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Growth performance of *Calophyllum inophyllum* at a bioenergy trial plot in Bukit Soeharto Research and Education Forest, East Kalimantan

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Abstract The Indonesian government has committed to providing its entire population with energy through the National Energy Policy, which highlights the importance of diversification, environmental sustainability, and enhanced deployment of domestic energy resources. The contribution of new and renewable energy (NRE) to the nation's energy supply is mandated to reach 23% by 2025, with bioenergy an important NRE alternative. If developed and deployed appropriately, bioenergy plantations have potential to restore degraded land and enhance biodiversity and environmental services while supporting rural livelihoods. As a potential biofuel tree species suited to the tropics, *Calophyllum inophyllum* (nyamplung) is being tested across wide-ranging degraded forest conditions in Indonesia. Nyamplung is a potential biodiesel alternative as it grows well in harsh environmental conditions, produces non-edible seed oil, has high amounts of kernel oil and fruits profusely. Here we report growth performance in a plantation trial plot established in February 2018, on previously burned land in Mulawarman University's Bukit Soeharto Research and Educational Forest. Growth of this two-year-old plantation is strong compared to other Indonesian sites, with average survival rate above 90% on Ultisol soil, which is classified as low fertility and acidic. The findings reveal that different doses of fertilizer applications and slope gradient have no significant effects on growth performance. In addition, trees have already started to flower and fruit, and are colonized by bird species and insects, including bees and butterflies. The study indicates that nyamplung adapts well to different land and soil types. Bioenergy plantations on degraded land are a promising approach for land restoration, and enhance native biodiversity and environmental services while providing a source of renewable energy.

Key words: *Calophyllum inophyllum*; nyamplung; bioenergy; degraded land; growth performance; biodiversity, East Kalimantan

1. Introduction

The Indonesian government has committed to providing its entire population with access to modern energy sources through its National Energy Policy (*Kebijakan Energi Nasional*), a document which highlights the importance of diversification and environmental sustainability, along with enhanced supply and deployment of domestic energy resources. These diversified energy sources include coal, oil, gas and new renewable energy (NRE). The contribution of NRE to the nation's energy supply is mandated to reach 23% by 2025 [1]. Bioenergy features as an important NRE alternative in the policy. To further the development of biofuel, the Ministry of Environment and Forestry (MoEF) has been assigned an important role in terms of providing unproductive forestland [2,3]. Based on recent MoEF data, 14 million hectares of Indonesian land is unutilized and classified as 'degraded', with the government earmarking it for conversion to plantations, energy production and infrastructure [4].

Calophyllum inophyllum (nyamplung) is one potential species able to produce bioenergy, especially for biodiesel as it meets US and European Union biodiesel standards [5]. In addition, the biodiesel has the highest calorific value compared to other energy species, such as jatropha, *Pongamia pinnata* and others [6]. Further, Calophyllum biodiesel could replace fossil diesel without any need for engine modification [7]. The species produces non-edible seeds with significant amounts of kernel oil, and seeds can be harvested repeatedly from the age of 4 to 5 years until the tree is 50 years old [8]. Nyamplung flowers attract honeybees and are a great source of honey [9,10]. The species can also be grown alongside a variety of agricultural crops, such as maize, soybean and rice, which provides an opportunity to practice climate smart agroforestry practices [9].

Generally, nyamplung grows at a warm temperature in wet or moderate conditions. It grows in a wide range of soils, but grows best in sandy, well-drained soils in coastal areas. It is tolerant to wind, salt spray, drought and brief periods of waterlogging. It grows at altitudes of up to 500m, where annual rainfall ranges between 1000 and 5000mm, and annual temperatures range between 7–18^{0}C and 37–48^{0}C [11]. In Indonesia, it has very wide natural distribution, from Sumatra in the west to Papua in the east, and from Java in the south to Kalimantan in the north. The plant is also tolerant to harsh environmental conditions, and requires little care and maintenance when it comes to cultivation [12]. In natural stands, nyamplung seed can produce up to 58% crude oil [8]. In line with the breeding strategy for biofuel yielding nyamplung [13], tree populations were selected from Gunung Kidul, where trees produced the highest crude calophyllum oil (CCO) content (50.00–50.72%) among six nyamplung populations from Java, and were planted in Wonogiri in Central Java to establish a provenance seed stand. A provenance seed stand is an area where the potential provenance or land race is established and managed intensively and entirely for seed production [14]. Through the above breeding program, oil content was increased by 14–19% [15].

