EFFECT OF PULP SLUDGE COMPOST VS. MANURE FERTILIZER APPLICATION TO THE GROWTH OF GERONGGANG (*Cratoxylum arborescens*) SEEDLINGS IN PEAT SOIL

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EFFECT OF PULP SLUDGE COMPOST VS. MANURE FERTILIZER APPLICATION TO THE GROWTH OF GERONGGANG (*Cratoxylum arborescens*) SEEDLINGS IN PEAT SOIL. The pulp industry is crucial for Indonesia, but the waste produced should be managed. Pulp sludge contains organic matter suitable for compost material. This study examines the response of geronggang (*Cratoxylum arborescens*) seedlings' growth to the application of pulp sludge compost compared to commercial manure fertilizer and non-fertilized soil for six months. A fifteen kg of pulp sludge (water content of 60-70%) mixed with decomposers (*Penicillium citrinum* and *Penicillium oxalicum* (10^7 spores/mL)) was incubated for a month. The compost or fertilizer at a dosage of 0, 2, 4, 6, 8, 10, 12, 14, and 16 (tons/ha) was added to peat soil for the seedlings' growing media. The manure fertilizer contained higher macronutrients than the sludge compost, while the peat was considered poor soil. Seedlings with sludge compost or manure fertilizer addition at a dosage equal to 2 (tons/ha) showed the highest survival rate after six months. The sludge compost addition raised the seedling's height, diameter, and dry weight more than another treatment. The sludge compost at a dosage equal to 16 and 12 (tons/ha) significantly increased the height and diameter of the seedlings, respectively. The sludge compost has shrink-swell characteristics that are potent water retention in dry soil.

Keywords: Composting, decomposers, geronggang (*Cratoxylum arborescens*), peat, pulp sludge

*RESPONS BIBIT GERONGGANG (*Cratoxylum arborescens*) TERHADAP PENAMBAHAN KOMPOS DARI LIMBAH PULP DI TANAH GAMBUT. Industri pulp merupakan industri unggulan Indonesia, namun limbah yang dihasilkan harus dikelola. Limbah pulp mengandung bahan organik yang sesuai sebagai bahan kompos. Tulisan ini bertujuan untuk mengetahui respons pertumbuhan bibit geronggang (*Cratoxylum arborescens*) terhadap penambahan kompos dari limbah pulp dibandingkan dengan pupuk kandang dan tanpa pemupukan selama enam bulan. Sebanyak 15 kg limbah pulp (kadar air 60-70%) dicampur dengan dekomposer (*Penicillium citrinum* dan *Penicillium oxalicum* (10^7 spores/mL)) diinkubasi selama satu bulan. Kompos dan pupuk kandang dengan dosis 0, 2, 4, 6, 8, 10, 12, 14 and 16 (ton/ha) ditambahkan ke tanah gambut untuk media pertumbuhan bibit. Pupuk kandang memiliki kadar nutrisi makro yang lebih tinggi daripada kompos limbah pulp, sementara itu tanah gambut tergolong miskin hara. Bibit dengan penambahan kompos limbah pulp atau pupuk kandang dengan dosis setara dengan 2 (ton/ha) menunjukkan tingkat kelangsungan hidup tertinggi setelah enam bulan. Penambahan kompos dari limbah pulp mampu meningkatkan tinggi, diameter dan berat kering bibit dibanding perlakuan lainnya. Kompos dari limbah pulp dengan dosis setara dengan 16 dan 12 (ton/ha) secara berturut-turut signifikan meningkatkan tinggi dan diameter bibit. Kompos dari limbah pulp memiliki karakteristik mengembang-menyusut sehingga berpotensi sebagai penahan air pada tanah kering.*

*Kata kunci: dekomposer, gambut, geronggang (*Cratoxylum arborescens*), limbah pulp, pengomposan*

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I. INTRODUCTION

The Indonesian pulp industry has consistently increased its products through the years. During 2011-2017, the pulp industry ranked among the top three for forestry product exports (Ekarina, 2019). Then, in 2018, the production capacity for pulp and paper products was 16 tons and 11 tons, respectively (Rini, 2019). According to Bajpai (2015), 1 ton of the produced paper will generate sludge (dry) of about 40 to 50 kg. Meanwhile, Aldila (2016) mentioned that sludge production in pulp, paper, and integrated pulp and paper industries in Indonesia was 30 thousand tons per year, seven thousand tons per year, and 200 thousand tons per year, respectively. However, the sludge mainly generated from water sludge effluent was piled within industry areas and caused aesthetic disturbance, pollution, and an unpleasant odor (Yuzelma, Ahmad, & Nofrizal, 2013). According to Government Regulation No. 18/1999, sludge from the pulp and paper industries is categorized as dangerous and poisonous residues because it contains organic resin and binder, halogenated hydrocarbons, organometallic compounds, heavy metals (Pb, Cr), detergents and flammable solvents. On the other hand, the government released the Indonesian National Standard (ISN) 7847-2012 for a managed water effluent sludge into soil amendment (National Standardization Agency, 2012). However, the industries should report the use of the soil amendment to the government before applying it to industrial plantations (Aldila, 2016).

Recycling the pulp sludge into compost can reduce the volume of sludge piles in landfills or pulp industry areas. The sludge composting activities can be held by adding decomposers or organic materials to raise the compost quality. According to Ghribi, Mouelhi, & Beauregard (2016), paper sludge contains various bacteria, particularly the ligninolytic enzyme producer bacteria. However, the water-saturated sludge causes anaerobic bacteria to dominate the decomposition. Although bacteria are adaptive to abiotic factors, the degradation rate of wood by bacteria is slow (Aarti, Arasu, & Agastian, 2015). Meanwhile, pulp and paper sludge are high in lignin content and characterized by a dark color. Aerobic composting can be conducted by reducing the sludge water content through a pressing method or by sun-drying.

