Vol. 13(3): 662-675, September 2025

DOI: https://doi.org/10.23960/jsl.v13i3.1145

Jurnal Sylva Lestari

P-ISSN: 2339-0913
E-ISSN: 2549-5747

Journal homepage: https://sylvalestari.fp.unila.ac.id

Full Length Research Article

Utilization of Pulp and Paper Waste as an Ameliorant in Marine Clay Soil to Increase the Growth of *Eucalyptus pellita* F.Muell.

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ARTICLE HISTORY:

Received: 22 February 2025
Peer review completed: 4 June 2025
Received in revised form: 18 June 2025
Accepted: 17 July 2025

KEYWORDS:

Marginal land
Plant growth
Sludge
Soil improvement
Waste utilization

ABSTRACT

Marine clay land is formed due to hydrological factors, including acidity, low macronutrient levels, relatively high micronutrient levels, and a clay-dominant texture. Land improvement for marine clay land is necessary to enhance plant growth and productivity. *Eucalyptus pellita* is a plant that is adaptive to various types of land and is used as a raw material for pulp and paper, which is widely cultivated in Industrial Plantation Forest (HTI) in Indonesia. Research is needed to enhance the quality of marine clay soils and promote plant growth. Land quality can be improved by adding soil ameliorants from surrounding waste, such as waste from HTI, specifically pulp and paper sludge (KCa). This study used a combination of organic ameliorants (cocopeat and cattle manure) and inorganic (KCa, KCl, and dolomite), using a factorial complete random design consisting of two factors. The first factor was inorganic ameliorants, which consisted of four levels: A0 (no inorganic ameliorant), A1 (KCa 25 g), A2 (KCl 25 g), and A3 (dolomite 25 g). The second factor is organic ameliorants, which consists of 7 levels: B0 (no organic ameliorant); B1 (cocopeat 200 g); B2 (cocopeat 100 g); B3 (cocopeat 50 g); B4 (cattle manure 200 g); B5 (cattle manure 100 g); and B6 (cattle manure 50 g). The interaction of these two treatment factors resulted in 28 treatment combinations. A total of 1 kg of sterilized marine clay soil was placed in a polybag, then ameliorants were added according to the experimental design. The purpose of this study is to utilize HTI industrial waste as a soil ameliorant and to analyze the optimal dose of the ameliorant used during the study. The results of this study indicate that improving the quality of marine clay soil using a combination of organic and inorganic ameliorants enhances the growth in height and diameter of *E. pellita* compared to treatments using single ameliorants. The results showed that the treatment with B2A1 (cocopeat 100 g and KCa 25 g) was the most effective, yielding the highest growth response, diameter, and number of leaves compared to other treatments.

1. Introduction

Marine clay land is land that is affected by hydrological factors. This land is formed due to the weathering of feldspathic rocks, which produce secondary clay sediments that settle in lowlying areas, such as swamps. Most marine clay lands contain pyrite (FeS_2), which is formed by the reduction of sulfate ions to sulfide (Sustiyah et al. 2018). In anaerobic environments, the process is facilitated by reducing bacteria, often referred to as sulfate-reducing bacteria (Fahmi et al. 2024). Other studies have shown that microorganisms can reduce As, Fe, and Mn in the sedimentation of mine-contaminated rivers (Devore et al. 2022). Therefore, land improvement is necessary to enhance plant growth on marine clay land that contains soil microbes.

One example of marine clay land is in Ogan Komering Ilir (OKI) District, South Sumatra. OKI is a district located in the eastern part of Sumatra Island, with the landform of eastern Sumatra Island dominated by lowlands and peat swamps. Hydrologically influenced land, such as the OKI area, is characterized by acidic pH, low nutrient availability, high micronutrient availability, and dense soil texture. One type of plant that is suitable for growing in these conditions is *Eucalyptus pellita*. Research by Nadalia et al. (2021) shows that *E. pellita* can thrive in soils with low pH, low nutrient content, and low cation exchange capacity.

E. pellita is a fast-growing plant with a short life cycle, high economic value of wood, and good adaptability to climate and growing places.It is a raw material for pulp and paper due to its good wood properties (chemical and physical). Despite its widespread use as a substitute for *Acacia* spp. in the pulp and paper industry, *E. pellita* in Indonesia remains an underutilized resource with untapped potential (Andika et al. 2025). *E. pellita* plants are currently widely developed to replace *Acacia* spp., as a raw material for pulp and paper. The *E. pellita* tree is more resistant to leaf diseases. It is a fast-growing species with deep roots, so it is suitable for planting in industrial plantation forest areas. Even a hybrid clone of *E. pellita* and *E. camaldulensis* has been developed to meet the needs of industrial wood (Sukeno 2023).

