1-5/60	AB/BC	10YR 6/2	S-blocky			
		OB layer	>60	-	10YR 6/1	Massive			
U1K2 (I)	3-5	In situ process	0-3/10	A/B	10YR 5/6	S-blocky	3.93	2.40	9.81
		BC layer	3/10-55	BC	10YR 7/3	S-blocky	(U1K1)	(U1K1)	(U1K1)
		OB layer	>55	-	10YR 6/1	Massive			
U1K3 (I)	3-5	In situ process	0-3/6	A/B	10YR 6/6	S-blocky			
		BC layer	3/6-55	BC	10YR 7/6	S-blocky			
		OB layer	>55	-	10YR 6/1	S-blocky			
U1K1 (II)	0-2	In situ process	0-2	A	10YR 5/6	S-blocky			
		BC layer	2-9/94	Bw/BC	10YR 6/6	Massive			
		OB layer	>94	-	10YR 6/1	S-blocky			
U1K2 (II)	0-2	In situ process	0-2/4	A	10YR 5/6	S-blocky	3.59	2.32	10.10
		BC layer	2/4-55	BC	10YR 6/3	S-blocky	(U1K2)	(U1K2)	(U1K2)
		OB layer	>55	-	10YR 6/1	Massive			
U1K3 (II)	44684	In situ process	0-2/9	A/B	10YR 5/6	S-blocky			
		BC layer	2/9-90	BC	10YR 6/6	S-blocky			
		OB layer	>90	-	10YR 6/1	Massive			
U1K1 (III)	44684	In situ process	0-2	A	10YR 6/6	S-blocky			
		BC/OB layer	2-44	BC	5YR 6/6	S-blocky			
		OB layer	>44	B-	10YR 6/1	Massive			
U1K2 (III)	44684	In situ process	0-2/4	A	10YR 6/6	S-blocky	3.62	2.73	9.92
		BC layer	2/4-90	BC	10YR 7/3	S-blocky	(U1K3)	(U1K3)	(U1K3)
		OB layer	>90	-	10YR 6/1	Massive			
U1K3 (III)	44684	In situ process	0-2/10	A	10YR 6/6	S-blocky			
		BC layer	2/10-94	BC	10YR 7/2	S-blocky			
		OB layer	>94	-	10YR 6/1	Massive			

Notes: *OM= organic matter, CEC= cation exchange capacity.

Table 5. Morphological characteristics of a reclamation area of Bengalon site (2–5 years old, U2).

Sample	Slope (%)	Characteristics of dumping area			Morphological Characteristics		Chemical Properties		
		Origin	Thick (cm)	Horizon	Colour	Structure	pH (H_2O)	OM (%)	CEC (meq/100g)
U2K1 (I)	0-2	In situ process	3	Ah	10YR 4/2	S-blocky			
		BC layer	3-11/104	Bw/BC	10YR 6/6	S-blocky			
		OB layer	>104	-	10YR 6/1	Massive			
U2K2 (I)	0-2	In situ process	0-2	Ah	10YR 5/2	S-blocky	3.90	2.64	10.96
		BC layer	2-13/85	Bw/BC	10YR 6/6	S-blocky	(U2K1)	(U3K1)	(U2K1)
		OB layer	>85	-	10YR 6/1	Massive			
U2K3 (I)	0-2	In situ process	0-2	Ah	10YR 3/3	Crumb			
		BC layer	12-2/60	Bw/BC	10YR 6/6	S-blocky			
		OB layer	>60	-	10YR 6/1	Massive			
U2K1 (II)	2-5	In situ process	0-2	A	10YR 3/3	S-blocky			
		BC layer	2-13/60	Bw/BC	10YR 5/4	S-blocky			
U2K2 (II)	0-2	In situ process	0-4	A	10YR 3/3	Crumb	4.03	1.62	8.85
		BC layer	2-13/58	Bw/BC	10YR 6/6	S-blocky	(U2K2)	(U3K2)	(U2K2)
		OB layer	>58	-	10YR 6/1	Massive			
U2K3 (II)	5-8	In situ process	0-2	A	5YR 5/2	S-blocky			
		BC layer	2-9/41	Bw/BC	10YR 6/3	S-blocky			
		OB layer	>41	-	10YR 6/1	S-blocky			
U2K1 (III)	3-5	In situ process	0-2	A	10YR 5/2	Crumb			
		BC layer	2-17/72	BC	10YR 6/3	S-blocky			
		OB layer	>72	-	10YR 6/1	Massive			
U2K2 (III)	3-5	In situ process	0-2	A	10YR 7/2	S-blocky	3.98	2.69	10.88
		BC layer	2-110	BC	10YR 6/6	S-blocky	(U2K3)	(U3K3)	(U2K3)
		OB layer	>110	-	10YR 6/1	Massive			
U2K3 (III)	2-3	In situ process	0-2	A	10YR 7/2	S-blocky			
		BC layer	2-16/65	Bw/BC	10YR 6/3	S-blocky			
		OB layer	>65	-		Massive			

Notes: * OM= organic matter, CEC= cation exchange capacity.