Some fungus species have been known to degrade lignocellulose. *Penicillium citrinum* and *Penicillium oxalicum* are lignocellulose fungi that produce cellulolytic enzymes (Suely et al., 2014; Yao et al., 2015). *P. oxalicum* isolated from fresh cow dung and cow dung compost was identified as a strong cellulose decomposer (Zhu et al., 2015). *P. oxalicum* can produce CMCase in a high percentage in a basal medium by using banana peel as the C organic source (Shah, Kalia, & Patel, 2015). Meantime, *P. citrinum* that grew in carboxymethyl cellulose agar (CMC) formed the largest clear zone for about 21.20 mm after being incubated for five days (Waing, Abella, Kalaw, Waing, & Galvez, 2015). This study employed *P. citrinum* and *P. oxalicum* as decomposers for pulp sludge composting.

Geronggang (*Cratoxylum arborescens*) is a local native species of peatland with the potential for raw pulp material (Ariyanti, 2016; Aprianis, Akbar, & Rizqiani, 2018) and peatland rehabilitation (Giesen & Nirmala, 2018). Aprianis et al.(2018) showed that the lignin content of geronggang (21.71-23.70%) is lower than that of *Acacia crassicarpa* (27.25%), while the fiber of *A. crassicarpa* (1306 μm) is longer than that of geronggang (1134-1156 μm). However, a difference in wood density between geronggang and *A. crassicarpa* resulted in a higher need for raw pulp material for geronggang (Ariyanti, 2016; Suhartati, Rahmayanto, & Daeng, 2014). However, Balai Penelitian Teknologi Serat Tanaman Hutan (2014) explained that geronggang produces slowly decomposed litter for the forest floor, while litter decomposition of *A. crassicarpa* and *Eucalyptus pelita* generates fewer nutrients input for the soil and they accumulate the soil nutrients in biomass. Meanwhile, a study by Mojiol et al. (2014) showed that geronggang planted in ex-fired peatland has a higher life percentage (93.33%)

than pulai (*Alstonsia spatulata*) (86.67%) or katok (*Stemonurus scorpioid's*) (0%). Aprianis (2016) showed that geronggang naturally grows in peat and mineral soil. On the other hand, Danu & Kurniaty (2013) reported that the growth of geronggang seed performed the best in a media mix of rice husk charcoal and coconut fiber powder (1:2) (v/v) under shading of 25% after three months of planting. This study aims to compare the growth of geronggang seedlings in peat media with the addition of pulp sludge compost and manure fertilizer and without compost or fertilizer addition.

II. MATERIAL AND METHODS

A. Study Site

The study was conducted in a microbiology laboratory and a greenhouse of the Research and Development Centre for Forest Plant Fibres Technology, Kampar District, Riau Province, Indonesia (0.316504, 100.965330). Geronggang seedlings were collected from a natural forest located in Ketam Putih Village, Bengkalis District, Riau Province, Indonesia (102022’06” east longitude, 01022’43” north latitude). Geronggang seedlings were 40-50 cm height wild seedlings collected from under several mother trees. We collected around 1000-1200 seedlings by removing them from the soil, bundling about 50-60 seedlings with a rubber band, spraying them with water on the seedling bundle and wrapping the roots of the seedling bundle using plastic bags. Peat soil media originated from a forest area in Kepau Jaya, Kampar District, Riau Province, Indonesia (0.276882,101.513825).

B. Materials and Methods

Materials

Materials for fungi multiplication were sterile water, 95% alcohol, and Potato Dextrose Agar (PDA). Pulp sludge was a residue of *Eucalyptus* pulp collected from a pulp company in North Sumatra, Indonesia. In this study, we used fresh sludge deposited within the company areas. The manure fertilizer was a commercial fertilizer produced by a well-known local company to supply oil palm seedlings and fertilizer. Geronggang seedlings were 40-50 cm height wild seedlings collected from under several mother trees. We removed around 1000-1200 seedlings from the soil, bundling about 50-60 seedlings with a rubber band, spraying them with water on the seedling bundle, and wrapping the roots of the seedling bundle using plastic bags. Before treatment, the seedlings' acclimatization was held in a greenhouse for a month by placing the seedlings under shading and soaking the roots in water enriched with nutrients consisting of N, P, and K. After the acclimation, the survival rate of the seedlings was 80%. Equipment used for chemical analysis consisted of Erlenmeyer, test tubes, pipette, incubator, autoclave, Petri dishes, airflow laminar, pH meter, thermometer, haemocytometer, microscope, shovel, gloves, scales, plastic bags, and label paper.

Pulp sludge composting

Multiplication of each *P. citrinum* and *P. oxalicum* spore was carried out in PDA for seven days. The fungi had been collected from a former study (Wahyuningsih, 2013), and then the identification was carried out by the Indonesian Institute of Science Laboratory, Bogor, Indonesia. The fungi density was quantified by harvesting the isolates from PDA into 150 ml of sterile water and counting the spores using a haemocytometer. The spores’ suspension was pipetted to the haemocytometer and then the coverslip was fixed with gentle pressure. The spores were tallied from four corner squares subdivided into 4 x 4 grids under a microscope with a 10x objective. The spore density per mL of suspension was calculated from the average spore count per square and multiplied by 10^4. The fungi density for composting was 10^7 (spores/mL).

Before composting, the sludge was sun-dried for several days to have a water content ranging from 60-70%, and the sludge's moisture level was checked daily through the oven-drying method. The sludge was weighed at 15 kg and stored in a plastic container. The sludge composting was conducted by inoculating 150 ml of sterile water containing *P. citrinum* and *P. oxalicum* with a spore density of 10^7 (spores/mL) into the 15 kg of sludge for a month. In the process of composting, sterile water was sprayed on the sludge to maintain moisture, and the sludge container was covered with a plastic sheet to avoid fly contamination.

Peat soil

Grid-point soil sampling was employed to collect samples for soil physical characteristics. Samples were taken from a soil depth of 0-30 cm from the surface. The bulk density (g/cc), porosity (%), field capacity (pF 2.54) (%), wilting point (pF4.2) (%) and plant available water (%) of the soil are shown in Table 1.

