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Variation in soil characteristics of ex-coal mining areas in Sawahlunto, West Sumatra

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Abstract. Soil characteristics in ex-coal mining areas can be influenced by reclamation methods and the type and age of revegetation plants used. This reclamation can also significantly impact the soil chemistry of ex-mining areas. This research was conducted in ex-coal mining areas located in Parambahan, Batu Tanjung Village, Talawi District, Sawahlunto City, West Sumatra Province. The objective of this study is to analyze variations in the reclamation process and their effects on the chemical properties of soil in these areas. Observations were made in several plots, including land that had not been mined (natural forest), land revegetated with Acacia in the planting years of 1992, 2007, 2010 (without the use of topsoil), 2019, and 2021, and land revegetated with Sengon in 2022. In each plot, soil samples were collected at three depths: 0–5 cm, 5–10 cm, and 10–20 cm, to analyze soil chemical properties. These properties included pH, total nitrogen (N), available phosphorus (P), organic carbon (C), exchangeable base cations (K, Ca, Mg, and Na), cation exchange capacity, and exchangeable aluminum (Al). The results showed that variations in the years of revegetation and reclamation practices, such as the use of topsoil and plant types, significantly influenced soil chemical characteristics. The longer the period of revegetation, the better the improvement in the soil's chemical properties, as indicated by changes in pH, total N, organic C, exchangeable K, Na, Ca, and Mg, cation exchange capacity, and a reduction in exchangeable Al. However, the availability of P, as indicated by available P, decreased after more than 30 years of revegetation.

1 Introduction

West Sumatra, a province in Indonesia, is notable for its coal mining activities, particularly in Sawahlunto City. Spanning an area of 273.45 km², approximately 8% of this region is dedicated to coal mining, predominantly in the Baragin and Talawi Districts. Coal mining in this area has been operational for an extended period, making significant contributions to both local and national economies. However, the mining techniques employed have gradually

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begun to affect environmental quality, particularly in terms of ecology, land, and water systems, especially in the context of open-pit mining.

Open-pit mining, a surface mining technique, involves the conventional excavation of coal deposits situated near the Earth's surface [1]. This mining method, during its exploration, development, and beneficiation stages, leads to denudation, handling, and accumulation processes in the mining areas. These processes significantly alter the vegetation, soil composition, and landscape, resulting in the formation of pits, generation of solid waste, and soil erosion due to slope development in the mining areas, consequently necessitating the creation of drainage systems [2-4].

The physical and chemical properties of soil are considerably disrupted by the open-pit mining approach [5]. Moreover, this method detrimentally affects land productivity due to the deterioration of soil physical and chemical properties. These include reduced water absorption capacity, increased porosity, excessively acidic pH levels, diminished nitrogen (N) and phosphorus (P) content, decreased cation exchange capacity (CEC), lower base saturation (K, Ca, Mg, and Na), and heightened aluminum (Al) saturation. It has been observed that open coal mining leads to diminished nutrient distribution and a decline in soil quality, particularly concerning soil organic matter and total nitrogen content [6].

Open-pit mining systems substantially disrupt landforms and soils, hindering the restoration of ecosystems to their original states. Mining activities disturb soil function, resulting in significant reductions in total nitrogen, nitrate nitrogen, and total carbon. Effective topsoil management strategies, such as the application of inorganic fertilizers, can promote plant growth, affect the distribution of soil bacteria, and facilitate the restoration of soil chemical and biological properties to conditions more akin to their natural state. Appropriate topsoil management during the reclamation process is crucial to minimize the degradation of soil carbon and other physicochemical properties, as emphasized in several studies [7,8].

Mining companies are obligated to conduct reclamation efforts focused on organizing, restoring, and enhancing environmental and ecosystem quality, particularly the soil conditions, to ensure functionality aligns with intended purposes. A variety of strategies have been implemented to improve post-mining land reclamation. These methods include: (1) using plant growth regulators to promote the growth of slow-growing native plants, seedlings, and transplanted cuttings [9]; (2) incorporating organic amendments, both rapidly and slowly decomposing, sourced from agricultural, forestry, and urban waste [10]; (3) combining biochar with compost, manure, and other amendments to augment the effectiveness of ex-mining land revegetation [11]; (4) applying mycorrhiza as a biological approach to optimize land restoration and organic material accumulation in various revegetation types [12]; and (5) conducting ecological environmental restoration in mining areas by planting high-value hardwood trees, thereby improving tree survival, growth rates, and accelerating forest habitat formation through suitable tree planting techniques [13]. Extensive research on these methods indicates that revegetation using plant species is a viable approach for enhancing the condition of post-mining land and fostering the development of an ecosystem that approximates natural conditions.

