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Solid Decanter-AMF Biostimulation for Oil Palm Nursery Development on Ex-iron Mining Land

Adrinal[1]*, Yesi Widia[2], Elsa Lolita Putri[3], Edwin[2], Gusmini[1]

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ABSTRACT

This study investigates the impact of decanter solid and arbuscular mycorrhiza on the growth of oil palm seedlings in pre-nursery on ex-iron ore mining sites. The construction of pits during iron mining has resulted in soil degradation and abandonment. The addition of solid decanter and arbuscular mycorrhiza can improve the chemical characteristics of soil. The study sought to determine the interaction between solid decanter and arbuscular mycorrhiza, as well as the optimal dose of solid decanter and arbuscular mycorrhiza for oil palm seedling growth in the pre-nursery. This study employed a factorial Completely Randomized Design with two factors and four treatment levels. The first factor was solid decanter (0, 200, 300, and 450 g), whereas the second was arbuscular mycorrhiza (0, 5, 10, and 15 g/polybag). The parameter studied included initial soil analysis, solid decanter analysis, final soil analysis, seed height, stem diameter, number of leaves, leaf length, fresh and dry seedling weights. The study's findings revealed an interaction between solid decanters and arbuscular mycorrhiza on leaf length, fresh weight, and dry weight of seedlings. The treatment dose of 450 g solid decanter and 5 g/polybag arbuscular mycorrhizae resulted in the best growth in all variables.

Keywords: arbuscular mycorrhizae, fertility, mycorrhiza, pre-nursery

INTRODUCTION

Palm oil is one of Indonesia's most important commodities in international trade. It is one of Indonesia's top 10 export commodities, accounting for the majority of its foreign exchange earnings. According to data from the Central Statistics Agency (BPS), Indonesia's total exports in 2025 were 62,146,112 tons, while crude palm oil (CPO), a product of processing fresh fruit bunches (FFB) of oil palm, accounted for 30,889,638 kg of Indonesia's total export value in September 2025 (BPS 2025).

Mining is a temporary land use with variable durations. Mines close when resources are depleted or mining becomes no longer economically viable (Haque *et al*. 2014; Kivinen 2017; Laurence 2011; Pokhrel & Dubey 2013; Balai Penelitian Tanah 2005). Ex-mining sites demonstrate a variety of landscape and geophysical changes that differ from the pre-mining landscape. Mining causes a variety of land disturbances, including open pits, waste rock heaps, tailings, and soil deterioration (Larondelle & Haase 2012; Mengel *et al*. 2012; Rigina 2002). Gold, iron, tin, and coal mining operations leave behind a wasteland known as ex-mining land. Mining holes and layers of soil of variable composition and color are common features of post-mining terrain. For example, there could be alternating layers of sandy soil and clay, loam, or silt. There may also be layers of grey soil at the bottom, red in the center, and blackish at the top (Sahputra *et al*. 2023).

Efforts to increase soil nutrition in ex-iron mines include the use of soil additives to expedite recovery. The fundamental goal of soil amendments is to improve the physical, chemical, and biological quality of the soil, resulting in maximum productivity. Soil treated with natural organic amendments is predicted to have a good impact on plant growth and development in nurseries. Solid decanter is one of the soil amendments utilized at the nursery stage. A solid decanter can be added to the growing medium to suit the nutrient needs of oil palm plants (Nurjanah *et al*. 2025; Ruffell *et al*. 2024). Solid decanter is a byproduct of crude palm oil processing that can be utilized as organic fertilizer to add organic matter and nutrients to the land. The primary nutrients in the dry solid decanter are 1.47% nitrogen, 0.17% phosphorus, 0.99% potassium, 1.19% calcium, 0.24% magnesium, and 14.4% organic carbon (Mariani 2018).

In addition to adding solid decanters to ex-mining soil to promote nutrient availability, bacteria or fungi can also help plants get more nutrients. The use of solid decanters and the tropical fungus *P. pulmonarias* significantly boosted the biodegradability of