Application of the pulp sludge compost to the peat soil

The compost sludge was applied to peat soil as the growing medium for geronggang seedlings. The nutrient content of pulp sludge, composted pulp sludge, and commercial manure fertilizer is shown in Table 2. The peat soil weighed 10 kg and was stored in a polybag 40 x 20 cm in size. The dosage of the sludge compost or manure fertilizer was based on Naik (2007) (Table 3). Dosages of sludge compost or the manure fertilizer were applied to the peat soil shown in Table 3. The treatments were 1) without fertilizer or compost addition (negative control), 2) commercial manure fertilizer addition (positive control); and 3) sludge compost addition. Each treatment was replicated five times. The seedlings were grown in a greenhouse, while the layout of the treated

Table 1. Physical characteristics of the peat soil

Soil Samples	Bulk density (g/cc)	Porosity (%)	Water content (%v/v) pF 2.54	pF 4.20	Plant available water (%)
1	0.60	63.64	49.12	31.76	17.36
2	0.57	65.45	55.22	35.40	19.82
3	0.48	70.91	51.65	30.47	21.18
4	0.45	72.73	52.02	28.55	23.47
5	0.44	73.33	52.50	30.32	22.18

Table 2. Nutrients content of pulp sludge, pulp sludge compost and commercial manure fertilizer

Parameters	Pulp sludge*	Compost of pulp sludge*	Manure fertilizer
pH H_2O	7.2	6.7	7.2
Org C (%)	39.5	43.85	36.25
N Total (%)	0.63	1.09	1.48
CN ratio	62.7	40.2	24.5
P_2O_5 (%)	0.26	1.08	3.24
K_2O (%)	1.62	1.08	1.43
Ca (%)	0.39	0.26	0.41
Mg (%)	0.21	0.29	0.57
CEC (me/100 g)	47.33	46.81	36.53
S (ppm)	137.4	162.8	232.6
Zn (ppm)	26.3	360.4	962.4
Cd (ppm)	4.8	0.9	1.6
Pb (ppm)	2.6	1.1	0.4

* Wahyuningsih (2019)

Table 3. Dosage of the pulp sludge compost and manure fertilizer based on Naik (2007)

Dosages (tons/ha)	Manure Fertilizer (g/10 kg)	The pulp sludge compost (g/10 kg)
0	0	0
2	8.9	13.16
4	17.8	26.32
6	26.7	39.49
8	35.6	52.51
10	44.6	65.96
12	53.5	79.12
14	62.4	92.28
16	71.3	105.44

Notes: The different percentage of water content was the cause of the composted sludge or manure fertilizer's different weight. The water content of the sludge compost and manure fertilizer was 69.7% and 47.13%, respectively

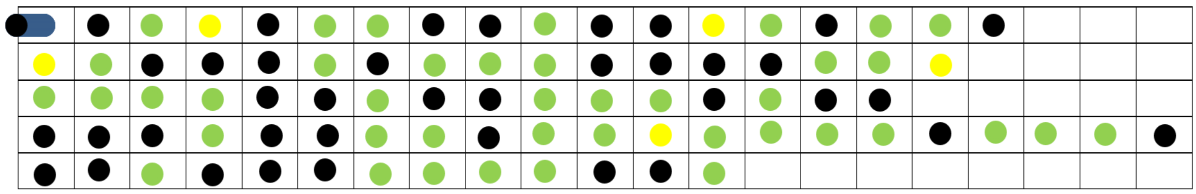

Figure 1. A layout of a randomized design experiment: a black dot represented seedlings with any dosages of manure fertilizer (MF) equal to 2-16 tons/ha, a green dot represented seedlings with any dosages of sludge compost (SC) equal to 2-16 tons/ha, and the yellow dot represents seedlings without the addition of manure fertilizer or compost

seedlings was randomized (Figure 1). Watering was done using an overhead sprinkler irrigation system every morning and evening.

Observation and data collection

Observation and data collection were conducted for six months. The collected data included chemical analyses of the growing media, manure fertilizer, pulp sludge compost, and seedlings. The vegetative growth of geronggang seedlings was observed every month for six months. The chemical analysis consists of pH, C organic, cation exchange capacity (CEC), soil and plant macronutrients (N, P, K, Ca, Mg, S), soil and plant micronutrients (Cu, Zn, Mn, Fe), soil and plant heavy metals (Pb, Cr, Cd, As, Hg) were based on Evianti & Sulaeman (2009). Soil bulk density was analyzed using a ring sample. The porosity method was employed to measure total pore space. Field capacity and wilting point were each examined using the oven method at 105°C and the flooding method.

For the soil and manure analysis, each sample consisting of peat soil, manure fertilizer, and pulp sludge compost was sieved using a 2 mm sieve. The H_2O pH was determined by diluting 10 g of a prepared sample into 50 ml of sterile water, stirring for 30 minutes, and then measuring it with a pH meter. The N organic, C organic, and CEC determinations were based on the Kjeldahl method, the Walkley & Black method and percolation, respectively. P_2O_5 and S were determined using spectrophotometry, and K_2O, Ca, Mg, Zn, and Cd were measured by atomic absorption spectrophotometer.

A chemical analysis of the plant was prepared by washing the seedlings with sterile water to remove soil and other residues. Then, the seedlings' leaves, stems, and roots were kept in envelopes and dried in an oven at 70°C for 48 hours or until the weight measurement was stable. The dry weight of the leaves, stems, and roots was recorded to get the total dry weight of the seedlings. Those dried leaves, stems, and roots were each ground and sieved at 0.5 mm for plant tissue analysis. The N determination was by the Kjeldahl digestion. The determination of macronutrients (P, K, Ca, and Mg) (%), micronutrients (Cu, Zn, Mn, and Fe) (ppm) and heavy metals (Pb, Cr, and Cd) (ppm) was done by wet digestion method with perchloric and nitric acid. The macro- and micronutrients were measured using atomic absorption spectrophotometer and spectrophotometry. Meanwhile, data collection of the height and diameter of the seedlings was conducted regularly, month by month, until the six-month observation.