Sustainable land management needs to be elaborated to increase crop productivity and improve soil quality by adding organic ameliorant and utilizing surrounding waste that can be used as soil ameliorant. A soil ameliorant is a material used to improve the physical and chemical properties of soil (Balai Penelitian Tanah, 2011). The research of Ginting et al. (2024) shows that adding soil ameliorants can increase soil nutrients and microorganisms in inceptisol land.

Types of ameliorants can be organic, inorganic, and biological. Organic ameliorants are plant and animal composting materials rich in complex nutrients, such as coir pith (also known as cocopeat) and cattle manure. Cocopeat possesses physical and chemical properties that make it an ideal medium for planting. Physical properties such as space capacity, humidity, porosity, and water-holding capacity are suitable for use as a medium, especially on dense land, such as marine clay. High porosity can improve the density of dense marine clay and make it looser. A study by Raju et al. (2023) shows that cocopeat has a total porosity of 87.5%. Cattle manure has a total porosity of 41.57% (Khater 2015).

Inorganic ameliorants are soil enhancers produced through a chemical process or containing chemicals, such as KCa (derived from pulp and paper sludge waste). In addition to being used as an ameliorant, KCa can also be utilized as a sustainable raw material for producing bio-CH_4, bio-H_2, bioethanol, biobutanol, and biodiesel (Kumar et al. 2025). Sludge from the paper industry has the potential to serve as a soil ameliorant, as it meets the requirements outlined in the Ministry of Agriculture's Kementan Number 261 of 2019 (Kusumarini et al. 2022). KCa can be used as an ameliorant because it has a neutral pH, can increase cation exchange capacity, thereby increasing nutrient availability, and does not contain harmful microbial contamination (Kusumarini et al. 2022; Lee et al. 2023).

Research on the application of organic ameliorants and KCa on marine clay land has not been widely carried out on *E. pellita* plants. Therefore, this research can serve as a reference for utilizing pulp and paper sludge waste to enhance plant growth, particularly in *E. pellita*, in Industrial Plantation Forests (HTI). The application of several levels of organic ameliorants aims to determine the optimal fertilization dose and utilize KCa waste from the pulp and paper industry, making it a more environmentally friendly approach. Optimizing plant growth can increase plant volume, resulting in optimal production outcomes.

2. Materials and Methods

2.1. Description of Research Location

This research was conducted over a period of 6 months, including 8 weeks of plant growth observation, and was carried out in open nurseries. The research location was situated in Air Sugihan Sub-District, Ogan Komering Ilir Regency, South Sumatra Province (**Fig. 1**). When viewed on the map, the research location is close to the sea and is located in a peat area. This condition makes the research location categorized as marine clay land.

Fig. 1. Research location.

2.2. Research Materials and Tools

The materials used in this study were 20 cm × 20 cm polybags, marine clay soil, 20-day-old *E. pellita* seedlings with a height of about 18–20 cm and a diameter of about 1.6–2.0 mm, organic ameliorants (cocopeat and cattle manure), inorganic ameliorants (KCa fertilizer, KCl fertilizer, and dolomite lime). The form of KCa and KCl fertilizer is granular. Dolomite lime comes in powder form. The tools used in this study were digital scales, digital calipers, tally sheets, dosing spoons, plant tags, hoes, gloves, biopore drills, 5 m of measuring tape, and DSLR cameras.

Each ameliorant used has a different nutrient content. The nutrient content of cocopeat is as follows: pH 5.02; C-organic 55.87 mg/kg; P 7.95 mg/kg; total N 0.49 mg/kg; and CEC 86.47 (Shafira et al. 2021). Cattle manure contains the following nutrients: pH 8.1, total C-organic

18.16%, total N 0.93%, total P 0.21%, and C/N ratio 19.53:1 (Khater 2015). The physical and chemical characteristics of the KCa are as follows: pH 7.5; moisture content 68.3%; total solids 31.7%; ash content 12.89%; total N 138.6 mg/kg; total C 48.6%; and C/N ratio 34.91% (Wahyono 2000). KCl fertilizer contains 60% K_2O and 40% Cl (Kamaratih and Ritawati 2020). The nutrient content of dolomite is as follows: Ca^{2+} 19.04%; Mg^{2+} 9.72%; and pH 9.4 (Puspitasari et al. 2023).