Despite the species having potential for biofuel production from non-edible oil, there are limited studies into the adaptability and suitability of nyamplung to different locations in Indonesia. This paper aims to communicate early findings relating to nyamplung's growth performance on previously burned degraded land in East Kalimantan.

2. Materials and methods

2.1. Study site

The research site is located at Mulawarman University's Bukit Soeharto Research and Education Forest (KHDTK HPPBS) in the district of Kutai Kartanegara district, East Kalimantan (Figure 1). This 20,271- hectare forestland is a part of the Bukit Soeharto Great Forest Park (*Tahura*) and was assigned to Mulawarman University by the Ministry of Environment and Forestry (MoEF) as a special purpose forest estate (KHDTK) in 2014. Site characteristics of the trial plot in Bukit Soeharto and the provenance seed stand in Wonogiri (as the source of nyamplung seeds) are shown in Table 1.

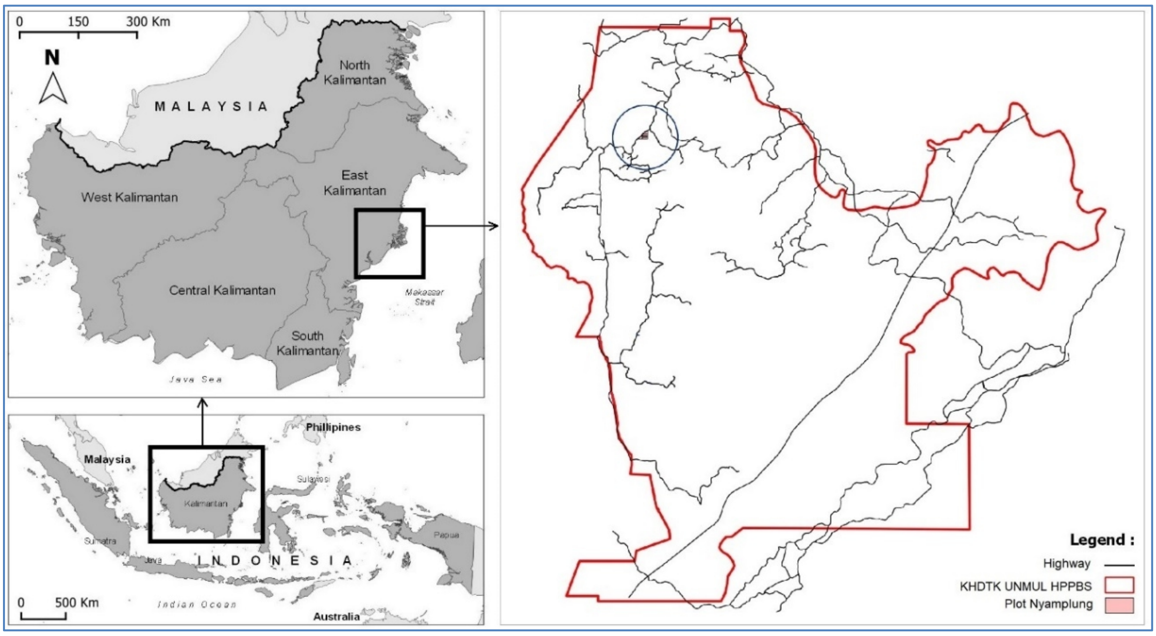

Figure 1. Location of the research site – Mulawarman University's Bukit Soeharto Research and Education Forest, East Kalimantan (Map created by CIFOR, 2020)

Table 1. Characteristics of the previously burned *Calophyllum inophyllum* (nyamplung) plantation trial site in Bukit Soeharto Research Forest, and the seed source site in Wonogiri, Central Java.

Site characteristics	Bukit Soeharto	Wonogiri
Total area	20,271 ha	93.34 ha
Latitude (South)	00°47'47.5"	7°32' – 8°15'
Longitude (East)	117°01'15.3"	110°41' – 111°18'
Rainfall (mm/year)	2000 – 2500	1878
Temperature (°C)	20 – 36	20 – 38
Altitude (m asl.)	117	141
Soil type	Ultisol	Vertisol
Last burned	2016	Never burned
Vegetation cover	Acacia, bamboo, scrub	Bamboo, Dalbergia, scrub

The soil is classified as Ultisol (formerly red-yellow podzolic), a soil with lower-based status which is more acidic in reactions than Oxisols. It has been formed from more acidic parent materials (like dacitic and liparitic tuffs) and is rich in quartz [15]. The area has experienced frequent fires since the late 1990s with the last fire prior to the experiment being in 2016. Such fires lead to degradation of the forest and land, which is visually apparent from the species dominating the area, i.e. unplanted *Acacia mangium*, wild bamboo and scrub.