The formation of Ah and Bw horizons is caused by the contribution of organic matter on the soil surface and a pedogenesis process in the original soil. The subsoil in the B, BC, and C horizons is partially mixed with the parent material. The thickness of the top soiling is quite thick, namely ≥41 cm to 110 cm, and in some parts of the soil, there are fractures in the Bw and BC layers (Table 5). The OB layer is generally mudstone, and massive, the presence of fractures in the layer above helps the decomposition process due to the presence of water and air. The massive B layer with cracking and topsoil processes can be seen in Figures 11 and 12. Soil reaction is very acid, with low to very low organic matter content and very low cation exchange capacity. Most of the soil used for topsoil in this area was originally taken from the forest area. Ultisols mostly form in warm, humid climates under forest vegetation (Soil Survey Staff, 2013); between the surface horizon and the lower soil is a leaching zone that is lighter in colour (Soil Survey Staff, 2013; 2014b).

Ultisols have limited water retention, firm consistency and slow to good permeability (Fandicha, 2011). Ultisols showed acid to very acid reaction, had a low content of organic matter and low base saturation. Soils generally exhibited a net negative charge, and the point of zero charges was reached at pH 3.6. Both potential and available phosphates were low, and there was a trend that amorphous aluminium was responsible for phosphate fixation. The low content of exchangeable potassium in topsoil and subsoil indicated a positive correlation with potential potassium. Clay mineral was composed chiefly of kaolinite, with small amounts of illite, vermiculite, and quartz (Prasetyo et al., 2016). The most common clay mineral found in Ultisols is kaolinite (Buol et al., 2011), and its fraction is dominated by low-activity clays such as kaolinite, halloysite and iron and Al oxides; it has a low negative charge and a point of zero charges (PZC), high or close to the actual pH (Hermawan, 2011).

Morphological characteristic of reclamation area >5 years old

The slope class of the land reclamation area is more than 5 years old, ranging from flat (0-2%) to 3-5%. The layers found in this land reclamation area generally derive from weathering of the parent material of mudstone and sandstone, but they have undergone pedogenesis at their place of origin with brown to yellow colours and angular to massive soil structures. The properties of the parent material are identified in the solum of the soil profile of land reclamation areas in the form of coarse fragments or other physical forms. The soil layers formed in this land reclamation area are Ah–BC–C, Ah–Bw–BC, Ah–Bw–BC, and A –BC. The cambic horizon is quite dominant in subplots U3K2 (I), U3K3 (I), U3K1 (II), U3K2(II) and U3K1 (III), formed due to local processes that may occur due to the topsoiling having weathered in its original place. The topsoiling is quite thick due to the weathering of the parent material of mudstone and sandstone.

The OB layer is generally massive and causes water lock, but the presence of fractures in the Bw–BC layer can reduce the risk of inundation in the event of rain (Figures 11 and 12). The identified pedogenetic characteristics of the local process (in situ) are the formation of thin O and Ah layers and a cambic horizon. Chemical characteristics tend to increase organic matter content in the upper part (<10 cm thick) compared to areas <5 years old (3.21%). The morphological characteristics of the reclamation area >5 years old can be seen in Table 6. The morphological characteristics of soil under forests are different from reclamation soils at all sites. The lower silt fraction and organic matter content of reclamation soils are less fertile compared to forest soils. Silt and the organic matter content of soil are vital to nutrient availability, as well as for improved soil aeration and structure. Furthermore, the higher clay content of reclamation soils may predispose it to high compaction, poor aeration, and poor penetration of plant roots (Ezeoko et al., 2020).

Figure 11. Massive impermeable layer and topsoiling processes of OB materials (massive OB/horizontal).