Revegetation is executed by employing local pioneer species that exhibit rapid growth, low nutrient requirements, substantial litter production that decomposes easily, robust root systems, and the capability to form symbiotic relationships with specific microbes, aiding in the arrival of seed-bearing vectors. These species are both simple and economical to propagate and maintain [14]. Revegetation is instrumental in improving the condition of post-mining soil by enhancing its physical and chemical properties, thus supporting the growth of revegetated plants and transforming post-mining land into an ecosystem that closely mimics natural conditions. The objective of this research is to assess the impact of revegetation practices on the chemical properties of soil in ex-coal mining areas, considering various planting years and soil depths.

2 Methods

2.1 Study area

The study was conducted from April to August 2023 at PT Allied Indo Coal Jaya, located in Parambahan, Batu Tanjung Village, Talawi District, Sawahlunto City, West Sumatra Province. Geographically situated between 0°35'55” and 0°36'50” South Latitude and 100°47'00” and 100°48'10” East Longitude, the area is positioned 378 meters above sea level. It experiences temperatures ranging from 24-33°C and an average annual rainfall of 2042.27 mm. The company operates a mining area of 372.4 hectares using both open and closed mining systems. Since 1985, coal extraction has been conducted using an open-pit system, with revegetation initiatives starting in 1990. As of now, these revegetation efforts have been ongoing for 33 years. The extended duration of planting provides insights into soil characteristics that vary according to different revegetation practices.

The research focused on both natural forest land and areas revegetated in 1992 with sengon (*Albizia chinensis*), acacia (*Acacia mangium*), and seri (*Muntingia calabura*) plants. In 2007, revegetation included sengon and acacia; in 2010, it involved reclaimed land without topsoil, planted with the same species. For the years 2019, 2021, and 2022, revegetation incorporated local long-cycle plants like mahogany (*Swietenia mahagoni*), meranti (*Shorea* spp.), surian (*Toona sinensis* Roem), candlenut (*Aleurites moluccana* (L.) Willd), and multi-purpose trees (MPTS) such as petai (*Parkia speciosa* Hassk), matoa (*Pometia pinnata*), jengkol (*Archidendron jiringa*), jackfruit (*Artocarpus heterophyllus*), and breadfruit (*Artocarpus altilis*).

2.2 Data and analysis

The study was conducted across various revegetation sites, including areas of unmined land categorized as natural forests. These natural forests are typically characterized by mixed stands, comprising trees of diverse ages and sizes [15]. The land was subjected to revegetation with Acacia in the planting years of 1992, 2007, 2010 (without topsoil application), 2019, and 2021. Additionally, revegetation with Sengon was undertaken in 2022. For each plot, composite soil sampling was performed at five distinct points within three depth intervals: 0–5 cm, 5–10 cm, and 10–20 cm.

Soil analyses were conducted at the Soil Science Laboratory of the Department of Soil Science and Land Resources, Faculty of Agriculture, IPB University. These analyses focused on various chemical properties of the soil. The pH was measured in a H2O solution using a 1:2.5 soil-to-water ratio. Total nitrogen (N) was determined using the Kjeldahl method. Available phosphorus (P) was quantified using the Bray I method, and organic carbon (C) was assessed using the Walkley-Black method. The analysis also included the measurement of exchangeable base cations (potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na)). The cation exchange capacity (CEC) was evaluated using 1 N NH4OAc extraction, and exchangeable aluminum (Al) was measured using 1 N KCl.

3 Results and discussions

The analysis of soil chemical properties was carried out on both forested and revegetated lands from 1992 to 2022 at various soil depths (0-5 cm, 5-10 cm, 10-20 cm). The parameters assessed included pH, total nitrogen (N), available phosphorus (P), organic carbon (C), exchangeable base cations (potassium (K), calcium (Ca), magnesium (Mg), sodium (Na)), cation exchange capacity (CEC), and exchangeable aluminum (Al). The findings are presented in Table 1.

The pH values of soils from the ex-mining area varied depending on the age of revegetation and soil depth, ranging from 3.48 to 5.35. This range indicates very acidic to acidic conditions. The year of planting for revegetation significantly influenced the pH levels. Notably, the 1992 planting, primarily with Acacia, showed higher pH values compared to other planting years and the natural forest across all examined soil depths. The table demonstrates a trend of increasing pH in the soil from ex-mining areas as the age of revegetation progresses, suggesting older vegetation tends to increase soil pH levels [16].