2.2. Research design and materials

The trial plot was established on a 5-hectare area of the study site in early 2018 to examine the suitability of energy production tree species to degraded (previously burned) mineral soil. The trial plot was divided into 5 subplots with different slope gradients (see Figure 2). In February 2018, the plot was planted using genetic material from the nyamplung provenance seed stand in Gunung Kidul, Yogyakarta. This nyamplung, planted in a forest managed by the Center for Forest Biotechnology and Tree Improvement Research and Development (CFBTIRD), was found to have the highest crude calophyllum oil (CCO) content of six nyamplung populations in Java (see Table 2).

Table 2. Crude calophyllum oil (CCO) content of six provenance tree populations in Java.

No.	Provenance/Land race	Dry seeds (kg)	Residual waste (kg)	CCO (kg)	CCO (%)
1.	Banyuwangi (East Java)	2.09	1.20	0.89	42.58
2.	Gunung Kidul (Yogyakarta)	2.10	1.08	1.02	48.57
3.	Purworejo (Central Java)	1.90	1.04	0.87	45.79
4.	Cilacap (Central Java)	2.10	1.25	0.85	40.48
5.	Ciamis (West Java)	2.00	1.20	0.80	40.00
6.	Pandeglang (Banten)	1.81	1.16	0.67	37.02

Source: [5]

The trial plot was arranged in a completely randomized design to examine the responses of the different NPK fertilizer doses and different slope gradients with the same doses. Two thousand nyamplung seedlings were planted with a spacing of 5m x 5m, aiming to give space for the species to grow in width, given that the main objective was to obtain seeds for oil production. The plot was divided into 15 permanent measurement plots (PMPs) with three replications for each plot. 227 seedlings were randomly selected for regular measurement. Three different doses of NPK fertilizer were applied on different plots to examine growth performance: 50 g, 100 g and 200 g (Figure 2). Plot 1 and Plot 5 were given 100-gram and 200-gram doses of NPK respectively, while 50-gram doses were applied on plots 2, 3 and 4. The plots were monitored every three months between August 2018 and December 2019, with height, diameter and number of branches measured as growth parameters. Soil samples were collected from each plot with tree replication and were analyzed to examine soil fertility.

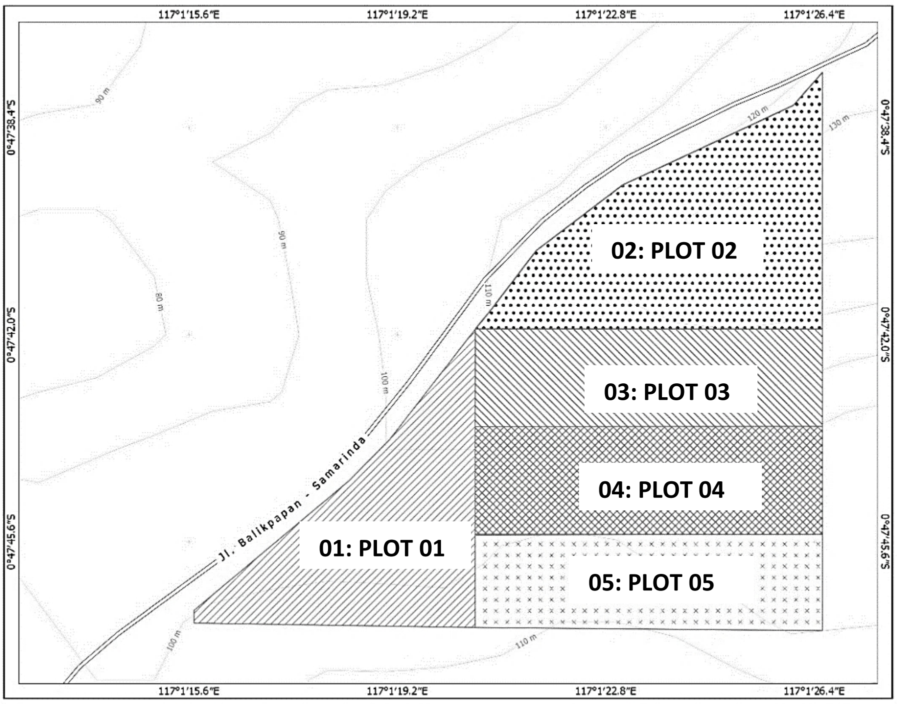

Figure 2. Plot design for the nyamplung trial plot at Bukit Soeharto Research and Education Forest.