[1] Department of Soil and Land Resources, Faculty of Agriculture, Andalas University, Padang 25163, Indonesia
[2] Department of Agroecotechnology, Faculty of Agriculture, Andalas University, Padang 25163, Indonesia
[3] Soil Science Study Program, Faculty of Agriculture, University of Bengkulu, Bengkulu 38119, Indonesia
* Corresponding Author: E-mail: adrinal@agr.unand.ac.id

polychlorinated chemicals. A mixture of solid decanter and mushrooms lowered PCDD/F in soil to below Taiwan's statutory limit of 1000 ng I-TEQ kgy1 (Kewlaoyoong *et al*. 2020). Arbuscular mycorrhizal fungi (AMF) are a type of helpful fungus. AMF is a biological product used as an inoculant that contains active substances from living organisms that provide nutrients or improve soil nutrient availability for plants (Asfiyak *et al*. 2023; Petlamul & Prasertsan 2014). Using solid decanters to grow oil palm seedlings on topsoil from former coal mines resulted in greater growth in height, diameter, number of leaves, and leaf area than pre-nursery oil palm seedlings. The most substantial boost in oil palm seedling growth was obtained using solid decanters at a dose of 400 g/polybag (Mariani 2018). The purpose of this study was to evaluate the effectiveness of solid decanter and arbuscular mycorrhiza for the growth of oil palm pre-nursery utilizing ex-iron ore mining soil as a planting medium.

METHODS

This study was carried out from September to December 2022 on the experimental field of Andalas University's Campus III in Pulau Punjung District, Dharmasraya Regency, West Sumatra. The materials utilized in this investigation included DxP PPKS 540 Simalungun oil palm seeds. The planting materials utilized in this study included ex-iron ore mining soil, a solid decanter, arbuscular mycorrhiza, and 25 cm × 25 cm polybags. The following tools were utilized in the study: hoes, 75% paraffin, gloves, oven, hand sprayer, cellphone camera, 2 mm sieve, vernier calipers, and analytical scales.

This study employed a factorial Completely Randomized Design (CRD) with two factors and four treatment levels. The first element was the solid decanter (0, 200, 300, and 450 g), whereas the second factor was arbuscular mycorrhizae (0, 5, 10, and 15 g/polybag). The effect of the solid decanter nutrient gradient and inoculum intensity (MA) was assessed at various doses. Each treatment level had three replications, totaling 16 experimental units. Each experimental unit contained three plants, resulting in a total of 48 oil palm plants evaluated.

This study's implementation includes providing composted solid decanters, selecting a location, cleaning the research area, preparing the planting media, filling the polybags, applying arbuscular mycorrhiza to each treatment, providing solid decanters, planting, labeling, maintenance, and observation. The factors studied included initial soil analysis, solid decanter analysis, final soil analysis, seedling height, stem diameter, number of leaves, leaf blade length, fresh and dry seedling weight.

RESULTS AND DISCUSSION

Initial Soil Properties

This study employed previously examined soil from an iron ore mining operation. Table 1 shows the findings of the initial soil analysis. The initial soil investigation of the former iron ore mine revealed deteriorated soil chemistry. This soil included low to very low levels of essential nutrients such as N, P, and K. This issue was compounded by a soil pH of 3.97, which is considered highly acidic and inhibits plant root growth and development. The soil's low carbon content also resulted in limited nitrogen availability (Cotrufo *et al*. 2019). Organic carbon in soil is stored in a variety of chemical compounds, many of which contain nitrogen (N) and/or are produced by nitrogen-requiring bacteria. SOM (soil organic matter) requires more N per unit C than the available N (Averill *et al*. 2014; Georgiou *et al*. 2022; Schlesinger & Amundson 2019). The N nutrient content in the soil is very low, which was 0.09%. The low N concentration of the ex-iron ore mining soil is related to its low organic C content (0.93%), which is in the low range, with losses due to leaching and evaporation. (Ardiansyah *et al*. 2021; Sahputra *et al*. 2023) exposed that the low total N content was caused by a shortage of organic C in the soil due to leaching (run off), evaporation into the air, and transfer during harvest.

Solid Decanter Properties

The solid decanter was tested at the Sukarami Agricultural Technology Assessment Centre in West Sumatra. This analysis was performed prior to the field research. Table 2 shows the findings of the solid decanter analysis. N nutritional analysis revealed 3.81%, a very high percentage. The P nutrient concentration in the solid decanter was 901.41 ppm, which is extremely high. The K nutrition value was 0.49 cmol/kg, indicating a modest criterion. The pH study

Table 1 Initial soil analysis

Parameter	Value	Criteria*
N (%)	0.09	Very low
P (ppm)	6.42	Low
K (cmol/g)	0.22	Low
pH	3.97	Very acid
C-Organic (%)	0.93	Low
C/N	10.33	Low

Remark: *soil chemical criteria.

revealed a value of 6.81, which is within the neutral range. The organic carbon analysis yielded 23.64%, a very high criteria, however the C/N analysis yielded 6.20%, a low value.

Solid decanter waste from oil palm plantations has a high potential for usage as an organic fertilizer due to its high concentration of organic compounds and nutrients. However, these chemicals must decompose before plants may absorb them. Solid decanter waste from palm oil processing plants contains enough nutrients to be used as a growth media for oil palm nurseries (Maryani 2018).