2.3. Research Procedure

2.3.1. Soil Sample Collection

Soil samples were taken from the marine clay at a depth of 20 cm at five points and then composited (Badan Standardisasi Nasional 2018). The soil samples were then analyzed in the soil laboratory for physical and chemical properties. Soil chemical properties analyzed were pH-H_2O with water extraction method; Al and H elements with 1 N-KCl extraction method; Cu, Fe, Mn, and Zn with 0.05 N hydrogen chloride + 0.025 N sulfuric acid; P_2O_5 Bray I method; C-organic method Walkley and Black; N-Available Kjeldahl method; CEC, K, Ca, Mg, Na with 1 N ammonium acetate method pH 7. This analysis method follows the soil laboratory standard, as outlined in SNI 5006.2:2018 (Badan Standardisasi Nasional 2018).

2.3.2. Preparation of planting media

The soil medium in the form of marine clay was sterilized by drying in the sun for 2-3 days. The sterilized media were put into polybags with a diameter of 20 cm and a soil weight of 1 kg per polybag. The addition of cattle manure and cocopeat is at three levels: 50 g, 200 g, and 100 g per polybag. The doses were given based on similar research references and modified according to this study. Research by Herawati et al. (2021) shows that organic ameliorants, such as those found in cattle manure and biochar, provide the best response compared to the combination of fertilization with inorganic materials. The dosage of each inorganic ameliorant (KCa, KCl, and dolomite) was 25 g per 1 kg of soil. Each inorganic ameliorant was added to 1 kg of marine clay soil and then placed in a polybag (**Fig. 2**).

Fig. 2. Preparation of planting media for *E. pellita*.

2.3.3. Seedling Preparation

The seedlings used were 20-day-old *E. pellita* from shoot cuttings with a height of about 18-20 cm and a diameter of about 1.6-2.0 mm (**Fig. 3.**). Those samples refer to the book of seedling quality standards for plantation forests and land rehabilitation by modifying the seedling quality standards according to field conditions (Nurmin et al. 2019).

Fig. 3. *E. pellita* seedlings from shoot cutting.

2.3.4. Growth and Maintenance Measurement

The observed plant growth parameters included an increased number of leaves, height growth, and plant diameter. Measurements were taken every 1 week for 3 months. The increase in the number of leaves was calculated every week, and the total increase was recorded at the end of the study. Height measurements were parallel to the height of the plant and were measured from the lower base of the plant to the nodes or shoots of *E. pellita*. The increase in stem diameter was measured using digital calipers in two different directions, 1 cm from the base of the stem (**Fig. 4**). The climatic factors used in this study included rainfall, temperature, and humidity data. Rainfall data were obtained from Manggala Agni in the South Sumatra region, while temperature and humidity were measured using a hygrometer.

Fig 4. Plant measurement *E. pellita*.

2.3.5. Analysis procedures

The experimental design in this study employed a completely randomized design (CRD) with two factors. The first factor consists of 7 levels with organic ameliorant treatment, and the second factor consists of 4 levels using inorganic ameliorant treatment (**Table 1**).

There are 28 treatment combinations, each with three replications, resulting in a total of 84 experimental units. The linear model used is:

$$Yijk = \mu + \alpha i + \beta j + (\alpha\beta)ij + \varepsilon ijk \quad (1)$$

where *Yijk* is the response from observation of organic ameliorant factor level i, inorganic ameliorant factor level j, and treatment repetition k inorganic ameliorant factor at level j and replicate k, μ is the general mean value, αi is the effect of organic ameliorant treatment level i, βj is the effect of inorganic ameliorant treatment level j, $(\alpha\beta)ij$ is the effect of interaction between organic ameliorant factor level i and inorganic ameliorant factor level j, εijk is the random effect of the treatment of organic ameliorant at level i, inorganic ameliorant fertilizer at level j, and replication k, *i* is the organic ameliorant factor, *j* is the inorganic ameliorant factor, and *k* is replication 1, 2, and 3.

Table 1. The treatment combinations

Inorganic ameliorants	Organic ameliorants
A0 (without inorganic ameliorants)	B0 (without organic ameliorant)
A1 (KCa 25 g)	B1 (cocopeat 200 g)
A2 (KCl 25 g)	B2 (cocopeat 100 g)
A3 (dolomite 25 g)	B3 (cocopeat 50 g)
	B4 (200 g cattle manure)
	B5 (100 g cattle manure)
	B6 (50 g cattle manure)

The data obtained will be analyzed using SPSS 25.0 (Statistical Package for the Social Sciences) with the two-way ANOVA method and a 5% significance level. Analysis of variance is a statistical test used to evaluate hypotheses about the effect of treatment factors on various types of experimental data results. These results will be used to determine whether each treatment in this study significantly affects the combination treatment, as assessed by the Duncan Multiple Range Test (DMRT).

