Growth of Four Types of Forest Plants Combined with Legume Cover Crop (LCC) in Central Kalimantan Gold Mine Tailings

Patricia Erosa Putir[1,2]*,Wahyudi[2], Sih Winarti[3], Sosilawaty[2]

[1]*Doctoral Program in Environmental Science, Postgraduate Program, University ofPalangka Raya, Central Kalimantan, Indonesia*

[2]*Department of Forestry, Faculty of Agriculture, University of Palangka Raya, Indonesia*

[3]*Department of Agronomic, Faculty of Agriculture, University of Palangka Raya, Indonesia*

Abstract:-Tailings are one of the wastes that are produced in large quantities in gold mining activities, which can have an impact on the environment if not managed properly. The presence of hazardous substances containing heavy metals in the remaining tailings can damage the environment and health. Phytoremediation is a technique that uses plants to restore land contaminated with heavy metals. This study aims to find the types of plants that can grow well in gold mine tailings. Four (4) types of forest plants were selected, namely Shoreabalangeran, Combretocarpusrotundatus, Melaleuca cajuputi, and Alstoniascholaris combined with three (3) types of cover crop legumes (LCC), namely Mucuna bracteata, Pueraria javanica and Calopogoniummucunoides. Forest plants and LCC were planted in two (2) Mirah I and Mirah II tailings storage facility (TSF) areas with the addition of compost ameliorant. The method used is split plot design. The growth parameters observed were survival percentage, height growth and diameter growth. The results showed that M. cajuputi plants had the best growth on 3 parameters, namely survival percentage, height growth and diameter growth followed by Alstoniascholaris and S. balangeran plants while C. rotundatus plants had relatively lower growth on all parameters.

Keywords: *tailings, physical properties, chemical properties, revegetation plants.*

1. Introduction

Gold mining in general, produces residue from the mining process in the form of muddy waste (tailings) which contains several heavy metals and some contains potentially reactive minerals. This tailings waste, if not managed properly, can have a negative impact on the environment in the form of a decrease in the surface of ex-mining land such as loss of soil layer profile, occurrence of soil compaction (increased bulk density), deficiency of essential nutrients, low pH, contamination of heavy metals on land. former mines and decreased soil microbial populations (Rusdiana et al 2000; Setyaningsih, 2007; Sabtanto, 2008; Tamin, 2010). Mining activities have an impact on decreasing the quality of land and increasing the rate of land degradation. Deterioration in land quality on ex-mining land is associated with a decrease in soil chemical properties (soil fertility), soil physical properties, soil texture, slope and waterlogging, making land difficult to plant (Mansur, 2011).

One of the gold mining companies in Central Kalimantan, namely PT Kasongan Bumi Kencana (PT KBK) which has been operating since 2012. Gold mining activities carried out by PT KBK have produced tailings waste which is included in the criteria for B3 waste (Hazardous Toxic Materials) which can be toxic to living things. Tailings in the form of muddy material contain substances that are potentially reactive, for example containing pyrite which when oxidized causes the formation of acid mine drainage and metal leaching. Mining activity is part of the consequences of development which will result in ex-mining land. This ex-mining land can cause environmental changes including chemical changes, physical changes and biological changes. Sophocleous, (2002); Anibas et al, (2012); Nosetto et al, (2013); Munir and Setyowati (2017); Fritz et al, (2018); Xin et al, (2022) state, chemical changes have an impact on the presence of groundwater and surface water, physically causing changes in land morphology and topography. The application of phytoremediation can be an effort to overcome tailings sludge, where phytoremediation is an activity to degrade, absorb or inhibit contaminants in soil and/or groundwater by using plants and/or microorganisms so that they become harmless to living organisms. Four types of forest plants were selected viz Shoreabalangeran, Combretocarpusrotundatus, Melaleuca cajuputi dan Alstoniascholarisserta 3 jenislegum cover crop (LCC) yaitu Mucuna bracteata, Pueraria javanica dan Calopogoniummucunoides combined planting. This research is to examine the growth of forest plants in gold mine tailings and their interaction with legume plants (LCC).

2. Methods

1) Research Location

PT Kasongan Bumi Kencana (KBK) is a gold mining company located in Mirah Kalanaman Village, Katingan Tengah District, Katingan Regency (Figure 1), which has been operating since 2012. Gold ore processing produces waste in the form of sludge with characteristics of 60% water and 40% solids that are accommodated in a disposal site called a tailings dam. Tailings sludge contains potentially reactive minerals, pyrite when oxidized causes acid mine drainage and metal leaching to form. The rock waste is stockpiled in a landfill and tailings is stockpiled in a final storage facility known as a tailings storage facility (TSF). Since 2013 PT KBK has been actively carrying out reclamation by revegetating the disposal area with pioneer plants including Albizia falcataria, enterolobiumcylocarpumGriseb and Samanea saman. During 2018-2020 PT KBK is working with SEAMEO BIOTROP IPB to plant the tailings area; in the wetland the test plants used were Ipomoea aquatica Garp, Eichhornia crassipes) and Pisciastatiotes but these three species did not grow well. In dry areas the plants tested were Shoreabalangeran, Alstoniasp, Combretocarpusrotundatus, Melaleuca leucadendra, Melaleuca cajuputi, Anthocephalus cadamba, Anthocephalus macrophyllus and sago Metroxylon without the addition of organic matter. Consequently, three types of plants; S. belangeran, Alstonia _ sp and C. rotundatus did not grow well (stagnant) and some were stunted while Melaleuca leucadendra and Melaleuca kayuputih could grow well. To find out more about the growth of some of these forest plants, it is necessary to do research by adding compost as a nutrient for plants and in combination with legume plants.