C. Analysis

The height and diameter increments of the seedlings were analyzed using analysis of variance (ANOVA), and treatment means were compared using Duncan's Multiple Range Test (DMRT). ANOVAs were significant at $P< 0.05$. The mean difference between the treatments was considered to be significant at the level of $P< 0.05$.

III. RESULT AND DISCUSSION

A. Nutrients content of the growing media

Peat soil as a growing medium for geronggang seedlings has the nutrient content shown in Table 4. The fertility of the studied peat soil was considered poor. The soil pH was low, and the CN ratio was high. An organic decomposition process in peat soil is commonly slow because of its high phenol content. As a result, the available macro- and micronutrients are low. The CEC was analyzed using acetic acid and resulted in a higher cation absorption capacity, about 61.24 (me.100 g^{-1}). However, the base cations' power absorption in peat soil is weak (Hartatik et al., 2011). As a result, cations such as Ca, Mg, K and Na will be easily leached when no binding is formed. Meanwhile, the high Zn and S contents of the studied peat soil could be from chemical fertilizers in the surrounding oil palm plantations.

B. Nutrient contents of the pulp sludge, pulp sludge compost, and manure fertilizer

The composting activities of the pulp sludge decreased the CN ratio from 62.7 to 40.2 (Table 2). However, the CN ratio of the composted pulp sludge is above the CN ratio of the Indonesia National Standard (ISN)

Table 4. Nutrients of peat soil

Parameters	Peat soil
pH H_2O	4.1
Org C (%)	57.33
N Total (%)	0.97
C/N ratio	59.1
P_2O_5 (%)	0.97
K_2O (%)	0.79
Ca (%)	0.11
Mg (%)	0.4
CEC (NH Acetate 1 N) (me.100 g^{-1})	61.24
S (ppm)	21.42
Zn (ppm)	93.6
Cd (ppm)	1.6
Pb (ppm)	1.9
As (ppm)	0.3
Hg (ppm)	Not detected

for compost of organic waste at a range of 10-20 (Standar Nasional Indonesia, 2004). The high CN ratio indicated that the organic decomposition was not finished yet. On the other hand, the CN ratio of manure fertilizer was also above the national standard. The addition of compost or manure fertilizer with a high CN ratio to support the growth of the seedlings can harm the seedlings because of the low nutrient availability, particularly nitrogen. Microbes in the rhizosphere will use the nutrients to support their activities, like C organic decomposition. Also, the metabolism of the microbes in the rhizosphere will deplete oxygen availability for the seedlings and cause phytotoxicity (Bazrafshan et al., 2016).

The sludge compost contains higher macronutrients (N, P, Mg, and S) than the pulp sludge but lower than the manure fertilizer. The degradation of cellulose, hemicellulose, and lignin in the pulp sludge increased the macronutrients of the sludge compost (Sarika et al., 2014). On the contrary, a lower K and Ca content of the sludge compost could be caused by the microbe nutrient consumption during the decomposition of organic materials. In the kraft pulping process, K and Ca are derived from the chips, water or makeup chemicals (Gemzická, Šima, Vrška, & Holeš, 2010). The Ca content of wood can be varied, such as when Ca content of pulp from *Eucalyptus dunii* is about 705 to 4,668 ppm (Vegunta et al., 2022). Their study also found that in a kraft process, Ca causes problems in delignification that affect the yield. Potassium and chloride in the wood can be impurities and cause corrosion of the boiler's heat transfer tubes by lowering the melting temperature of fly ash deposits (Tran & Earl, 2004). Thus, Ca and potassium can disturb the pulping process and should be removed. As a result, the content of Ca and K in the pulp sludge is high.

The composted sludge has a lower CEC than the pulp sludge or manure fertilizer. Exchangeable cations measured for CEC are Na, Ca, K and Mg. However, in this study, Na was not measured. Meanwhile, a high CEC of the studied pulp sludge could be from Na. In kraft pulping, chips are cooked using white liquor that consists of NaOH and Na_2S (Andersson, 2014). However, the pulp sludge application as a soil amendment will not automatically provide nutrients for the seedlings. A high CN ratio of the pulp sludge will cause microbes in a rhizosphere to immobilize the available nutrients to decompose the C organic. The composting mineralizes the sludge's organic matter, and the seedlings can utilize the available nutrients to support their growth.

The composted sludge had a lower heavy metals (Pb, Cd) content than the pulp sludge. The Pb and Cd content of the sludge compost were 0.9 and 1.1 ppm, respectively (Table 2). The ISN for composting organic waste mentioned that the maximum concentrations Pb and Cd are 3 and 150 ppm, respectively (ISN, 2004). Pb and Cd are toxic for humans and animals but less toxic for plants (Tiruneh, Fadiran, & Mtshali, 2014). Plants and microbes can accumulate heavy metals during their life cycles. The biomass of *P. oxalicum* can absorb Pb for about 65.9% when it lives and 89.82% when it is dead (Mahish et al. 2018). *P. oxalicum* and *P. citrium* are tolerant of Pb up to a concentration of 20,000 ppm (Oso et al. 2015). Meanwhile, *P. citrinum* at a pH of 6 can absorb Cd with a dosage of 2,000 ppm through biomass immobilization and 4,000 ppm without biomass immobilization (Suhag 2011).