Soils from newly revegetated ex-mining areas showed very low pH values, indicative of high acidity. This aligns with findings from a previous study that analyzed chemical properties of soils at revegetation sites aged 3 to 4 years, where pH values ranged from 3.60 to 4.40 [17]. Low soil pH can significantly affect the availability of other macronutrients. The observed increase in soil pH over time with revegetation is attributed to the ecological succession occurring due to plant growth. As plants grow and decompose, they contribute organic matter, such as leaves, twigs, and plant litter, to the soil. This decaying matter then raises the soil pH.West Sumatra, a province in Indonesia, is notable for its coal mining

The content of total nitrogen (N) and organic carbon (C) in soil from ex-mining areas increases with the age of revegetation, exhibiting the highest values at a depth of 0–5 cm. The range of total N content is between 0.01% and 0.36%, classified from very low to medium. Notably, the highest total N content was observed in the revegetation efforts from 1992. Similarly, the organic C content in ex-mining soil varies from 0.20% to 6.29%, categorized from very low to very high, with the 1992 revegetation again exhibiting the highest organic C content. This increase in total N and organic C in the 1992 revegetation is likely due to the accumulation of litter from vegetation. The vegetation planted contributes organic matter to the soil, influencing the total N and organic C levels [18]. The enhancement of organic matter in replanted land is affected by the specific type of vegetation introduced.

The content of available phosphorus (P) in ex-mining soil shows variation across different years and revegetation practices, ranging from 1.84 to 12.19 ppm, classified as very low to high. The highest available P content is found in forest land, likely due to the natural nutrient cycling within forests that facilitates the recycling of phosphorus nutrients. The forest litter, comprising leaves and organic debris, contains phosphorus which is gradually decomposed by soil microbes, thereby releasing phosphorus back into the soil for plant uptake. A layer of leaf litter and other organic materials accumulates on the soil surface, acting as a source of phosphorus. Additionally, it is observed that revegetation practices exceeding 30 years lead to decreased solubility of available P.

Table 1. Analysis of chemical properties of forest soil and ex-mining soil from 1992 to 2022.

Land Use and Soil Depth (cm)	**Observation Parameters**									
	pH	**N-total (%)**	**C-organic (%)**	**P-available (ppm)**	**CEC (Cmol. Kg^{-1})**	**Exchangeable Cations**				
						Potasium (Cmol. Kg^{-1})	**Calcium (Cmol. Kg^{-1})**	**Magnesium (Cmol. Kg^{-1})**	**Natrium (Cmol. Kg^{-1})**	**Aluminum (ppm)**
Revegetation 1992										
0-5	5.35	0.36	6.29	1.84	30.83	0.35	12.97	4.47	0.21	0.50
5-10	4.72	0.12	1.94	5.34	17.56	0.18	3.45	2.83	0.15	0.70
10-20	4.92	0.08	1.94	2.34	12.48	0.24	2.77	2.13	0.13	0.72

Revegetation 2007										
0-5	3.75	0.30	6.12	8.35	28.60	0.53	1.67	0.95	0.19	4.07
5-10	4.11	0.09	1.39	12.19	17.05	0.31	2.07	0.69	0.12	4.06
10-20	4.19	0.06	0.49	8.51	15.44	0.3	0.93	0.48	0.14	2.12
Revegetation 2010										
0-5	4.51	0.15	3.49	3.17	16.78	0.52	4.98	1.84	0.24	1.32
5-10	4.68	0.10	2.04	5.34	17.24	0.55	1.24	1.66	0.18	0.69
10-20	4.50	0.06	0.70	6.51	14.43	0.43	1.28	1.41	0.12	2.59
Revegetation 2019										
0-5	4.02	0.10	3.38	8.51	9.01	0.18	1.68	0.70	0.11	2.25
5-10	3.82	0.12	3.18	4.01	13.3	0.16	1.12	0.82	0.13	2.33
10-20	3.53	0.10	2.98	3.17	14.98	0.20	2.08	0.64	0.13	3.37
Revegetation 2021										
0-5	4.74	0.04	0.55	3.34	3.45	0.28	2.81	2.50	0.12	2.20
5-10	4.79	0.03	0.20	3.17	18.19	0.23	3.39	4.12	0.12	4.81
10-20	4.65	0.04	0.15	7.18	15.18	0.17	0.45	0.50	0.09	3.31
Revegetation 2022										
0-5	4.54	0.04	0.34	8.68	7.66	0.12	0.64	0.31	0.13	2.94
5-10	3.64	0.03	0.28	3.34	7.49	0.09	0.61	0.35	0.13	1.89
10-20	3.48	0.01	0.30	4.34	12.56	0.11	0.42	0.48	0.16	3.02
Forest										
0-5	3.69	0.19	3.88	6.34	18.09	0.23	0.46	0.43	0.16	3.74
5-10	4.37	0.12	2.17	10.85	18.55	0.16	0.80	0.17	0.24	3.30
10-20	4.35	0.11	1.90	9.35	16.49	0.22	0.80	0.42	0.11	3.74

The cation exchange capacity (CEC) of ex-mining soil also varies depending on the age of revegetation and the specific practices implemented, ranging from 3.45 to 30.83 Cmol/kg, and is categorized from very low to high. The trend indicates that older revegetation efforts correspond to higher CEC in ex-mining soil. This suggests that such soils have an enhanced capacity to absorb and supply nutrients for plant growth. CEC is intrinsically linked to exchangeable base cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) and soil pH. There is a correlation between CEC, base saturation, and soil pH; higher pH values typically result in increased CEC and elevated levels of exchangeable base cations. This relationship is evident in the data, showing that as revegetation matures, pH values, CEC, and exchangeable base cations increase concurrently.