This research was conducted in two areas of PT KBK's TSF; (1) Mirah I TSF which is a 7 year old tailings area and (2) Mirah II TSF which is a 1 year old tailings area. The study was conducted for 7 months (April – October 2022).

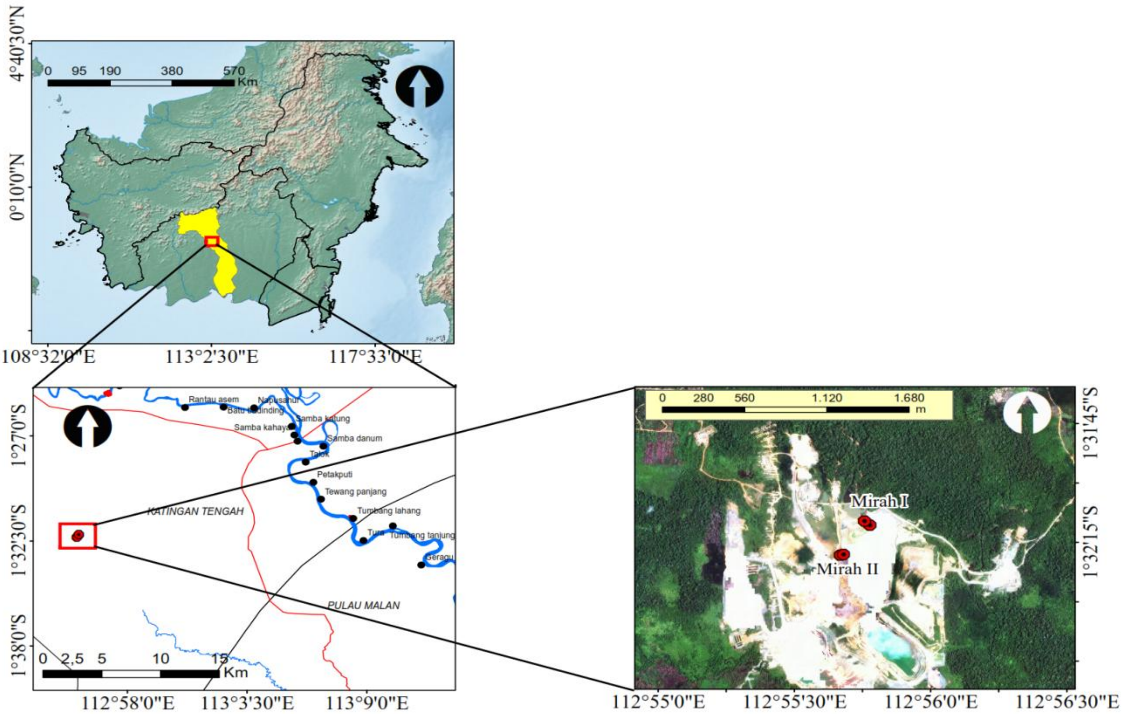

Figure 1. Research Area in PT KBK

2) Research design

Make 8 plots measuring 3 x 3 m in Mirah I and Mirah II TSFs. In each plot, 4 (four) forest plants were planted, namely Shoreabalangeran, Combretocarpusrotundatus, Melaleuca cajuputi and Alstoniascholaris. LCC plants are planted around forest plants by making small holes which are given enough compost before the LCC seeds are sown, while in each planting hole for forest plants are given compost as much as 7 kg. Growth parameters measured for 7 months include survival percentage, growth height and growth. diameter. Measurements are carried out once a month. Soil samples in TSF Mirah I and TSF Mirah II before planting and composting (starting soil) were taken randomly at a depth of 0-20 cm, then soil samples after planting and composting were also taken for laboratory analysis. Analysis of the physical and chemical properties of the soil including the texture of the 3 fractions (sand, clay and silt), pH, organic C, total N, available P and K.

This study used a split plot design (Split Plot Design) with a basic randomized block design (RAK) with the main plot being the study sites of TSF Mirah 1 and TSF Mirah 2 as subplots consisting of land cover plant species (LCC) and revegetated plants consisting of 19 sub plots containing pure plants and LCC and combinations of plants and LCC.