3. Results and Discussion

3.1. Analysis of Soil Chemical Properties

The characteristics of soil chemical properties are essential to know the condition of marine clay soil used in plant growth media. The data is essential to provide information in conducting soil management with integrity. Based on the data in **Table 2**, the marine clay soil used is peat soil with a clay substrate or sediment. Soil with clay content or deposits will be difficult for plant growth, especially in root development. The criteria for soil chemical properties below the threshold are challenging to support plant growth. The parameters of the chemical properties of marine clay soil have values below the threshold, such as soil pH < 4.5, available P < 15, Ca < 2, and Mg < 2.

The results of the pH analysis of the marine clay soil fall within the very acidic category, with a value of 3.77. This phenomenon is caused by the interaction of pyrite in the soil that has been oxidized. The pyrite oxidation reaction that causes acidity in the soil is as follows:

$$2FeS_{2(s)} + 7O_2 + 2H_2O \rightarrow 2Fe^{2+}{}_{(aq)} + 4H^+ + 2SO_4{}^{2-} \quad (2)$$

$$2Fe^{2+}{}_{(aq)} + 1/2O_2 + 2H_2O \rightarrow 2Fe_2O_{3(aq)} + 4H^+ \quad (3)$$

Table 2. Results of chemical property analysis of marine clay soil

Parameters	Value	Unit	Criteria
pH H_2O	3.77		Very acid
C-organic	4.06	%	High
N	0.27	%	Medium
P-availability	13.42	Ppm	Low
Ca	0.19	$cmol^+/kg$	Very low
Mg	1.00	$cmol^+/kg$	Low
K	0.26	$cmol^+/kg$	Low
Na	0.43	$cmol^+/kg$	Medium
KTK	24.29	$cmol^+/kg$	Medium
H	3.96	$cmol^+/kg$	Medium
Al	18.45	$cmol^+/kg$	High
Fe	547.85	%	Very high
Zn	1.35	%	Very low
Mn	2.90	%	Very low
Cu	1.01	%	Very low

Equations 2 and 3 show that each mole of oxidized pyrite produces 4 H^+ (Maftu'ah et al. 2024). The pyrite oxidation reaction increases soil acidity (pH 2-3). Fe or iron content is a key factor in forming pyrite, which is assisted by reducing bacteria. A high iron content is typically accompanied by an increase in pyrite content in the soil (Fahmi et al. 2024). This statement follows the analysis of iron (Fe) content in marine clay soil, which is categorized as very high.

Another low quality of chemical properties of marine clay soil is P-available, with a value of 13.42 (ppm) below the low criteria. The study of P nutrient adequacy in acid-sulfate soils stated that low P nutrient availability is the primary problem in these soils. Low P availability is caused by soil acidity due to the more significant amount of P bound by micronutrients in the soil, so P is unavailable to plants. This phenomenon is attributed to the fixation of P by positively charged Al and Fe, resulting in a lack of nutrient availability in the soil. Excess Al, Fe, and Mn in the soil can cause plant toxicity (Maftu'ah et al. 2024).

The compound produced by the fixation of P by Al is aluminum phosphate. Acidic soil conditions cause the aluminum content that can bind phosphorus elements to increase, thereby releasing base cations that enhance phosphorus availability in the soil. Based on the research (Gypser et al., 2021), the greater the pyrite oxidation, the greater the increase in Al will be. The resulting reaction can be written as follows:

$$Al(OH)_3 + 3H_2PO_4 \rightarrow Al(H_2PO_4)_3 + 3OH \quad (4)$$

If the $Al(OH)_3$ concentration in the soil increases, the reaction will shift to the right, resulting in the formation of insoluble aluminum phosphate compounds. These conditions render $H_2PO_4^-$ ions unavailable to plants. These results follow the soil conditions in **Table 2,** where the Al element is included in the high criteria. In-ground with a very low pH (< 4), the solubility of Al will be high, resulting in considerable mobility of Al in the soil. Al and Fe have an important role in the release of P in the soil. P release occurs through anion exchange if there is a decrease in P adsorption in pure amorphous Al-hydroxide (Gypser et al. 2021).