Topography is a factor that influences the development of soil morphology while identifying the genetic horizon suggests observing the soil profile according to the horizon boundary, horizon thickness, texture, structure, consistency, effective depth, type and number of pores, and other characteristics (Aditya et al., 2021). Generally, the soil colour is dark greyish brown to dark brown (A), with yellow-pale brown to brownish-yellow (B) and grey (OB) horizons (Figure 13). The darker colour at horizon A suggests a sufficient duration to accumulate organic soil matter (Aditya et al., 2020). The increasing soil depth (subsoil) has undergone brownification from yellowish-brown to yellow (10YR 6/6 to 10YR 7/6). Markley (2017) stated that a browner colour of the soil generally indicates a high content of goethite, and a redder soil colour indicates higher hematite content.

Table 6. Morphological characteristic of a reclamation area of Bengalon site (>5 years old).

Sample	Slope (%)	Characteristics of dumping area			Morphological Characteristics		Chemical Properties		
		Origin	Thick (cm)	Horizon	Colour	Structure	pH (H_2O)	OM (%)	CEC (meq/100g)
U3K1 (I)	0-2	Litter	1	O	-	-			
		BC layer	1-5/60	AB/BC	10YR 6/2	S-blocky			
		OB layer	>60	-	10YR 6/1	Massive			
U3K2 (I)	3-5	In situ process	0-3/10	A/B	10YR 5/6	S-blocky	3.97	3.21	9.45
		BC layer	3/10-55	BC	10YR 7/3	S-blocky	(U3K1)	(U3K1)	(U3K1)
		OB layer	>55	-	10YR 6/1	Massive			
U3K3 (I)	3-5	In situ process	0-3/6	A/B	10YR 6/6	S-blocky			
		BC layer	3/6-55	BC	10YR 7/6	S-blocky			
		OB layer	>55	-	10YR 6/1	S-blocky			
U3K1 (II)	0-2	In situ process	0-2	A	10YR 5/6	S-blocky			
		BC layer	2-9/94	Bw/BC	10YR 6/6	Massive			
		OB layer	>94	-	10YR 6/1	S-blocky			
U3K2 (II)	0-2	In situ process	0-2/4	A	10YR 5/6	S-blocky	4.22	2.67	11.25
		BC layer	2/4-55	BC	10YR 6/3	S-blocky	U3K2)	(U3K2)	(U3K2)
		OB layer	>55	-	10YR 6/1	Massive			
U3K3 (II)	3-5	Insitu process	0-2/9	A/B	10YR 5/6	S-blocky			
		BC layer	2/9-90	BC	10YR 6/6	S-blocky			
		OB layer	>90	-	10YR 6/1	Massive			
U3K1 (III)	3-5	In situ process	0-2	A	10YR 6/6	S-blocky			
		BC/OB layer	2-44	BC	5YR 6/6	S-blocky			
		OB layer	>44	B-	10YR 6/1	Massive			
U3K2 (III)	3-5	In situ process	0-2/4	A	10YR 6/6	S-blocky	4.08	2.57	12.75
		BC layer	2/4-90	BC	10YR 7/3	S-blocky	(U3K3)	(U3K3)	(U3K3)
		OB layer	>90	-	10YR 6/1	Massive			
U3K3 (III)	3-5	In situ process	0-2/10	A	10YR 6/6	S-blocky			
		BC layer	2/10-94	BC	10YR 7/2	S-blocky			
		OB layer	>94	-	10YR 6/1	Massive			

Notes: * OM= organic matter, CEC= cation exchange capacity.

Figure 12**.** Massive impermeable layer and topsoiling processes of OB materials (topsoil processes).

Figure 13. Representation of soil profile (>5 years).

Bedrock (OB materials) >40% causes the land to be damaged, which is marked by limited and lateral soil development. A soil depth of less than 60 cm results in easily degraded land, causing trees to collapse because their roots do not get enough water and nutrients (Aji et al., 2020). The soil in the study sites can be characterized as acidic with lower content of exchangeable cations (K, Na, Ca, Mg). The number of exchangeable bases was much lower than the CEC value, indicating that the development of a negative charge of soil organic matter would be limited under acidic soil conditions (Yusoff et al., 2017). Aditya et al. (2020) also stated that the higher CEC in surface soil might be due to a higher quantity of organic carbon in surface layers, soil texture, clay mineralogical composition, and degree of erosion. The influence of selected soil properties such as pH and bulk density on bacterial communities suggests that post-mining reclamation practices must ensure minimizing soil compaction and preserving the pre-mining soil horizon and quality, as well as including measures for soil pH amelioration