Overall there were 38 experimental units repeated 2 (two) times so that there were 76 experimental units in total. Each type of plant (S. balangeran, C. rotundatus, M. cajuputi, A. scholaris) was planted 4 (four) seeds each in each experimental plot so that the number of seeds in each experimental unit was 64 seeds, thus for 4 (four) the experimental unit total number of seeds is 64 x 4 = 256 seeds

The additive linear model for the Split Plot Design with the basic Randomized Block Design (RBD) is:

$Yijk = \mu + \rho i + \alpha j + Yij + \beta k + (\alpha\beta)jk + \varepsilon ijk$

Information:

ϒijk : Observations on the k-th experimental unit that obtained the i-level treatment combination from factor A (tailings characteristics) j-level from factor B (type of revegetated plant)

μ : The true mean (population mean)

ρk : The additive effect of the to group -k

αi : The additive effect of the i-level of the factors A

βj : The additive effect of the jth level of the factor B.

(αβ)ij : Additive effect of the i-level of factor A and the j-th level of the factor B

ϒik : Random effect of the main plot that appears at the i-th level of factor A in the k-group. Often called a key tile error

ɛijk : Random effect of the k-th experimental unit that receives the ij treatment combination (often called the subplot error)

All data is recorded in an Excel table and analyzed using the SmartstatXL computer program.

3. Resultsand Discussion

a. Percentage of Live Forest Plants

The results of the analysis of variance of the average percentage of survival of forest plants showed that there were highly significant differences between the treatments of the revegetated plant seeds.

Table 1. Analysis of the variety of live forest plant percentages

Variety Source	DB	JK	KT	F-Count	Value-P	F-0,05	F-0,01
Mirah	1	87.7813	87.7813	1.225 tn	0.349	10.128	34.116
Vegetation	3	10125.0625	3375.0208	47.114 **	0.005	9.277	29.457
Galat a	3	214.9063	71.6354				
LCC	3	98.3125	32.7708	0.234 tn	0.871	3.490	5.953
Interaction A x L	9	246.5000	27.3889	0.195 tn	0.990	2.796	4.388
Galat b	12	1682.3125	140.1927				
Total	31	12454.8750					

Information: * = significantly different at a significant level 5%; ** = significantly different at a significant level 1%;
tn = not significantly different.
CV (a) = 9,60; CV (b) = 13,43;

Based on the results of further tests, it is known that without LCC, planted with Pueraria javanica (PJ) and Calopogoniummucunoides (CM) the survival percentage of S.balangeran, M. cajuputi and A. scholaris was not significantly different with an average survival percentage of ± 100%, but for C. rotundatus significantly lower percentage of life. The low survival percentage of C. rotundatus illustrates the resilience of the plant in adapting to the environment in which it grows, the lower the survival percentage of C. rotundatus indicates the plant has the ability to survive C. rotundatus indicates the plant has low adaptability, conversely the higher the percentage. plant life shows that the plant has a high ability to adapt to the environment in which it grows.

The relatively low percentage of survival in C rotundatus plants, allegedly because the place to grow at the study site is rocky soil filled with tailings from former gold mining activities which are dominated by the sand fraction. While some research results state that C.rotundatus is more suitable to grow in flooded swamplands. The results of the analysis of peat soil (as a control) where C. rotundatus lived showed a relatively higher organic C content, namely an average of 18.41% and the clay fraction (46.49%) was relatively higher than the sand fraction (37.42%) and dust (16.10%) it can be said that C.rotundatus is more suitable for living on peat soils. Saito et al (2005) stated that C. rotundatus grows well with low mortality with an annual height increment of 27-255 cm-1y-1 under open conditions, low humidity and high soil temperature. C. rotundatus is one of the local species recommended for rehabilitation of degraded peat swamp forests (Istomo et al., 2012). This is reinforced by Rachmanadi et al (2021); Suwito&Poedjirahajoe, (2021); Suwito&Poedjirahajoe, (2021, Nov); Tata et al, (2022); Kissinger et al, (2022) that C. rotundatus is a pioneer species in peat swamp forests and grows well in flooded conditions and inundated conditions are a natural environment in peat swamp forest ecosystems. The results of soil analysis also showed that the organic C content in the S. balangeran sub-plot in the control plot increased by 0.42% after planting compared to before planting (0.28%), LCC P. javanica combined with S. balangeran (0.33%) %), LCC C. mucunoides combined with M.cajuputi (0.30%), it can be said that planting LCC is thought to have contributed to increasing the survival percentage of M. cajuputi, S. balageran and A. scholaris plants but vice versa with the survival percentage of C plants relatively lower rotundatus. One indication of the plant's adaptability to the tailings area is the good growth of the plant. The following is the performance of Melaleuca cajuputi, Alstoniascholaris, Shoreabalangeran and Combretocarpusrotundatus plants growing in gold mine tailings.

Picture 2. Performance of plants growing on gold mine tailings M. cajuputi (1), A. scholaris (2), S. balangeran (3), C. rotundatus(4).

b. High Growth of Forest Plants

The results of the analysis of variance in the average height growth of revegetated plants (Table 2) showed that the average growth height of revegetated plants was highly significant between tree species at the 0.01 level and the interaction between plants and LCC was significantly different at the 0.05 level.