Aluminum concentrations in soil from ex-mining areas, measured across various depths from 1992 to 2022, exhibit notable variability, with values ranging from 0.50 ppm to 4.81 ppm. It is observed that the deeper soil layers (10–20 cm) tend to have higher aluminum concentrations compared to the shallower layers (0–5 cm and 5–10 cm). Such significant fluctuations in aluminum concentrations have implications for nutrient availability, crucial for plant growth. As the age of revegetation increases, the solubility of exchangeable aluminum in the soil decreases. For example, soil revegetated in 1992 shows lower exchangeable aluminum concentrations than in more recent years. The concentration of exchangeable aluminum is intricately linked to soil pH levels; typically, a lower soil pH is associated with higher concentrations of exchangeable aluminum, and conversely, higher soil pH levels generally lead to lower concentrations of exchangeable aluminum. This relationship underscores the importance of monitoring and managing soil pH in efforts to optimize conditions for plant growth in revegetated ex-mining areas.

4 Conclusion

Reclaimed ex-mining soil through revegetation impacts its chemical properties, including pH, total nitrogen (N-total), organic carbon (C-organic), available phosphorus (P-available), cation exchange capacity, and exchangeable bases (K, Ca, Mg, and Na), as well as exchangeable aluminum. Over time, revegetation enhances the chemical properties of ex-mining soil. The 1992 revegetation with Acacia, for instance, showed an increase in pH, N-total, C-organic, cation exchange capacity, and exchangeable bases (K, Ca, Mg, and Na), particularly at a soil depth of 0–5 cm. Additionally, the longer the vegetation period, the lower the solubility of exchangeable aluminum. In terms of phosphorus availability, research indicates that revegetation exceeding 30 years reduces P availability; the highest availability was observed in natural forests and in the 2007 revegetation. This trend highlights the dynamic changes in soil chemistry associated with the age and type of revegetation in reclaimed ex-mining areas.

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References

1. A. Prakash, V. M. S. R. Murthy, and K. B. Singh. Int. J. Min. Sci. Technol. **33–40** (2013)
2. W. Xiao, H. Ren, T. Sui, H. Zhang, Y. Zhao, and Z. Hu. Int. J. Coal Sci. Technol. **9**, 1 (2022)
3. W. Chen, X. Li, H. He, and L. Wang. Remote Sens **10**, 1 (2018)
4. Subowo G. Biodiversity," J. Sumberd. Lahan 5, 2, **83–94** (2011)
5. V. A. Kusumaningtyas et al. IOP Conf. Ser. Earth Environ. Sci. **882**, 1 (2021)
6. Z. Jing, J. Wang, Y. Zhu, and Y. Feng. J. Clean. Prod. 177, **350–361** (2018)
7. M. R. Ngugi, P. G. Dennis, V. J. Neldner, D. Doley, N. Fechner, and A. McElnea. Restor. Ecol 26, 5, **839–850** (2018)
8. K. Stephan and J. A. Hubbart. Land **12**, 1 (2023)
9. C. C. Small and D. Degenhardt. 118, **43–51** (2018)
10. F. J. Larney and D. A. Angers.. J. Soil Sci 92, 1, **19–38** (2012)
11. L. Beesley, E. Moreno-Jiménez, J. L. Gomez-Eyles, E. Harris, B. Robinson, and T. Sizmur. Environ. Pollut 159, 12, **3269–3282** (2011)
12. Y. Bi, L. Xiao, C. Guo, and P. Christie. Catena **195** 104791 (2020)

13. Pratiwi et al., Land **10,** 6 (2021)
14. R. D. N. Setyowati, N. A. Amala, and N. N. U. Aini. Al-Ard J. Tek. Lingkung 3,1, **14–20** (2018)
15. A. Salatalohy, A. Esa, and R. Hadun. J. Inov. Penelit. 3, 3, **5239–5246** (2022)
16. R. Oktavia. BIOnatural 6, 1, **67–79** (2019)
17. O. Rusdiana, D. Mulyana, and C. U. Willujeng, J. Silvikultur Trop., vol. 04, no. 3, pp. **183–189**, 2013.
18. S. Yongguang et al., “Effect of reclamation time and land use on soil properties in Changjiang River Estuary, China,” Chinese Geogr. Sci., vol. 21, no. 4, 403–416 (2011)
19. Rosmarkam and N.W. Yuwono. (2002)