C. The response of geronggang (*Cratoxylum arborescens*) seedlings after the addition of manure fertilizer and e pulp sludge compost for six months in peat soil

Geronggang seedlings with manure fertilizer or sludge compost addition at a dosage equal to 2 (tons/ha) showed the highest survival rate (100%) after six months of application (Figure 2). Meanwhile, the non-fertilized seedlings showed a survival rate of about 80% after six months of being planted in peat soil. Geronggang is a local species of peat swamp forest that gives the seedlings have a high

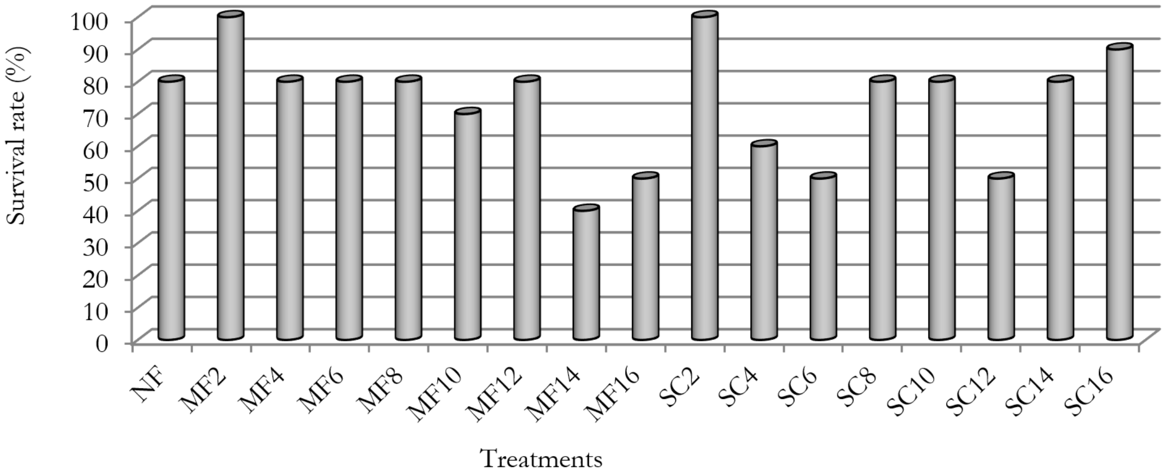

Figure 2. The survival rate of seedlings (%) after being treated for six months.
NF showed seedlings without manure or compost addition: MF showed seedlings with manure fertilizer addition at a dosage equal to 2-16 tons/ha, SC showed seedlings with sludge compost addition at a dosage equal to 2-16 tons/ha

survival rate in the non-fertilized peat soil. However, manure fertilizer or compost sludge addition at a dosage above 2 (tons/ha) that was 4 to 16 (tons/ha) resulted in geronggang's survival rates below 100%. On the other side, the peat soil used in the study is categorized as decomposed and compacted (Table 1). The soil characteristics had a high bulk density (0.44-0.6 cc/g) and a low water holding capacity (49.12-55.22%). According to Wawan, Ariani, & Lubis (2019), the water-holding capacity of peat range from less than 450% to 3000%, and the bulk density of peat soil at a depth of 0-10 cm at a groundwater level of 20-60 cm was 0.22-0.31 (g/cc). Meanwhile, packing peat soil into polybags squeezed the soil water from the soil body and dried the peat. In addition, overhead irrigation utilized during the study accelerated peat drying because the seedlings' leaves splashed some irrigation water.

A different result in those seedlings' survival rate after manure fertilizer or compost sludge application at various dosages can be caused by gradual soil drying. The addition of sludge compost or manure fertilizer at a dosage equal to 2 (tons/ha) enhances the seedlings' survival rate by providing sufficient nutrients. On the contrary, higher dosages of manure fertilizer or sludge compost are vulnerable to being leached by irrigation water. Moreover, the lack of irrigation water penetration caused peat soil structures to become massive over time. Manure fertilizer has a granular form that causes the fertilizer to be more easily washed by irrigation water than sludge compost, which has an aggregate structure. In this study, manure fertilizer and sludge compost application with a dosage equal to 16 (tons/ha) showed a contrary seedling survival rate of 50% and 90%, respectively. However, the sludge compost's characteristic shrink and swell is suitable for dry soil for open-space application to get direct contact with water.

Application of the sludge compost at a dosage equal to 16 (tons/ha) to the peat soil can raise the height of the seedlings to 18.52 cm (56%) after six months (Figure 3). However, the average height rise of seedlings with the sludge compost addition at various dosages was 9.95 cm (27.5%) (Figure 4). Seedlings with sludge compost addition also had a heavier total dry weight than seedlings with another treatment (Figure 5). Seedlings with sludge compost addition absorbed nutrients of N, P, Cu, Zn,

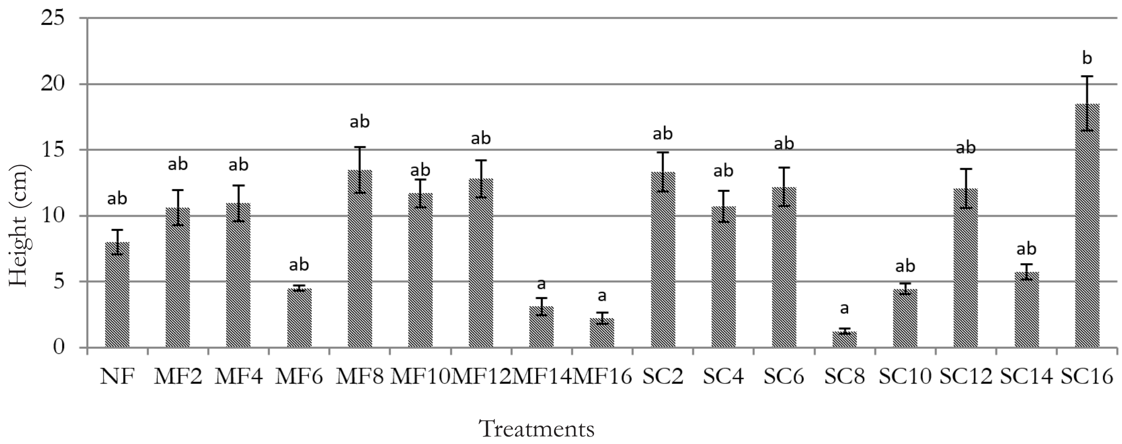

Figure 3. The increasing height (cm) of seedlings of various treatments in peat soil after six months planting (NF: without fertilizer orcompost, MF 2-16: manure fertilizer at dosages equal to 2-16 (tons/ha), SC 2-16: sludge compost at dosages equal to 2-16(tons/ha)). Bars followed by different letters showed the increasing height of seedlings was significantly different at P < 0.05