Table 2. Analysis of Variety of Growth in Revegetation Plant Height

Variety Source	DB	JK	KT	F-Count	P-value	F-0,05	F-0,01
Mirah (M)	1	228.2583	228.2583	0.559 tn	0.509	10.128	34.116
Vegetation (A)	3	52376.1215	17458.7072	42.790 **	0.006	9.277	29.457
Galat a	3	1224.0222	408.0074				
LCC (L)	3	32.2021	10.7340	1.319 tn	0.314	3.490	5.953
Interaction A x L	9	215.7957	23.9773	2.947 *	0.042	2.796	4.388
Galat b	12	97.6249	8.1354				
Total	31	54174.0247					

Information: * = significantly different at a significant level 5%; ** = significantly different at a significant level 1%; ns = not significantly different

CV (a) = 21,08; Cv (b) = 2,98;

Based on the data in Table 2, it can be seen from the sub-plot without LCC (P0), the LCC Mucuna bracteata sub-plot (P1), the LCC Pueraria javanica sub-plot (P2) and the LCC Calopogoniummucunoides sub-plot (P3) the average height growth of M. plants. cajuputi was very significantly different from C. rotundatus and A.scholaris (151.99 cm;138.58 cm;149.42 cm;148.67 cm) but not significantly different from S. balangeran while the interaction between plants and LCC was seen that M. cajuputi plants were significantly different from LCC M. bracteata.

The increase in the number and dimensions of trees, both the height and diameter of a stand, is the result of growth. Height is one aspect of plant development. Field observations showed that M. cajuputi performed well, followed by S. balangeran, A. scholaris and the lowest was C. rotundatus. It can be said that M. cajuputi, S. balangeran and A. scholaris were able to adapt to gold mine tailings in the research location while C.rotundatus relatively lower growth. Malau and Utomo (2017) stated that M. cajuputi is able to grow on barren soil, is heat tolerant and sprouts again despite fires. This species can also be developed as a remediation plant on contaminated soil (Mohd et al., 2013; Chibuike & Obiora, 2014; Ye et al., 2017; Wang et al., 2017; Zhang et al., 2020; Song et al., 2022). Rahmawati et al (2020) stated that M. cajuputi plants have a high ability to adapt to various soil conditions, besides that they are fast growing species which are expected to cover land and enrich soil nutrients quickly. Based on research by Nutavia and Ellettaria (2020), it was stated that the diameter and height of M. cajuputi plants planted on post-coal mining land showed very good plant growth and performance. Mansur and Kadarisman (2019); Sekarjannah et al, (2021); YUNINGSIH et al, (2021); Siregar et al, (2021) stated that ecologically M. cajuputi is a potential local Sumatran species for post-mining land reclamation plants. LCC plants planted in the M. cajuputiputih sub-plot and the S. balangeran and A. scholaris sub-plots are thought to have contributed to the nutrients needed by plants for high growth.

Based on the results of soil analysis, there was an increase in organic C nutrients in the M. cajuputi sub-plot combined with LCC C. mucunoides by 0.32% while there was no additional total N, but when viewed from the results of the analysis of the number of root nodules in the eucalyptus sub-plot was relatively high (500 nodules) this indicates that there was an addition of nitrogen (N) from the binding of N in the air. The formation of root nodules in large numbers can increase nitrogen (N) fixation efficiently so that it can be used to form enzymes and chlorophyll. The formation of enzymes and chlorophyll will increase the vegetative growth of plants (Surtiningsih et al. 2009; El-Kereti et al., 2013; Khattab et al., 2016; Wang et al., 2020). Vegetation from grass species such as Typha angustifolia grass, Cyperus sp, Crotalaria juncea is also thought to have contributed to the high growth of revegetated plants through the organic matter they produce. C. juncea has the advantage of being easy to grow in a variety of soil conditions, has a fast growth rate, has a high N content and has a lot of biomass (Cook dan White, 1996; TeBeest et al., 2015; Cardoso et al., 2019; Gonzaga et al., 2019).

c. Growth Diameter of Forest Plants

The results of the analysis of variance for the average diameter growth (Table 3) showed that there were significant differences in the treatment of revegetated plants.

Table 3. Analysis of Average Growth Average Diameter of Revegetated Plants

Variety Source	DB	JK	KT	F-Count	P-value	F-0,05	F-0,01
Mirah (M)	1	0.0540	0.0540	0.641 tn	0.482	10.128	34.116
Vegetation (A)	3	2.6952	0.8984	10.663 *	0.042	9.277	29.457
Galat a	3	0.2528	0.0843				
LCC (L)	3	0.0014	0.0005	0.104 tn	0.956	3.490	5.953
Interaction A x L	9	0.0489	0.0054	1.248 tn	0.353	2.796	4.388
Galat b	12	0.0522	0.0044				
Total	31	3.1044					

Information: * = significantly different at a significant level 5%; ** = significantly different at a significant level 1%;

ns= not significantly different; CV (a) = 31,04; CV (b) = 7,05;