Soil acidity also causes a reduction in macronutrients in the soil, such as calcium (Ca), magnesium (Mg), and potassium (K). In the analysis of marine clay soil conditions in **Table 2**, the available macro-nutrient content is categorized as low to very low. This reduction is due to the high decomposition activity of organic matter, which is always accompanied by the release of macronutrients into the soil.

The low calcium (Ca) or calcium availability in marine clay soil conditions is attributed to the high organic matter content and does not correlate with the value of base saturation (Räty et al. 2023). Ca elements can be absorbed by plants in the form of Ca^{2+}. Plant roots can absorb this element through root interception or mass flow. Additionally, low Ca elements can also be caused by soil leaching from rainwater or drainage water. The higher the leaching, the more Ca elements are leached into the soil layer. Leaching of the soil also results in the reduction of the Mg or Magnesium element in the soil. Magnesium is an element that slowly depletes as the soil-leaching process continues (Gypser et al. 2021).

The condition of soil chemical properties indicates that soil amendments are necessary to enhance soil quality and promote plant growth. Organic and inorganic ameliorants are administered singly or in combination to achieve the optimal dose and treatment in this study. The best treatment is indicated by the response of plant growth to the addition of organic ameliorants, specifically the increase in height, diameter, and number of leaves.

3.2. Plant Height Growth

Plant height growth was measured weekly until 8 weeks after planting. Each treatment showed a significant effect when compared to the control. This result shows that the soil amendments given have a positive effect on the growth of *E. pellita* plants. In detail, the Duncan test results of plant height parameters are presented in **Table 3**.

Table 3. Results of height growth parameters (cm) of *E. pellita* plants

Organic ameliorants	Inorganic ameliorants			
	A0	**A1**	**A2**	**A3**
B0 (without organic ameliorant)	18.67a	33.33bc	28.33b	35.67cde
B1 (cocopeat 200 g)	35.00bcde	37.33cdefg	33.67bc	37.33cdefg
B2 (cocopeat 100 g)	45.00hi	52.33j	39.67cdefgh	50.00ij
B3 (cocopeat 50 g)	37.67cdefg	41.00defgh	34.67bcde	41.00defgh
B4 (200 g cattle manure)	38.67cdefgh	37.33cdefg	34.00bcd	37.33cdefg
B5 (100 g cattle manure)	35.67cde	34.00bcd	41.67defgh	43.33fgh
B6 (50 g cattle manure)	33.33bc	43.67gh	40.33cdefgh	36.33cdef

Notes: A0= without inorganic ameliorants, A1= KCa 25 g, A2= KCl 25 g, A3= dolomite 25 g. Notes: The analysis in this study uses a 95% confidence interval with an alpha value of 0.05. So, in the data, the significance value is less than 0.05 or ($p < 0.05$). Numbers followed by the same letter in the column and row show no significant difference based on the results of Duncan's Multiple Range Test (DMRT).

The results of ANOVA at a 95% confidence interval and DMRT on plant height growth of *E. pellita* obtained a combination with the best response, namely the application of mixing cocopeat 100 g + KCa 25 g (B2A1), which is not significantly different from the combination treatment of cocopeat 100 g + dolomite lime 25 g (B2A3). Significantly different in the control treatment (B0A0). This phenomenon occurs because the use of ameliorants with high organic matter content and complete nutrients can improve soil structure and nutrient levels, thereby increasing the growth rate of forestry plants, particularly in terms of plant height (Herawati et al. 2021).

KCa fertilizer contains organic matter that is amphotic and has a neutral pH to alkaline pH (6.4-11), total C 381 – 432 g/kg dry weight, and moisture 53.8 – 66.2% (Räty et al. 2023). Dolomite lime can also increase and maintain pH levels because its content can improve soil microorganisms and remove residues. Neutral pH conditions and balanced nutrient content will result in normal plant growth.

Providing soil ameliorants can improve soil chemical properties, particularly in terms of nutrient availability and soil acidity. This is because neutral pH can optimize nutrient absorption and plant growth. Providing inorganic ameliorants in the form of KCa fertilizer (waste sludge pulp and paper) can increase soil fertility and nutrient availability.

Primer pulp and paper mill sludge (Pri PPMS), or in this study called KCa, is composed of high-fiber materials, contaminants, and inorganic paper fillers (e.g., calcium carbonate ($CaCO_3$), kaolin (Al_2O_3, SiO_2), and titanium dioxide), as well as lignin and ash by-products (Kumar et al. 2025). Because KCa has inorganic content, combining KCa treatment with organic ameliorant in this study is necessary to reduce contaminants.