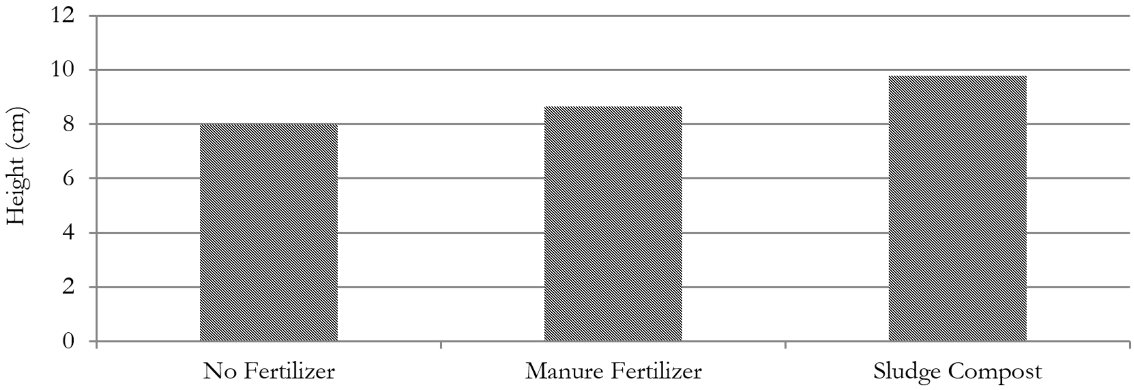

Figure 4. The average height increment (cm) of seedlings from three different treatments after being planted in peat soil for six months

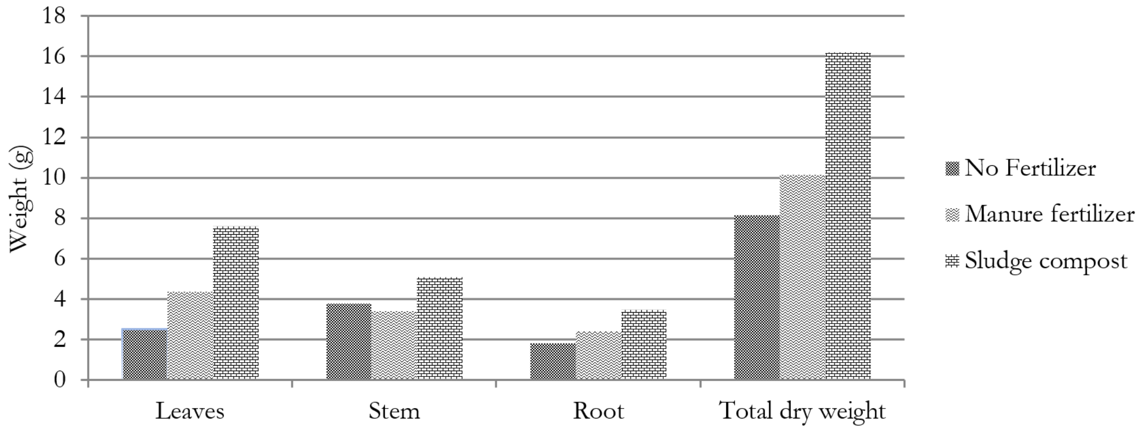

Figure 5. The average dry weight of leaves (g), stem (g), root (g), and total dry weight (g) of seedlings after being treated with no-fertilizer, manure-fertilizer, and sludge compost addition for six months

Mn, and Fe. Higher absorption of N, P, Cu, Zn, Mn, and Fe was also shown by the seedlings with sludge compost addition (Figures 8 and 9). A high N and P absorption of the seedlings with sludge compost addition indicates the micronutrient sufficiency of the sludge compost. A study by Razaq, Zhang, Shen, & Salahuddin (2017) reported that N and P application to *Acer mono* seedlings for six months increased the height of the seedlings and both seedlings' root and root collar diameter. On the other side, a high Fe absorption by the seedlings could be an adaptation to low phosphate availability in peat soil. Phosphate limitation triggers the primary root to accumulate Fe in the root's apical meristem, which is related to apical root meristem exhaustion (Mora-Macías et al., 2017). Peat soil is poor soil, particularly in its phosphorus content. In this study, peat soil contains a low percentage of phosphate (0.97%) (Table 4). The high Mn absorption of the seedlings was probably related to the high Mn solubility in acidic and waterlogged soils such as peat (Takagi et al., 2021). Mn is an essential nutrient for photosynthesis and an enzyme antioxidant' cofactor, but Mn phytotoxicity results in biochemical disorder, less biomass, and photosynthesis (Alejandro, Höller, Meier, & Peiter, 2020).

Seedlings height rise with manure fertilizer addition to a dosage equal to 2 -12 (tons/ha) was not statistically different from the sludge compost addition of a dosage of 2, 4, 6, 10, 12, and 14 (tons/ha) after six months of observation (Figure 3). Meanwhile, the average height increment of seedlings with manure fertilizer addition at various dosages after six months of application was 8.67 (cm) (22.76%) (Figure 4). However, seedlings with the manure fertilizer addition with a dosage of 14 and 16 (tons/ha) showed slower growth. The height increments were about 3.11 and 2.22 cm, respectively. Potassium absorption by seedlings with the manure fertilizer was the highest among other treatments (Figure 8), probably related to the high potassium content in the manure fertilizer (Table 3). The high sulfur content of the manure fertilizer can also lower the soil pH, and as a result, the Mn and Fe availability for the seedlings increases. Hence, the manure-fertilized seedlings absorbed Mn and Fe at a higher concentration than the non-fertilized seedlings.