Further test results showed that the average growth diameter of the pulai plants was significantly different from the tummih plants in the control sub-plot, P. javanica sub-plot and C. mucunoides sub-plot (1.25cm;1.27cm;1.30cm) while with balangeran plants and eucalyptus plants showed no difference. Based on the table, the highest average growth in diameter was in pulai plants in the control sub-plot, the combination of LCC P javanica and C.mucunoides followed by M. cajuputi, S.balangeran and the lowest in C. rotundatus. The relatively high growth in diameter of A. scholaris is thought to be due to the conditions where it grows, which is open and free from shade. Marjenah (2001) states that diameter growth is faster in open places than in shaded places so that plants grown in open places tend to be short and stocky. This can be seen from the growth of A. scholaris in the research location which looks fertile with a large diameter indicating that A. scholaris can adapt to the environment where it grows in gold mine tailings. The results of the research by Mawazin and Susilo (2016) showed the best growth in height and diameter in A. scholaris plants aged 8, 16 and 24 months in coal mining soil with a height of 93.35 cm, 106.87 cm, 131.15 cm and a diameter of 16 .54mm, 25.38mm and 35.75mm. Adman et al (2012) stated that A. scholaris could be used as an alternative plant for efforts to revegetate degraded lands. A.scholaris is also able to grow in open areas that have been damaged because it is tolerant of nutrient-poor and alkaline soils (Prayudianingsih, 2014).

To see the average percentage of life, the average height growth and the average growth diameter of forest plants are presented in Table 4. The following:

Table 4. Average Percentage of Life, Height Growth and Growth Diameter of Revegetated Plants

Forest plants	LCC	Percentage of Life (%)	High Growth (cm)	Diameter Growth (cm)
Shoreabalangeran	*Control*	93,75	118,09	0,90
	Mucuna bracteata	100	116,08	0,87
	Pueraria. javanica	100	116,84	0,84
	Calopogoniummucunoides	100	117,84	0,94
Combretocarpusrotundatus	*Control*	51,50	37,14	0,48
	Mucuna bracteata	62,50	42,31	0,50
	Pueraria javanica	53,25	38,75	0,47
	Calopogoniummucunoides	62,50	39,10	0,49
Melaleuca cajuputi	*Control*	100	151,99	1,15
	Mucuna bracteata	93,75	138,58	1,14
	Pueraria javanica	93,75	149,42	1,16
	Calogoniummucunoides	100	148,67	1,07
Alstoniascholaris	*Control*	100	78,45	1,25
	Mucuna bracteata	100	79,41	1,19
	Pueraria javanica	100	80,91	1,27
	Calopogoniummucunoides	100	79,75	1,30

Based on the data in Table 4, it can be seen that M. cajuputi plants on 3 parameters, namely the percentage of growth in the control plot (100%) and the combination plot with LCC C. mucunoides (100%), the best height growth in the control plot, the combination plot with LCC P. javanica, combination plots with LCC C. mucunoides and combination plots with M. bracteata (151.99 cm;149.42 cm;148.67 cm;138.58 cm) and growth in diameter in the combination plots with LCC P. javanica, control plot, combination plot with LCC M. bracteata and combination plot with C. mucunoides (1.16 cm;1.15 cm;1.14 cm;1.07 cm) followed by Alstoniascholaris (Pulai) the best growth on 2 parameters, namely the percentage of survival (100%) in all treatment plots and the highest diameter growth respectively in the combination plot with LCC C. mucunoida, the combination plot with LCC P. javanica, the control plot and the combination with LCC M. bracteata (1.30 cm; 1.27 cm; 1.25 cm;1.19 cm) and S. balangeran plants on 2 parameters, namely the best survival percentage (100%) in the combination plot with LCC M.bracteata, LCC P.javanica and LCC C. mucunoides and high growth in all treatment plots successively in control plots, combination plots with LCC C. mucunoides, combination plots with P. javanica and combination plots with LCC M. bracteata (118,09 cm;117,84 cm;116,84 cm;116,08 cm).

The results of soil analysis on TSF Mirah I and TSF Mirah II) showed that the physical properties of the texture of the sand fraction between the two tailings before and after planting had a change (decrease) in the sand fraction but not too significant, namely in a row at Mirah I TSF of 89, 36% and 78.13%, in Mirah II TSF 82.90% and 78.13%. The decrease in the sand fraction was in line with the increase in the clay and silt fraction, namely in Mirah I TSF before planting it was 9.81% and after planting it was 19.05% and the clay fraction before planting was 0.83% after planting it was 2.83%, in Mirah II TSF the dust fraction before planting was 14.76% after planting 19.06% and the clay fraction before planting was 2.34% after planting 2.83%.

The addition of the value of the content of the dust and clay fractions is suspected as a result of the treatment of adding organic matter in the form of compost when planting trees. Tejada et al (2009) stated that aggregate stability is a very important soil property that affects soil sustainability and crop production. The addition of organic matter informs that the addition of manure or compost increases the stability of soil aggregates. The level of acidity (pH H2O, pH KCl) is neutral. The organic C content found in TSF Mirah I and TSF Mirah II was in the low category both before and after planting. This is in line with the opinion of Isnaniarti et al (2017) that former gold mining land in Monterado contains N, P and C which are included in the very low soil fertility criteria. Furthermore, according to Aryanti and Hera (2019) former gold mining soils generally have low nutrient content including carbon content (C).