2.3. Data analysis

The trial plot was established with a two-way ANOVA statistical model to: i) examine the response of species growth after different treatments; and ii) examine the effect of slope gradient on species growth, regardless of treatment. Such two-way ANOVA analysis is commonly used to compare the effects of different treatments between two populations [16].

ANOVA was performed using the plot's mean data (Y_{ijk}) for growth, with the following linear model:

$$Y_{ijk} = m + T_i + P_j + e_{ijk}$$

where, m is the overall mean, T_i is the i-th treatment effect, P_j is the effect on the permanent measurement plot, and e_{ijk}. is the experimental error for Y_{ijk}.

An SAS (Statistical Analysis System) ver. 9.0 program was used to analyze the data.

3. Results and discussion

3.1 Results

3.1.1. Growth performance

Plant survival rate is one of the common parameters by which the health of plants is measured; it is dependent on environmental stress [17]. First-year survival of transplanted seedlings plays a crucial role in the subsequent success of plantations [18]. Table 6 shows that at 20 months, the survival rate for seedlings in the trial plot was above 90%, varying between 91.1 (Plot 3) and 98.1 (Plot 2). These survival rates, however, tended to decline after the seedlings reached 20 months old, particularly in Plot 3 where the rate declined almost 9% within 1.5 years.

Table 3. Survival rate of nyamplung under different treatments (i.e. NPK fertilizer doses and slope gradients).

Treatments	Survival rate (%)				
	6 months	9 months	12 months	14 months	20 months
Plot 1	93.8	91.7	91.7	91.7	91.7
Plot 2	100.0	100.0	100.0	100.0	98.1
Plot 3	100.0	100.0	97.8	93.3	91.1
Plot 4	100.0	97.8	95.6	95.6	95.6
Plot 5	97.8	97.8	97.8	97.8	95.6

3.1.2. Doses of NPK fertilizer

Different fertilizer doses resulted in differing growth characteristics (height, diameter, number of branches) in nyamplung seedlings in the trial plot (Table 4 and Figure 3). At the time of monitoring, there were no significant differences between plots and PMPs in terms of height. Height ranged from 0.8–1.2m (at 9 months) and 3.8–5.5m (at 20 months). Likewise, treatments resulted in no significantly different effects in diameter growth between plots and PMPs, except at 6 months old. Diameter ranged between 0.7–1.0cm and 5.9–9.1cm at 6 and 20 months respectively. Analysis revealed that different treatments resulted in significantly different effects on the numbers of branches between plots and PMPs after 6 months old. The number of branches ranged from 0.8–1.8 (at 6 months) and 8.5–16.5 (at 20 months). At the time of monitoring, a dose of 100g of fertilizer gave the best effects, in terms of the number of branches.

Table 4. Variance analysis of nyamplung growth performance after three different doses of NPK fertilizer.

Source of variation	df	Mean square				
		6 months	9 months	12 months	14 months	20 months
1. Height						
Fertilizer	2	0.054**	0.134 ^{ns}	0.053 ^{ns}	0.818 ^{ns}	2.043 ^{ns}
PMP	2	0.069**	0.228*	0.489 ^{ns}	0.628 ^{ns}	0.403 ^{ns}
Error	4	0.002	0.027	0.412	2.086	9.252
2. Diameter						
Fertilizer	2	0.123 *	0.479 ^{ns}	0.387 ^{ns}	8.891 ^{ns}	6.399 ^{ns}
PMP	2	0.120 *	0.887 ^{ns}	3.118 ^{ns}	6.935 ^{ns}	12.785 ^{ns}
Error	4	0.040	0.310	1.091	19.983	10.441
3. Number of branches						
Fertilizer	2	0.836 **	9.994 **	30.434 **	57.221 **	50.692 ^{ns}
PMP	2	0.553 **	5.739 *	17.167 **	26.925 **	36.882 ^{ns}
Error	4	0.009	0.469	0.290	0.667	8.292