On the other side, peat soil contains phenolic acids that can inhibit root growth and plant nutrient availability (Hartatik et al. 2011). The phenolic acids are formed from decomposed materials rich in lignin. Some bacteria and fungi generate extracellular enzymes that can degrade the phenolic compound (Min, Freeman, Kang, & Choi, 2015). Ligninase is an enzyme that can oxidize the phenolic structure of lignin (Falade et al., 2017). *P. oxalicum* and *P. citrinum* generate secondary metabolites such as enzymes or other natural compounds. *P. oxalicum* generates MnP (Jha & Patil, 2011). Meanwhile, *P. citrinum* produces lignin peroxidase (Yadav, 2006), gibberellin (Khan et al., 2015) and indole acetic acid (Yadav, Verma, & Tiwari, 2011). However, native species of peatlands are adaptive to the high phenolic compounds (Yule, Lim, & Lim, 2018). Their study found that another peat swamp species, mahang (*Macaranga pruinosa*), can absorb phenolic compounds through the roots. Mahang can convert phenolic acid (ferulic acid, p-coumaric acid) to complex phenolic compounds (kaempferol, quercetin). The young leaves could produce a low-molecular-weight phenolic compound. Then, the falling leaves, rich in phenol, create a new peat environment. On the contrary, the old leaves contain a little phenolic compound.

In this study, the nutrient supply for the geronggang seedlings with no fertilizer addition was just from the peat soil. The seedlings' height increment without fertilizer addition was not statistically different from those with manure fertilizer addition or some of the sludge compost addition after six months of observation. However, the height of seedlings with sludge compost addition at a dosage equal to 16 (tons/ha) was statistically different with both the non-fertilized and manure-fertilized seedlings. The non-fertilized seedlings invested

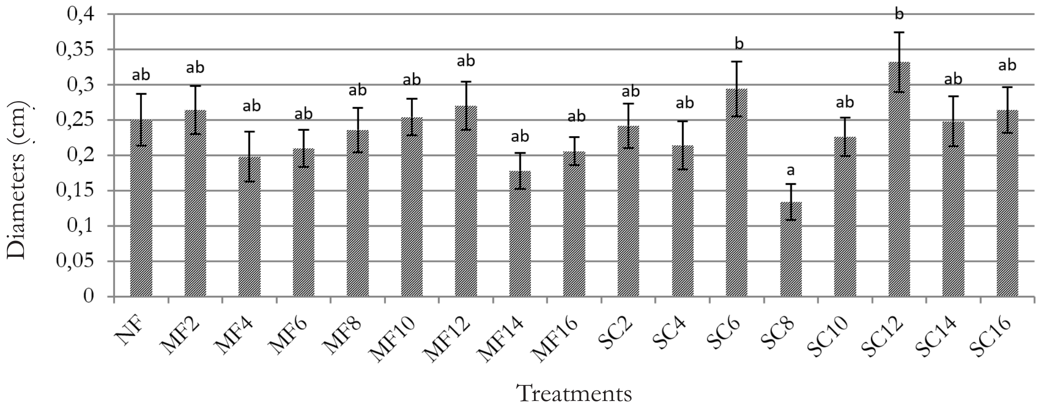

Figure 6. The increasing diameters (cm) of seedlings of various treatments in peat soil after six months of planting (NF: without fertilizer or compost, MF 2-16: manure fertilizer at dosages equal to 2-16 (tons/ha), SC 2-16: sludge compost at dosages equal to 2-16 (tons/ha)). Bars followed by different letters showed the increasing height of seedlings was significantly different at $P < 0.05$

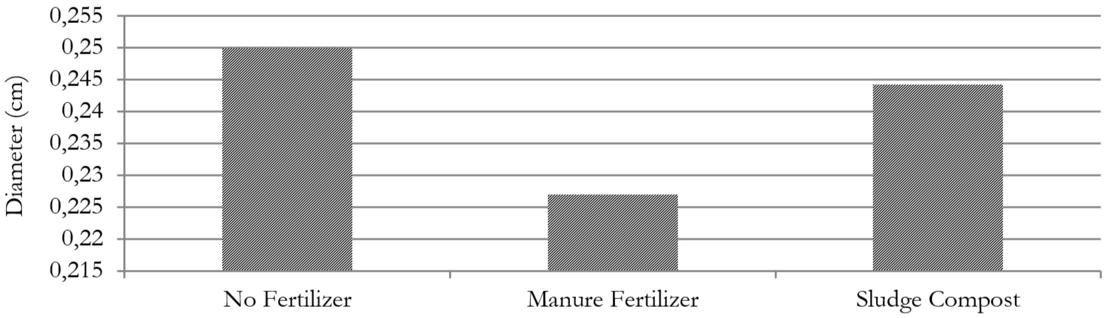

Figure 7. The average diameter increment (cm) of seedlings from three different treatments after being planted in peat soil for six months

more growth on the stem than the leaves or roots (Figure 5). Seedlings with sludge compost and manure fertilizer additions grow more on leaves. As a result, the height increment of most seedlings with sludge compost or manure fertilizer addition was almost the same as the non-fertilized seedlings. Although the average height of seedlings with sludge compost or manure fertilizer addition was higher than the non-fertilized seedlings (Figure 4).

Seedlings with the sludge compost addition at a dosage equal to 12 (tons/ha) showed the highest diameter increment (Figure 6). A seedling's base diameter is a morphology parameter that indicates the seedling's adaptability and growth in the field (Nurhasybi, Sudrajat, & Suita, 2019). On the contrary, the sludge compost addition at a dosage equal to 8 (tons/ha) resulted in the lowest seedling diameter growth. Meanwhile, the average diameter increment of seedlings of the non-fertilized, the sludge compost, and the manure fertilizer addition at various dosages were 0.25 cm (68.28%), 0.24 cm (64.43%), and 0.23 cm (72.72%), respectively (Figure 7). Different responses of the seedlings to the sludge compost addition at various dosages could be caused by the availability of active decomposers after application. The active decomposers contained in the sludge compost can raise the peat decomposition, which then, in turn, provides nutrients for the seedlings. On the other side, seedlings with sludge compost addition invested in the growth mainly for leaves (Figure 5). Poorter et al. (2012) mentioned that fast-growing species, such as geronggang, allocated the nutrients for a higher leaf mass fraction than slow-growing species. Meanwhile, seedlings with a high root mass fraction indicate growing media with less nutrient availability.