The biggest component in organic matter is carbon, so the addition of organic matter will increase the carbon content of the soil. Increasing soil carbon will affect soil properties to be better physically, chemically and biologically. However, in this study the application of compost as organic fertilizer was not enough to make a real contribution to increasing the organic C content in the soil. This is thought to be caused by the compost given which is directly absorbed for plant growth, resulting in significant growth for revegetated plants and ground cover plants (LCC).

The nutrients that are important for plants and include macro nutrients (nutrients most needed by plants), namely nitrogen, potassium and phosphorus. Nitrogen is useful for stimulating plant growth, especially stems, branches and leaves. In addition, the growth of chlorophyll, protein, fat and other organic compounds. Phosphorus serves to stimulate roots, flowers, fruits and seeds. Potassium to strengthen the plant body so that it does not easily collapse and the flowers and fruit do not fall easily (Neneng dan Saraswati, 2019).

In this study, the macronutrients analyzed were nitrogen (total N), phosphorus (P) and potassium (K). Based on the results of soil analysis, it showed that the N, P and K content were in the low criteria.

The low N content is due to mining activities that began with the felling of the vegetation on it causing a loss of organic matter sources. Although over time (7 years after mining) the TSF Mirah I type Typha sp and several types of grass that are adaptive to extreme environments such as Cyperus sp . has grown and can be a source of organic matter for the soil but has not been able to significantly increase the soil N content.

The low K content is due to the leaching of the top soil layer which contains gold so that the soil containing K (Potassium) is exchanged and dissolves in water causing the K content in the site to decrease. Dwijoseputro (1992) stated that available K elements are generally found in the top soil layer. In addition, stems, leaves and branches that fall (dead) and disintegrate together with the soil are factors that can increase exchangeable K availability in the soil. The P content is also low due to a lack of organic matter in the soil so that microorganisms in the soil cannot optimally break down organic matter resulting in slow availability of P. The rate of decomposition of organic matter is one of the factors that affect the availability of P in the soil besides pH, Fe ions and Al (Aryanti and Hera, 2019). Element P is needed for cell division and the development of plant tissues that form the point of plant growth (Neneng dan Saraswati, 2019).

4. Conclusion

M. cajuputi plants had the best growth on 3 parameters, namely the percentage of growth in control plots (100%) and combination plots with LCC C. mucunoides (100%), the best height growth in control plots, combination plots with LCC P. javanica, combination plots with LCC C. mucunoides and combination plots with M. bracteata (151.99 cm; 149.42 cm; 148.67 cm; 138.58 cm) and growth in diameter respectively in combination plots with LCC P. javanica,, plot control, combination plot with LCC M. bracteata and combination plot with C. mucunoides (1.16 cm;1.15 cm;1.14 cm;1.07 cm) followed by Alstoniascholaris (Pulai) plants had the best growth at 2 Parameters were survival percentage (100%) in all treatment plots and the highest diameter growth successively in combination plots with LCC C. mucunoida, combination plots with LCC P. javanica, control plots and combination with LCC M. bracteata (1.30 cm ; 1.27 cm; 1.25 cm; 1.19 cm) and S. balangeran plants on 2 parameters, namely the best survival percentage (100%) in the combination plot with LCC M.bracteata, LCC P.javanica and LCC C. mucunoides and high growth in all treatment plots successively in control plots, combination plots with LCC C. mucunoides, combination plots with P. javanica and combination plots with LCC M. bracteata (118,09 cm;117,84 cm;116,84 cm;116,08 cm).

Refrences

[1] A El-Kereti, M., A El-feky, S., S Khater, M., A Osman, Y., & A El-sherbini, E. S. (2013). ZnOnanofertilizer and He Ne laser irradiation for promoting growth and yield of sweet basil plant. Recent patents on food, nutrition & agriculture, 5(3), 169-181.

[2] Adman B., Hendrarto, B.,danSasongko DP. 2012. Pemanfaatan Jenis Pohon Lokal CepatTumbuhuntkPemulihan Lahan Pascatambang Batubara (Studi kasus di PT Singlurus, Pratama, Kalimantan Timur). JurnalIlmuLingkungan 10:19-25.

[3] Anibas, C., Verbeiren, B., Buis, K., Chormański, J., De Doncker, L., Okruszko, T., ... &Batelaan, O. (2012). A hierarchical approach on groundwater-surface water interaction in wetlands along the upper Biebrza River, Poland. Hydrology and Earth System Sciences, 16(7), 2329-2346.

[4] Aryanti E. dan N. Hera. 2019. Sifat Kimia Tanah Area Pasca Tambang Emas: (Studi Kasus PertambanganEmasTanpaIzin di Kenegerian Kari Kecamatan Kuantan Tengah, Kabupaten Kuantan, Singingi). JurnalAgroteknologi Volume 9 No.2 hal 21-26.

[5] Cardoso, F., Gomes, D. C. B. B., & Viegas, E. (2019). The influence of different types of manure and planting distance towards the growth and development of plants white mustard (Brassica juncea L.). International Journal of Development Research, 9(1), 25236-25245.

[6] Chibuike, G. U., & Obiora, S. C. (2014). Heavy metal polluted soils: effect on plants and bioremediation methods. Applied and environmental soil science, 2014.