The addition of PPMS in the study by Räty et al. (2023) increased air retention, resulting in an increase in the volumetric air content in soil with a coarse texture. Soil with a coarse texture has high permeability properties, which means it will quickly release water, easily causing drought for plants. Ameliorants from KCa can function to reduce air shortages during drought in coarse-textured soils (characterized by very high porosity), thereby providing a suitable environment for microbes. Conversely, in dense soil textures such as marine clay soil, KCa can increase soil porosity. This phenomenon is consistent with the condition of the marine clay soil before treatment, which has a low P element content (**Table 2**). The addition of P elements by cocopeat can increase root growth. Cocopeat can also increase the availability of the K element in the soil (Setyawati et al. 2023). The K element plays an important role in photosynthesis, helping to regulate water use and maintain the electrical charge balance at the ATP production site (Silva and Uchida 2000). Another study found that E. pellita plants aged 75 and 90 days, grown on cocopeat planting media, also met the physical quality criteria of target seedlings based on morphological characteristics (Ekamawanti et al. 2021).

3.3. Plant Diameter Growth

Based on an ANOVA at a 95% confidence interval, when applying organic and inorganic ameliorants, it was found that the compound of organic and inorganic ameliorants had a significant effect on the diameter growth parameters of *E. pellita* plants (**Table 4**). However, the inorganic ameliorant factor had no significant effect. This result is due to the use of inorganic ameliorants, which provide complex and rapidly available nutrients but are present in small amounts. Previous research results have reported that organic fertilizers can complement inorganic fertilizers by providing a more balanced set of elements and maintaining soil fertility effectively.

Based on ANOVA at a 95% confidence interval and DMRTon the diameter growth parameters of *E. pellita*, the most significant treatment combination results were obtained, namely the B2A1 treatment (cocopeat 100 g + KCa 25 g) which did not differ at the 5% level from the B6A1 treatment (cattle manure 50 g + KCa 25 g). This result is likely due to the significant influence of complete nutrient availability on plant growth.

The superiority of cocopeat in encouraging rapid root growth stems from its high water absorption and availability, its nutrient-rich composition, and its neutral pH. According to

Rosianty et al. (2021), using cocopeat and peat soil as planting media can increase the diameter growth of *E. pellita* compared to using peat soil alone. Cocopeat can enhance plant growth because it has a high water absorption capacity, thereby maximizing water uptake (Ariessandy et al. 2022). Cocopeat can provide nutrients that can support diameter growth and improve soil quality. Research on cocopeat as a substitute for topsoil states that cocopeat has a pH (5.02), C-organic (55.87), P (7.95), N-total (0.49), and CEC (86.47) levels (Shafira et al. 2021).

Table 4. Results of diameter growth parameters (mm) of *E. pellita* plants

Organic ameliorants	Inorganic ameliorants			
	A0	**A1**	**A2**	**A3**
B0 (without organic ameliorant)	24.33a	29.67ab	30.67abc	34.67bcdef
B1 (cocopeat 200 g)	34.00bcde	36.33bcdefg	32.00bcd	37.33cdefg
B2 (cocopeat 100 g)	41.00efghi	46.00i	40.00efghi	38.00cdefgh
B3 (cocopeat 50 g)	38.67defghi	37.00cdefg	33.67bcde	40.67efghi
B4 (cattle manure 200 g)	42.33ghi	36.00bcdefg	40.67efghi	42.33hi
B5 (cattle manure 100 g)	37.33cdefg	34.00bcde	41.67fghi	38.00cdefgh
B6 (cattle manure 50 g)	39.00defghi	45.00hi	41.67fghi	37.67cdefgh

Notes: A0= without inorganic ameliorants, A1= KCa 25 g, A2= KCl 25 g, A3= dolomite 25 g. The analysis used in this study employs a 95% confidence interval, corresponding to an alpha value of 0.05. So, in the data, the significance value is less than 0.05 or ($p<0.05$). Numbers followed by the same letter in the column and row show no significant difference based on the results of Duncan's Multiple Range Test (DMRT).

Inorganic ameliorants in the form of KCa Fertilizer, which is processed from pulp and paper sludge waste, contain N, P, and C-organic elements and other microelements. The low pH value and high element content can lead to better growth quality. Ameliorants in the form of KCa can increase nutrients, thereby enhancing photosynthesis and promoting productive stem development. Amending coarse mineral soils with KCa increased total porosity, decreased soil bulk density, and improved soil water retention properties (Räty et al. 2023).