Conclusion

The thickness of topsoiling less than 2 years ranged from 3/10-150 cm (Separi) and 44-90 cm (Bengalon), for 2-5 years between 0-120 cm (Separi) and 41-110 cm (Bengalon), while >5 years old it ranged from 3/5-150 cm (Separi) to 65-110 cm (Bengalon). Soil layers generally have the same soil morphological characteristics under forest stands (external weathering), i.e. soil colour, texture, and part of the structure. Leaching processes indicate that weathering has begun, and the reclamation area post-coal mining was only seen at more than two years old. Morphologically, it shows that swamp soil (Tropaquents) and parent material/ parent-rock sandstone (Psaments) are also used for top soiling (Separi) along with other soil-like Typic Hapludults/ Typic Dystropepts, which are generally red to yellowish in colour. Vegetation planted in the reclamation area tends to increase the organic matter content (Separi) and the cation exchange capacity (Bengalon) in the upper part (<10 cm thick) compared to an area less than 5 years old.

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References

Aditya, H.F., Gandaseca, S., Rayes, M.L., Karam, D.S., Prayogo, C. and Nugroho, G.A. 2020. Characterization, changes in soil properties and vegetation distribution as affected by topography in Ayer Hitam Forest Reserve, Selangor, Peninsular Malaysia. *AGRIVITA Journal of Agricultural Science* 42(3):548-562, doi:10.17503/agrivita.v42i3.2617.

Aditya, H.F., Gandaseca, S., Rayes, M.L. and Karam, D.S. 2021. Toposequent effect on soil morphology and classification of Ultisols in the Ayer Hitam Forest Reserve, Peninsular Malaysia. *Jurnal Sylva Lestari* 9(2):202–212, doi:10.23960/jsl29202-212.

Aji, K, Mas, A. and Nurudin, M. 2020. Relationship between soil morphology and variability of upland degradation in Bogowonto Watershed, Central Java, Indonesia. *Journal of Degraded and Mining Lands Management* 7(3):2209-2219, doi:10.15243/jdmlm.2020.073.2209.

Arisnawan, R.A. 2015. The mechanical and dynamic characteristics of clay shale due to changes in water content (Thesis). http://repository.its.ac.id.

Buol, S.W.M., Gouthard, R.J., Graham, R.C. and McDaniel, P.A. 2011. *Soil Genesis and Classification.* 6th ed, Willey-Blackwell, A. John Willey & Sons Inc., U.K.

Chaubery, O.P., Bohre, P. dan Singhal, P.K. 2012. Impact of bio-reclamation of coal mine spoil on nutritional and microbial characteristics. *International Journal of Bio-Science and Bio-Technology* 4(3):69-80.

Ezeoko, I.O.T., Bezuidenhout, C.C., Mouboeta, M.S., Khasa, D.M. and Adeleke, R.A. 2020. Structural and functional differentiation of bacterial communities in post-coal mining reclamation soils of South Africa: bioindicators of soils ecosystem restoration. *Scientific Reports* 10:1759, doi:10.1036/s41598-020-58576-5.

Fandicha, 2011. Soils in Indonesia. http://fandicha.blog.com/2011/03/25 (*in Indonesian*).

Hapsari, L., Trimanto, and Budiharta, S. 2020. Spontaneous plant recolonization on reclaimed post-coal mining sites in East Kalimantan, Indonesia: native versus alien and succession progress. *Biodiversitas* 21(5):2003-2018, doi:10.13057/biodiv/d210527.

Hartati, T.M. 2018. Evaluation of land, soil fertility of several plantation crops and improvement of soil properties to increase production of Pala in Galela, North Halmahera. Dissertation, Faculty of Agriculture, Universitas Gadjah Mada *(in Indonesian*).

Hermawan, B. 2011. Improving the quality of ex-mining land through revegetation and its suitability as food crop agriculture land. Proceedings of National Seminar on Agricultural Cultivation. Bengkulu University. Bengkulu (*in Indonesian*).

Kartawisastra, S and R.A. Gani. 2020. Ex-coal mine lands and their suitability for agriculture commodities in South Kalimantan. *Journal of Degraded and Mining Lands Management* 7(3):2171-2183, doi:10.15243/jdmlm.2020. 073.2171.

Khaidir A., Purwanto, B.H., Nurudin, M. and Hanudin, E. 2019. Morphology and psychochemical properties of soils in the reclamation of ex-coal mining. *Indian Journal of Agricultural Research* 52(2):184-189, doi:10.18805/IJARe.A-332.