[7] Fritz, K. M., Schofield, K. A., Alexander, L. C., McManus, M. G., Golden, H. E., Lane, C. R., ... & Pollard, A. I. (2018). Physical and chemical connectivity of streams and riparian wetlands to downstream waters: a synthesis. JAWRA Journal of the American Water Resources Association, 54(2), 323-345.

[8] Gonzaga, M. I. S., da Silva, P. S. O., de Jesus Santos, J. C., & de Oliveira Junior, L. F. G. (2019). Biochar increases plant water use efficiency and biomass production while reducing Cu concentration in Brassica juncea L. in a Cu-contaminated soil. Ecotoxicology and Environmental Safety, 183, 109557.

[9] Isnaniarti, U.N., W. Ekyastuti dan H.A. Ekamawanti. 2017. SuksesiVegetasi pada Lahan Bekas PenambanganEmas Rakyat di KecamatanMonteradoKabupatenBengkayang. JurnalHutan Lestari: 5 (4) : 952 - 961

[10] Istomo, H, S.Rahaju, E. Permana, SI Suryawan, A. Hidayat, dan Waluyo. 2007. Kajian Perolehan Karbon sebagaiDampakIntervensi pada Lokasi KegiatanProyek CCFPI Di Eks-PLG Blok A Mentangai, Kalimantan Tengah dan Sekitar TN. Berbak, Jambi. Bogor : LaboratoriumEkologiHutan, FakultasKehutanan IPB – Wetlands International Indonesia Programme.

[11] Khattab, M., Shehata, A., El-Saadate, A., & Al-Hasni, K. (2016). Effect of glycine, methionine and tryptophan on the vegetative growth, flowering and corms production of gladiolus plant. Alexandria Science Exchange Journal, 37(October-December), 647-659.

[12] Kissinger, K., Pitri, R. M., &Nasrulloh, A. (2022). Implementation of Plant Selection Based-On Plant Growth on Revegetation of Peatland in South Kalimantan. International Journal of Environment, Agriculture and Biotechnology, 7(2), 137-142.

[13] Mansur I. 2011. Teknik SilvikulturUntukReklamasi Lahan Bekas Tambang. SEAMEO BIOTROP, Bogor.

[14] Mansur I. dan MI Kadarisman. 2019. Teknik Pembibitan Kayu Putih (Melaleuca cajuputi) SecaraVegetatif di Persemaian Perusahaan Batubara PT Bukit Asam Persero Tbk 10 (01):21-28

[15] Marjenah, 2001. PengaruhPerbedaanNaungan di PersemaianterhadapPertumbuhan dan ResponMorfologi Dua Jenis Semai Meranti. JurnalIlmiahKehutanan “Rimba Kalimantan” Vol. 6. Nomor. 2. Samarinda, Kalimantan Timur.

[16] Mawazin dan A.Susilo. 2016. PertumbuhanTanaman Pulai (Alstoniascholaris) pada Lahan Bekas Tambang Batubara di Kalimantan Timur. Proseding Seminar Nasional Masyarakat Biodiversity Indonesia Volume 2 Nomor 2 hal:237-242

[17] Munir, M. dan RR D.N.Setyowati. 2017. Kajian Reklamasi Lahan Bekas Tambang Di Jambi, Bangka dan Kalimantan Selatan. Klorofil Vol.1 No.1;11-16. Fakultas Sains dan Teknologi, Universitas Islam Negeri Sunan Ampel. Surabaya.

[18] Neneng L. dan D. Saraswati. 2019. Reklamasi Lahan Kritis Bekas PenambanganEmasMenggunakan Metode Bioremediasi dan Fitoremediasi. EnviroScienteae Vol.15 No.2 hal 216-225

[19] Nosetto, M. D., Acosta, A. M., Jayawickreme, D. H., Ballesteros, S. I., Jackson, R. B., & Jobbágy, E. G. (2013). Land-use and topography shape soil and groundwater salinity in central Argentina. Agricultural Water Management, 129, 120-129.

[20] Prayudianingsih, R. 2014. Pertumbuhan Semai Alstoniascholaris, Acacia auriculiformis dan Muntingiacalabura yang Diinokulasi Fungi MikorizaArbuskula Pada Media Tanah Bekas Tambang Kapur. JurnalPenelitianKehutanan Wallace 3(1) hal:13-23

[21] Rachmanadi D., E. Faridah, Sumard, P.van deer Meer, M.A.Qirom. 2021. PengaruhGenangan dan Kompetisi Cahaya Terhadap Tingkat KeberhasilanPenanaman Pada HutanRawaGambutTerdegradasi. Jurnal Galam Vol.1(2):123-140

[22] Rusdiana O, Y.Fakuara, C.Kusmana, dan Y. Hidayat. 2000. ResponPertumbuhanTanaman Sengon (Paraserianthesfalcataria) TerhadapKepadatan dan Kandungan Air Tanah Podsolik Merah Kuning. JurnalManajemenHutanTropika. 6(2): 43-53.

[23] Sabtanto JS. 2008. TinjauanReklamasi Lahan Bekas Tambang dan AspekKonservasi Bahan Galian. Kelompok Program PenelitianKonservasi-Pusat Sumber Daya Geologi.