3.4. Leaf Number Increase

The growth of the number of leaves cannot be separated from the availability of sodium, potassium, and phosphorus nutrients. N, K, and P elements play a crucial role in forming new cells and regulating the movement of stomata, which can affect the growth and development of leaves. The growth in the number of leaves over a two-month period is shown in **Fig. 2**.

Based on **Fig. 5**, it is known that the number of leaves in the highest rank is the combination treatment of B2A1 and B3A3, with a total number of leaves of 39 strands. The lowest rank is the combination treatment B0A0, with a total number of 22 leaves, followed by the combination treatment B0A2, with 26 leaves. The most effective treatments for the growth of the number of leaves are cocopeat 100 g + KCa 25 g (B2A1) and cocopeat 50 g + dolomite lime 25 g (B3A3). The treatment of organic ameliorants in the form of cocopeat (50 g) without inorganic ameliorants (B3A0) also yields several leaves that are not significantly different from those of the highest treatment. Based on the research results of Rosianty et al. (2021), it was reported that using cocopeat and peat soil can significantly increase leaf growth every week, with a total of 34 leaves observed during the study. This result is thought to be due to the use of compound ameliorants that do not affect the growth of the number of leaves of *E. pellita*.

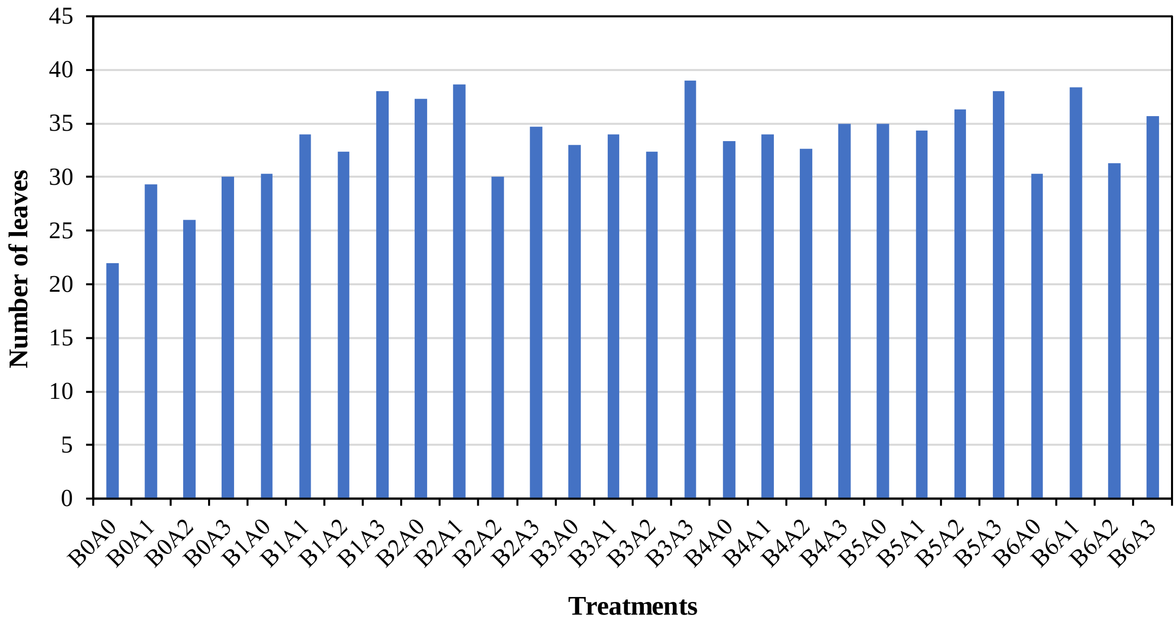

Fig. 5. Increase in *E. pellita* leaves in each treatment.

According to the ANOVA results at a 95% confidence interval, the use of organic and inorganic ameliorant applications does not significantly affect the use of ameliorants alone. This result is illustrated in **Fig. 5**. The combination treatment B2A0 (cocopeat 100 g + no inorganic ameliorants) with a total of 37 leaves is not significantly different from the highest treatment, B2A1, or treatment B3A3. However, the number of leaves increased weekly, as shown in **Fig. 6**.