Seedling Height

Table 3 shows the average height of oil palm seedlings with solid decanter and arbuscular mycorrhizal treatments 14 weeks after application. The analysis of variance for seedling height shows that there is no interaction between solid decanter and arbuscular mycorrhizal treatments on seedling height growth. Meanwhile, the solid decanter and arbuscular mycorrhizal treatments affect oil palm seedling height. The highest height of oil palm seedlings with solid decanter treatment was in the 450 g treatment (24.17 cm), which was significantly different from the 0 g treatment (19.25 cm) and the 200 g treatment (21.92 cm), but not from the 300 g treatment (19.67 cm) (Table 4). Meanwhile, the 10 g/polybag treatment had the highest arbuscular mycorrhizal growth (23.17 cm), which was substantially different from the 0 g/polybag treatment (20.25 cm) but not significantly different from the 5 g/polybag treatment (21.42 cm) or the 15 g/polybag treatment (22.83 cm). This demonstrates that the use of a solid decanter and arbuscular mycorrhizal fungi can influence oil palm height growth. Goswami *et al*. 2023 found that biological remediation approaches based on bacterial and fungal species had different degrees of efficacy in decolorizing melanoidins. AMF can help to enhance host plant biomass and improve nutrient delivery. They can also keep fertilizers and organic contaminants from entering groundwater through solid decanters (Nakatani *et al*. 2024). The level of organic substances found in plants treated with mycorrhizae was much lower than in non-mycorrhizal plants. This suggests that the fungus speeds up the breakdown of organic molecules (Goel *et al*. 2017; Goswami *et al*. 2023).

According to Egene *et al*. (2021), plant height growth is driven by the activity of the apical meristem, which is the component of the plant shoot that actively divides, allowing the plant to grow taller. Sutrisno *et al*. (2020) discovered that giving solid decanter bokashi had the greatest impact on oil palm seedling growth at a major nursery. The nutrients that plants can absorb

Table 2 Solid decanter content

Parameter	Value	Criteria*
N (%)	3.81	Very high
P (ppm)	901.41	Very high
K (cmol/g)	0.49	Middle
pH	6.81	Neutral
C-Organic (%)	23.64	Very high
C/N (%)	6.20	Low

Remark: Laboratory analysis by BPTP West Sumatra (2021).

Table 3 Seedling height (cm) in the 14th week with the provision of a solid decanter and arbuscular mycorrhiza

Solid decanter (g)	Arbuscular mycorrhiza (g/polybag)				Average
	0	5	10	15	
0	17.33	17.67	21.33	20.67	19.25 c
200	20.67	22.33	23.00	21.67	21.92 b
300	19.67	23.00	23.00	23.67	22.33 ab
450	23.33	22.67	25.00	25.33	24.17 a
Average	20.25 b	21.42 ab	23.17 a	22.83 a	21.92
CC = 10.16%					

Remark: Numbers in the same column and row followed by the same lowercase letter indicate no significant difference according to the DNMRT follow-up test at the 5% significance level.

Table 4 Stem diameter (mm) in the 14th week with the provision of solid decanter and arbuscular mycorrhiza

Solid decanter (g)	Arbuscular mycorrhiza (g/polybag)				Average
	0	5	10	15	
0	7.97	8.87	7.87	9.43	8.53
200	8.97	8.03	8.90	7.16	8.26
300	8.16	8.93	8.57	7.60	8.31
450	8.56	8.63	8.20	8.70	8.52
Average	8.41	8.61	8.38	8.22	8.41
CC = 12.87%					

are one of the variables that influence plant growth, resulting in increased cell size (Ginting *et al*. 2017). The diameter of the shadow is determined by the amount of nutrients taken by the plant; the more nutrients ingested, the larger the stem diameter (Lestari *et al*. 2020).

Stem Diameter

The average diameter of oil palm stems after 14 weeks of solid decanter and arbuscular mycorrhiza treatments (Table 5). The analysis of variance of stem diameter discovered that there was no interaction between solid decanter and arbuscular mycorrhiza, and neither had a significant effect on oil palm stem diameter. The average stem diameter of oil palm seedlings ranges between 7.16 and 9.43 mm. This is assumed to be because solid decanter and arbuscular mycorrhizae were unable to promote the growth of the oil palm seedling's stem diameter. Hayata *et al*. (2025) reported that plants will grow rapidly provided the needed nutrients, particularly nitrogen, are accessible in sufficient quantities. Nitrogen is a vital nutrient that promotes root, stem, and leaf growth, as well as plant height. Plants will develop rapidly if the necessary nutrients, particularly nitrogen, are accessible in sufficient quantities. Nitrogen is a vital nutrient that promotes root, stem, and leaf growth, as well as plant height.