[24] Saito H, M.Shibuya M, SJ.,Tuah, M. Turjaman, K. Takahashi, Y.Jamal, H.Segah, PE Putir and SH Limin. 2005. Initial Screening of Fast-Growing Tree Spesies being Tolerant of Dry Tropical Peatlands in Central Kalimantan, Indonesia. Journal of Forestry Research 2 (2) hal: 1-10

[25] Sekarjannah, F. A., Mansur, I., & Abidin, Z. (2021). Selection of organic materials potentially used to enhance bioremediation of acid mine drainage. Journal of Degraded and Mining Lands Management, 8(3), 2779.

[26] Setyaningsih L. 2007. PemanfaatanCendawanMikorizaArbuskula dan KomposAktifUntukMeningkatkanPertumbuhan Semai Mindi (Melia azedarach Linn) pada Media tailing tambangemasPongkor [tesis] Bogor: SekolahPascasarjana IPB.

[27] Siregar, C. A., Turjaman, M., Hidayat, A., Rachmat, H. H., &Mulyanto, B. (2021). Suwardi; Iskandar; Maharani, R.; et al. Managing and Reforesting Degraded Post-Mining Landscape in Indonesia: A Review. Land 2021, 10, 658.

[28] Song, P., Xu, D., Yue, J., Ma, Y., Dong, S., & Feng, J. (2022). Recent advances in soil remediation technology for heavy metal contaminated sites: A critical review. Science of the Total Environment, 838, 156417.

[29] Sophocleous, M. (2002). Interactions between groundwater and surface water: the state of the science. Hydrogeology journal, 10, 52-67.

[30] Suwito, D., &Poedjirahajoe, E. (2021). The potency of Cratoxylumarborescens Blume (Geronggang) and Combrecarpusrotundatus Dans (Tumih) as natural regeneration in degraded tropical peat swamp forest. The Journal of Indonesia Sustainable Development Planning, 2(3), 272-289.

[31] Suwito, D., &Poedjirahajoe, E. (2021, November). The Covid-19 pandemic impact on indigenous people livelihoods in the peat swamp forest ecosystem in Central Kalimantan Indonesia. In IOP Conference Series: Earth and Environmental Science (Vol. 894, No. 1, p. 012023). IOP Publishing.

[32] Tamin R.P. 2010. Pertumbuhan Semai Jabon (Anthocephalus cadambaRoxb Mic) pada Media Pasca Penambangan Batubara yang Diperkaya Fungi MikorizaArbuskula, Limbah Batubara dan Pupuk NPK [Tesis]. Bogor: SekolahPascasarjana IPB.

[33] Tata, H. L., Nuroniah, H. S., Ahsania, D. A., Anggunira, H., Hidayati, S. N., Pratama, M., ... & Kolka, R. (2022). Flooding tolerance of four tropical peatland tree species in a nursery trial. Plos one, 17(4), e0262375.

[34] TeBeest, M., Esler, K. J., & Richardson, D. M. (2015). Linking functional traits to impacts of invasive plant species: a case study. Plant Ecology, 216, 293-305.

[35] Tejada M., M. Hernandes, C. Garcia. 2009. Soil Restoration using composted plant residues: Effect on soil properties. Soil and Tillage Research 102 pp 109-117

[36] Wang, M., Chen, L., Liang, Z., He, X., Liu, W., Jiang, B., ... & Lin, Y. E. (2020). Metabolome and transcriptome analyses reveal chlorophyll and anthocyanin metabolism pathway associated with cucumber fruit skin color. BMC plant biology, 20, 1-13.
[37] Wang, S., Xu, Y., Lin, Z., Zhang, J., Norbu, N., & Liu, W. (2017, August). The harm of petroleum-polluted soil and its remediation research. In AIP Conference proceedings (Vol. 1864, No. 1). AIP Publishing.
[38] Xin, P., Wilson, A., Shen, C., Ge, Z., Moffett, K. B., Santos, I. R., ... & Barry, D. A. (2022). Surface water and groundwater interactions in salt marshes and their impact on plant ecology and coastal biogeochemistry. Reviews of Geophysics, 60(1), e2021RG000740.
[39] Ye, S., Zeng, G., Wu, H., Zhang, C., Dai, J., Liang, J., ... & Zhang, C. (2017). Biological technologies for the remediation of co-contaminated soil. Critical reviews in biotechnology, 37(8), 1062-1076.
[40] Yuningsih, L., Hermansyah, H., Ibrahim, E., & MARSI, M. (2021). Diversity, structure and composition of vegetation in post-coal mining reclamation area in Sumatra, Indonesia. Biodiversitas Journal of Biological Diversity, 22(8).
[41] Zhang, H., Yuan, X., Xiong, T., Wang, H., & Jiang, L. (2020). Bioremediation of co-contaminated soil with heavy metals and pesticides: Influence factors, mechanisms and evaluation methods. Chemical Engineering Journal, 398, 125657.

Acknowledgments

The authors would like to thank PT Kasongan Bumi Kencana for permission to carry out and funding this research at tailings storage facilities (TSF) Mirah Kalanaman, Katingan District, Central Kalimantan.