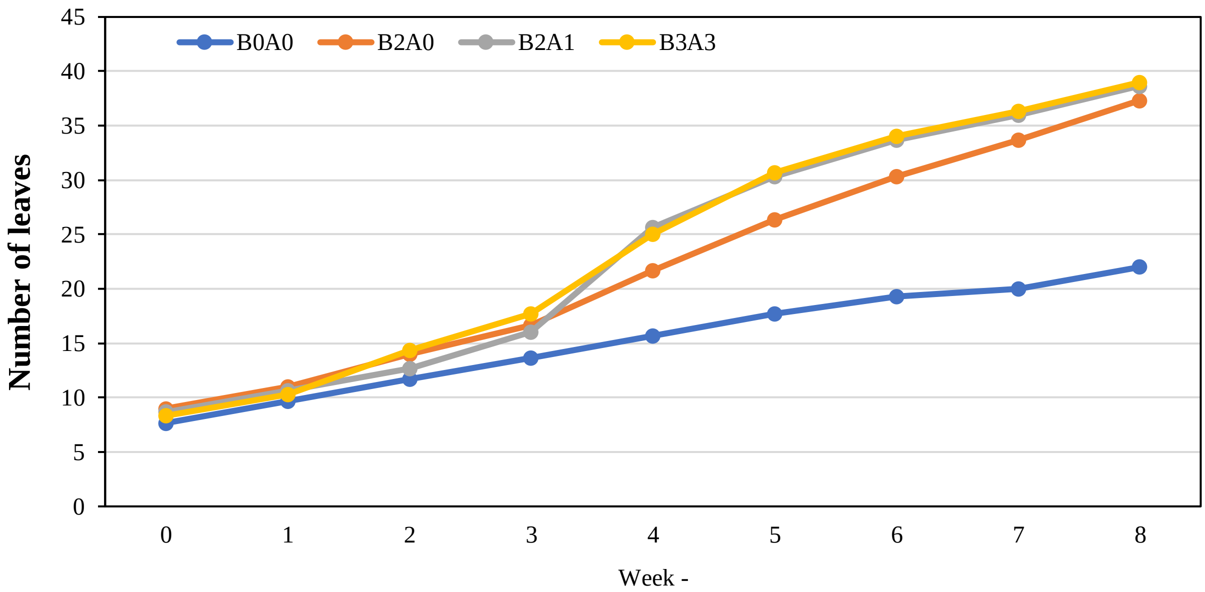

Fig. 6. Weekly leaf number increase in the best treatment and control.

The growth rate of the number of leaves shows no significant difference in **Fig. 6**. Each treatment with organic and inorganic ameliorants experienced the same increase but differed significantly from those without organic or inorganic ameliorants (B0A0). This phenomenon is influenced by climatic conditions, particularly rainfall, which affects leaf growth and development. Based on rainfall data from the Manggala Agni region in South Sumatra, the highest rainfall occurred in weeks 3 and 4. The data corresponds with **Fig. 6**, which shows a significant increase during those weeks. Water scarcity can decrease the number, width, and length of leaves (Medyouni et al. 2021). Water availability is essential for leaf growth, particularly during cell division and development. Cell development in the apical meristem can give rise to this primordial tissue, which will later become a leaf. The faster the cell development process is influenced by water availability, the greater the increase in leaf growth will be.

4. Conclusions

Marine clay soil in Air Sugihan District, Ogan Komering Ilir Regency, has soil chemical properties that are less favorable for plant growth. The threshold values, such as very acidic pH, macronutrients like P-available, Mg, and Ca, are low, high Al, and very high Fe. Improving the quality of marine clay soil by applying a combination of organic and inorganic ameliorants yields a significant response in terms of height and diameter growth of *E. pellita* plants, compared to the ameliorant treatment alone and without any ameliorants. However, it does not affect the variable number of leaves. The growth of leaves is related to water availability. In the variable growth of height, diameter, and number of leaves of *E. pellita*, the treatment combination of cocopeat 100 g and KCa fertilizer 25 g is the most optimal treatment compared to other treatments. As an implication of this study, a combination of organic and inorganic amendments is necessary to enhance plant growth in marine clay soils.

Acknowledgments

The authors would like to thank BIMA Kemendikbudristek of the Republic of Indonesia for funding this research under the Novice Lecturer Research Scheme, with the main contract number 039/E5/PG.02.00.PL/2024, dated 11 June 2024, and the derivative contract 1570r/IT9.2.1/PT.01.03/2024.

Author Contributions

K.M.: Conceptualization, Methodology, Writing–Original Draft Preparation, Supervision; M.H.: Software, Validation, Formal Analysis, Investigation, Resources, Data Curation; F.M.J.: Writing–Review and Editing, Proofreading; R.A.M.: Writing–Review and Editing, Supervision; J.: Project Administration.

Conflict of Interest

The authors declare no conflict of interest.

Declaration of Generative AI and AI-Assisted Technologies in the Manuscript Preparation

During script writing, the authors utilized Grammarly and Perplexity to refine the English writing. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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