Markley, L.A.T. 2017. Characterization of the Goethite-Hematite Ratio in Modern and Ancient Soil in the Mid-Atlantic Region as a Paleoprecipitation Proxy. Lehigh University, USA. https://preserve.lehigh.edu/cgi/view content.

Mukhopadhyay, S., Maiti, S.K. and Masto, R.E. 2014. Development of mine soil Quality Index (RMSI) for evaluation of reclamation success: a chronosequence study. *Journal of Ecological Engineering* 71:10-20.

Munawar. 1999. Coal-mine Soil Reclamation and Its Possible Agricultural Use in Bengkulu. Proceedings of Seminar Toward Sustainable Agriculture in Humid Tropics Facing 21st Century 107-124 (*in Indonesian*).

Nasrudin. 2021. Spatial characteristics of coal mining in Kutai Kartanegara Regency, East Kalimantan Province. *Sumatra Journal of Disaster, Geography and Geography Education* 1(2):152-154. doi:10.24036/sjdgge. v1j2.101.

Noviyanto, A., Junun, S. and Purwanto, B.H. 2020. The distribution of soil morphological characteristics for landslide-impacted Sumbing Vulcano, Central Java-Indonesia. *Geoenvironmental Disaster* 7, Article number: 25 (2020), doi:10.1186/ s40677-020-00158-8.

Noviyanto, A., Purwanto, S. Minardi and Supriyadi. 2017. The assessment of soil quality of various ages of land reclamation after coal mining: a chronosequence study. *Journal of Degraded and Mining Lands Management* 5(1):1009-1019, doi:10.15243/jgmlm.2017.051.1009.

Prasetyo, B.H., Suharta, N., Subagyo, H. and Hikmatullah, H. 2016. Chemical and mineralogical properties of Ultisols of Sasamba area, East Kalimantan. *Indonesian Journal of Agricultural Science* 2(2):37-47, doi: 10.21082/ijas.v2n2.2001.37-47.

Pratiwi, Narendra, B.H., Siregar, C.A., Turjaman, M., Hidayat, A., Rachmat, H.H., Mulyanto, B., Suwardi, Iskandar, and Maharani, R. 2021. Managing and reforesting degraded post-mining landscape in Indonesia: a review. *Land* 10(6):658, doi:10.3390/land10060658.

Schroeder, P.D., Daniels, W.L. and M.M. Alley, M.M. 2010. Chemical and physical properties of reconstructed mineral sand mine soil in Southeastern Virginia. *Soil Science* 175(1):1-9.

Singh, S.K. and Chandran, P. 2017. Soil Genesis and Classification. In: Rattan, R.K., Katyal, J.C. and B.S.Dwived, B.S. (eds), *Soil Science-An Introduction,* Indian Society of Soil Science pp.57-96

Soil Survey Staff. 2011. Soil Survey Laboratory Information Manual. Soil Survey Investigations Report No. 45, Version 2.0. R. Burt (ed.). U.S. Department of Agriculture, Natural Resource Conservation Services.

Soil Survey Staff. 2013. Simplified Guide to Soil Taxonomy. USDA - Natural Resources Conservation Services-National Survey Center, Lincoln, NE.

Soil Survey Staff. 2014a. Keys to Soil Taxonomy. USDA, Natural Resources Conservation Services. Twelfth Edition.

Soil Survey Staff. 2014b. Illustrated Guide to Soil Taxonomy. USDA, Natural Resources Conservation Services. National Soil Service Center, Lincoln Nebraska.

Sopialena, Rosfiansyah, and Sila, S. 2017. The benefit of topsoil and fertilizer mixture to improve ex-coal mining land. *Nusantara Bioscience* 1(1):36-43, doi:10.13057/nusbiosci/n090107.

Thomas, K.A., Sencindives, J.C., Skousen, J.G. and Gorman, J.M. 2020. Soil horizon development on a mountain top surface mine in Southern West Virginia. *Journal of Green Lands* 30:41-52.

Yusoff, K.H.M., Abdu, A., Sakurai, K., Tanaka, S. and Kang, Y. 2017. Soil morphology and chemical properties in home gardens on sandy beach ridges along the east coast of Peninsular Malaysia. *Soil Science and Plant Nutrition* 63(4):357-368, doi:10.1080/ 00380768.2017.1340077.

Zulkarnain, Z., Joy, B., Tuhpawana, P. and Prawira, I 2014. Soil erosion assessment of the post-coal mining site in Kutai Kartanegara District, East Kalimantan Province. *International Journal of Science and Engineering* 7(2):130-136.

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