Number of Leaves

Table 6 shows the average number of oil palm leaves treated with solid decanter and arbuscular mycorrhiza at 14 weeks post-application. The findings of the analysis of variance for the number of leaf blades show that there is no interaction between solid decanter and mycorrhiza, as well as no significant influence of solid decanter and arbuscular mycorrhiza on oil palm stem diameters. This study demonstrates that the application of solid decanter and arbuscular mycorrhiza had no effect on the growth of the number of leaves of oil palm seedlings, implying that the two treatments did not interact on the number of leaves of oil palm seedlings. The average number of leaves on oil palm seedlings 14 weeks after application was between 4.33 and 4.67. This is due to the very slow pattern of leaf production, making it impossible to influence the treatment of solid decanter and arbuscular mycorrhiza, which cannot help but increase the number of leaves in oil palm seedlings.

The number of leaves on oil palm seedlings is affected by genetic factors. Oil palm seedlings typically have 3.5 leaves after 3 months of planting, 4.5 leaves after 4 months, and 5.5 leaves after 5 months. Oil palm plants produce 2−3 leaves per month, with leaf output controlled by age, seasonal conditions, environment, and genetic factors (Suksa-ard *et al*. 2024).

Length of Leaf Blade

The results of the analysis of variance on the length of the leaf blades of 14-week-old oil palm seedlings exposed that there was an interaction between solid decanter and arbuscular mycorrhiza on the length of the leaf blades, indicating that the length of the leaf blades of oil palm seedlings in ex-iron ore mining soil is significantly affected. The average leaf blade length of oil palm seedlings ranged between 19.00 cm and 28.67 cm. The administration of solid decanter with a

Table 5 Number of leaves (mm) in the 14th week with the provision of solid decanter and arbuscular mycorrhiza

Solid decanter (g)	Arbuscular mycorrhiza (g/polybag)				Average
	0	5	10	15	
0	4.33	4.33	4.67	4.67	4.50
200	4.33	4.33	4.67	4.33	4.41
300	4.67	4.33	4.33	4.33	4.41
450	4.33	4.67	4.33	4.67	4.50
Average	4.41	4.41	4.50	4.50	4.45
CC = 12.95%					

Table 6 Leaf blade length (cm) in 14-week-old oil palm seedlings with solid decanter and arbuscular mycorrhiza application

Solid decanter (g)	Arbuscular mycorrhiza (g/polybag)				Average
	0	5	10	15	
0	19.00 a B	22.67 a A	20.33 b AB	23.00 b A	21.25
200	22.33 a A	21.33 a A	22.33 ab A	23.67 b A	21.67
300	21.33 a A	23.00 a A	22.33 ab A	20.67 b A	21.83
450	21.33 a B	24.00 a B	24.00 a B	28.67 a A	24.50
Average	20.99	22.75	22.24	24.00	22.31
CC = 8.65%					

Remark: Numbers in the same column followed by the same lowercase letter and in the same row followed by the same uppercase letter indicate no significant difference according to the DNMRT follow-up test at the 5% significance level.

dose of 450 g (S3) and arbuscular mycorrhiza with a dose of 15 g/polybag (M3) showed the best results for the length of oil palm seedlings' leaf blades, namely 28.67 cm, which was significantly different from the treatment of 0 g (S0) with arbuscular mycorrhiza 15 g/polybag (M3), 200 g (S1) with arbuscular mycorrhiza 15 g/polybag, and 350 g (S2) with arbuscular mycorrhiza 15 g/polybag (M3). MFA use in nurseries can improve plant disease resistance, while AMF can be effective in both pre-nursery and main-nursery settings (Hendarjanti & Sukorini 2022). Furthermore, applying a soil decanter directly to the soil can act as fertilizer and promote growth (Embrandiri *et al*. 2016).

Fresh Weight of Seeds

The analysis of variance revealed an interaction between the use of a solid decanter and arbuscular mycorrhizae on the fresh weight of oil palm seedlings, hence significantly influencing the fresh weight of oil palm seedlings in ex-iron ore mining soil (Table 7). The average fresh weight of oil palm seedlings aged 14 weeks after application ranged between 6.19 g and 16.33 g. The provision of solid decanter with a dose of 0 g (S0) and arbuscular mycorrhiza with a dose of 15 g/polybag (M3) showed the best results for fresh weight of seedlings, namely 16.33 g, which was significantly different from the treatment of 5 g (S1) with arbuscular mycorrhiza 15 g/polybag (M3), 200 g (S1) with arbuscular mycorrhiza 15 g/polybag, and 350 g (S2) with arbuscular mycorrhiza 15 g/polybag (M3) on the parameters of fresh weight of oil.