IV. CONCLUSION

The survival rate of seedlings with manure fertilizer or compost sludge addition at a dosage equal to 2 (tons/ha) was the highest (100%) value after six months of observation.

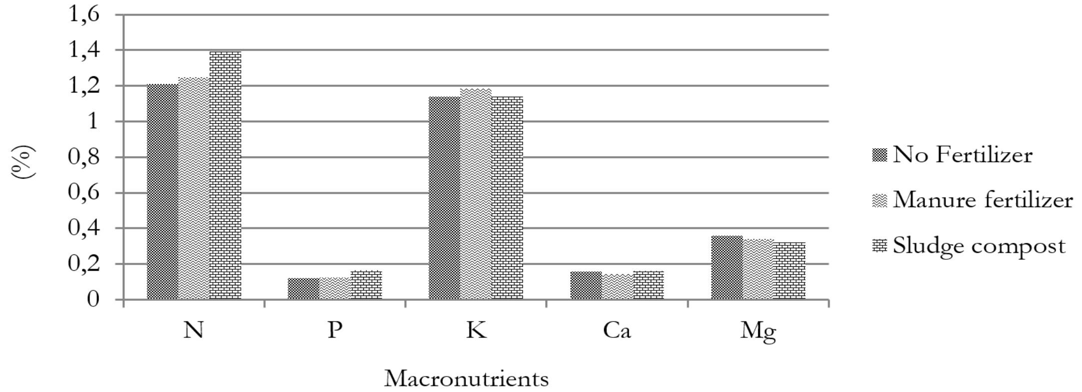

Figure 8. Seedling tissue analysis consisted of macronutrients (N, P, K, Ca, and Mg) (%) after being treated with no fertilizer, manure fertilizer, and sludge compost addition in peat soil for six months

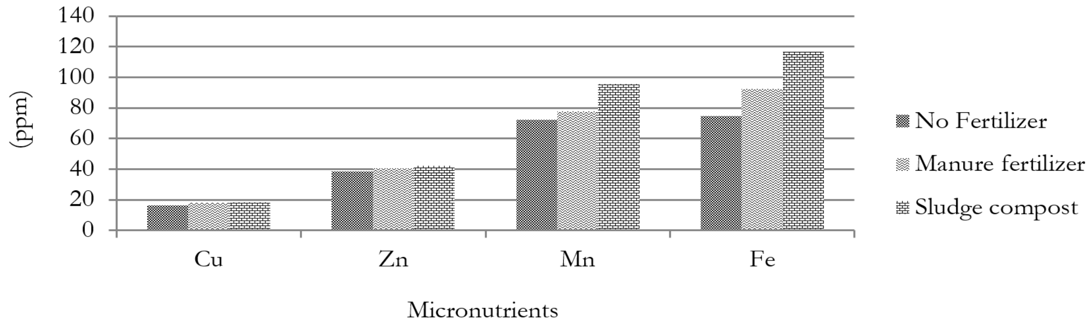

Figure 9. Seedling tissue analysis consisted of micronutrients (Cu, Zn, Mn and Fe) (ppm) after being treated with no fertilizer, manure fertilizer, and sludge compost addition in peat soil for six months

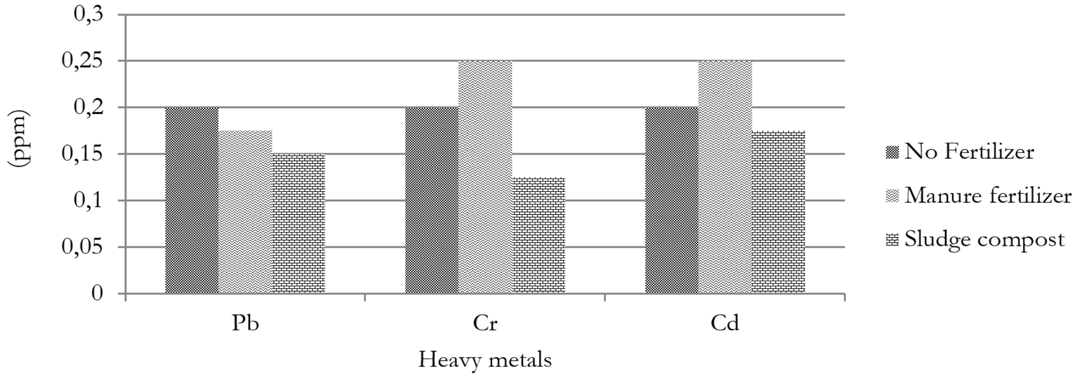

Figure 10. Seedling tissue analysis consisted of heavy metals (Pb, Cr and Cd) (ppm) after being treated with no fertilizer, manure fertilizer, and sludge compost addition in peat soil for six months

However, on average, seedlings with sludge compost addition in peat soil had a better height increment than the non-fertilized or seedlings with manure fertilizer addition. The height increment of seedlings with sludge compost addition at a dosage equal to 16 (tons/ha) was significantly different from another treatment. Seedlings with sludge compost addition at a dosage of 6 and 12 (tons/ha) had the highest diameter increment that was statistically different from another treatment. However, seedlings with sludge compost addition at a dosage equal to 6 and 12 (tons/ha) had a lower survival rate. The average dry weight of seedlings was better after the sludge compost addition than with other treatments. However, seedlings with either sludge compost or manure fertilizer added invested more growth on leaves than non-fertilized seedlings. The pulp sludge compost inoculated with *P. citrinum* and *P. oxalicum* can provide nutrients for geronggang seedlings. Thus, it is recommended that dosages of either 2 (tons/ha) or 16 (tons/ha) of pulp sludge compost could be used to raise seedlings' survival rate and height in peat soil, respectively. The shrink and swell characteristics of pulp sludge compost provide an opportunity as a material for water retention in dry soil. In the future, the pulp sludge compost that meets the ISN requirement (CN ratio 10-20) is essential to being acceptable for large-scale applications.

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