SEM examinations of the leaf epidermal reveal that guard cells close when soil decanter amendments or, in this case, OPDC are increased (Kawaguchi *et al*. 2008). Another study on kailan plants (*Vrassica oleracea* var. Alboglabra) discovered that they had the greatest morphological values for number of leaves, leaf area, shoots, root length, and root biomass (Bonny *et al*. 2023; George *et al*. 2024). Although physicochemical research indicates a favorable relationship between the OPDC ratio and nutritional concentration (Rahman *et al*. 2023). Adi and Yulianto (2022) and Mogea *et al*. (2022) defined fresh weight as the plant's whole weight. So, the plant's fresh weight is determined by its ability to absorb nutrients and water. According to Septian *et al*. (2021), fresh weight represents the plant's nutrient composition and water content. The availability of adequate levels of N, P, and K also influences plant water content.

Dry Weight of Seeds

The analysis of variance revealed that the solid decanter and arbuscular mycorrhizal dosages had a significant effect on the dry weight of oil palm seedlings in ex-iron ore mining soils (Table 8). The average fresh weight of 14-week-old oil palm

Table 7 Fresh weight of seedlings (g) in 14-week-old oil palm seedlings with the provision of solid decanter and arbuscular mycorrhiza

Solid decanter (g)	Arbuscular mycorrhiza (g/polybag)				Average
	0	5	10	15	
0	6.19 c C	13.8 ab B	13.95 ab B	16.33 a A	12.56
200	10.63 b B	14.59 a A	14.19 ab A	13.99 c A	13.35
300	10.87 b B	13.29 ab A	12.91 b A	14.15 bc A	12.8
450	13.31 a B	13.03 b B	15.35 a A	15.4 ab A	14.27
Average	10.25	13.67	14.1	14.96	13.24
CC = 6.98%					

Remark: Numbers in the same column followed by the same lowercase letter and in the same row followed by the same uppercase letter indicate no significant difference according to the DNMRT follow-up test at the 5% significance level.

Table 8 Dry weight of seedlings (g) in 14-week-old oil palm seedlings given solid decanter and arbuscular mycorrhiza

Solid decanter (g)	Arbuscular mycorrhiza (g/polybag)				Average
	0	5	10	15	
0	4.13 c B	5.76 a A	6.35 a A	6.57 a A	5.70
200	4.44 bc C	6.59 a A	5.51 ab B	5.86 ab AB	5.6
300	5.57 a A	5.76 a A	5.72 ab A	5.52 b A	5.64
450	5.24 ab A	4.70 b A	5.01 b A	5.70 ab A	5.16
Average	4.48	5.7	5.64	5.91	5.52
CC = 10.89%					

Remark: Numbers in the same column followed by the same lowercase letter and in the same row followed by the same uppercase letter indicate no significant difference according to the DNMRT follow-up test at the 5% significance level.

seedlings following application ranged between 4.13 g and 6.59 g. The provision of solid decanter with a dose of 200 g (S1) and arbuscular mycorrhiza with a dose of 5 g/polybag (M1) showed the best results for the fresh weight of seedlings, namely 6.59 g, which was significantly different from the treatment of 0 g (S0) with arbuscular mycorrhiza 5 g/polybag (M1), 0 g (S0) with arbuscular mycorrhiza 15 g/polybag and 350 g (S2) with arbuscular mycorrhiza 15 g/polybag (M3) on the parameters of fresh weight of oil palm seedlings.

The use of red soil or marginal soil in a soil decanter has little effect on microbial activity and speeds up composting, although it does lessen pile odors. Bacteria play an important role in composting because organic breakdown proceeds quickly during the first two weeks (Kananam *et al*. 2011; Tepsour *et al*. 2019).

CONCLUSION

Based on the findings of the study, we conclude that the administration of solid decanter and arbuscular mycorrhiza influences the length of leaf blades, fresh weight of seedlings, and dry weight of oil palm plants in the pre-nursery on ex-iron ore mine soil. A solid decanter dose of 450 g produced the highest values for plant height, number of leaves, and leaf blade length in oil palm plants grown in a pre-nursery on ex-iron ore mine site. The administration of 5 g of arbuscular mycorrhiza resulted in the optimal circumstances for stem diameter, number of leaves, and dry weight of seedlings in oil palm plants in the pre-nursery on ex iron ore mine soil.

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