Remarks: df = degree of freedom; ns = non-significant; * = significant difference at 0.05 level; ** = significant difference at 0.01 level; PMP = permanent measurement plot

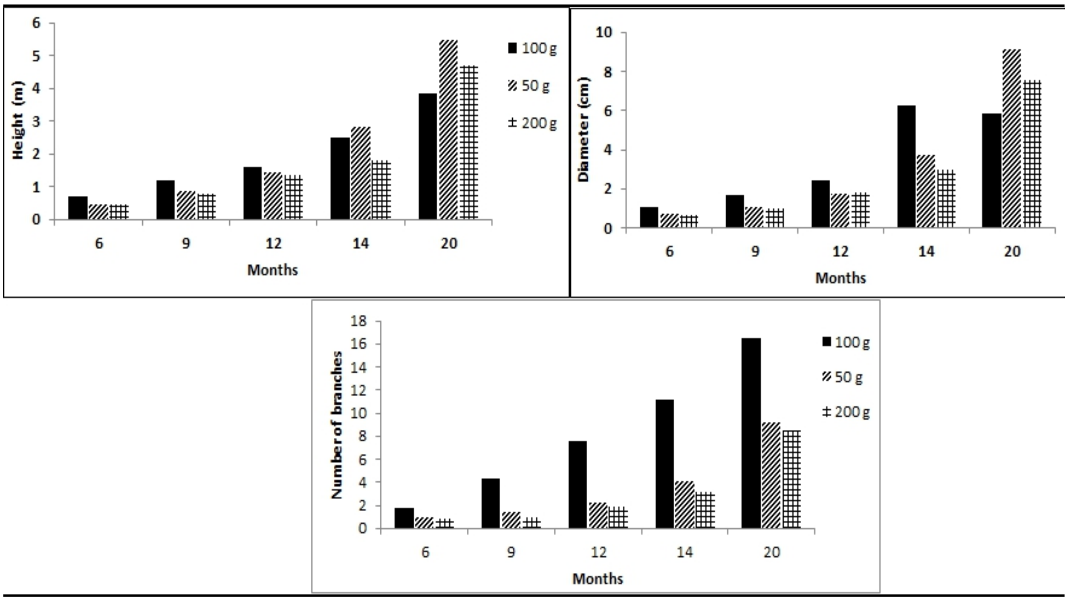

Figure 3. Mean growth performance after three different doses of NPK fertilizer.

3.1.3. *Effect of slope gradient*

Slope conditions showed no significant effects on growth performance between plots and PMPs until the age of 20 months, except in terms of diameter (Table 5, Figure 4). Height ranged from 0.8–0.9m (at 9 months) and 2.8–5.5m (at 20 months). Slope gradient had an apparent effect on diameter at the end of the observation period (i.e. at 20 months), when diameter ranged between 5.5 and 9.1cm. Meanwhile, the number of branches varied between 0.8–1.0 (at 6 months) and 8.6–9.2 (at 20 months).

Table 5. Variance analysis of nyamplung growth performance under three different slope conditions.

Source of variation	df	Mean square				
		6 months	9 months	12 months	14 months	20 months
1. Height						
Slope	2	0.001 ns	0.068 ns	0.334 ns	1.328 ns	6.098 ns
PMP	2	0.058 *	0.273 *	1.689 *	4.349 ns	11.739 ns
Error	4	0.006	0.031	0.173	0.761	2.474
2. Diameter						
Slope	2	0.001 ns	0.019 ns	0.179 ns	0.505 ns	8.190 **
PMP	2	0.148 *	2.061 **	7.217 **	14.697 **	27.577 **
Error	4	0.014	0.007	0.058	0.251	0.001
3. Number of branches						
Slope	2	0.026 ns	0.277 ns	0.845 ns	2.086 ns	0.153 ns
PMP	2	0.490 **	3.229 ns	9.279 ns	20.718 ns	49.407 ns
Error	4	0.017	0.649	1.691	3.838	14.949

Remarks: df = degree of freedom; ns = non-significant; * = significant difference at 0.05 level; ** = significant difference at 0.01 level; PMP = permanent measurement plot

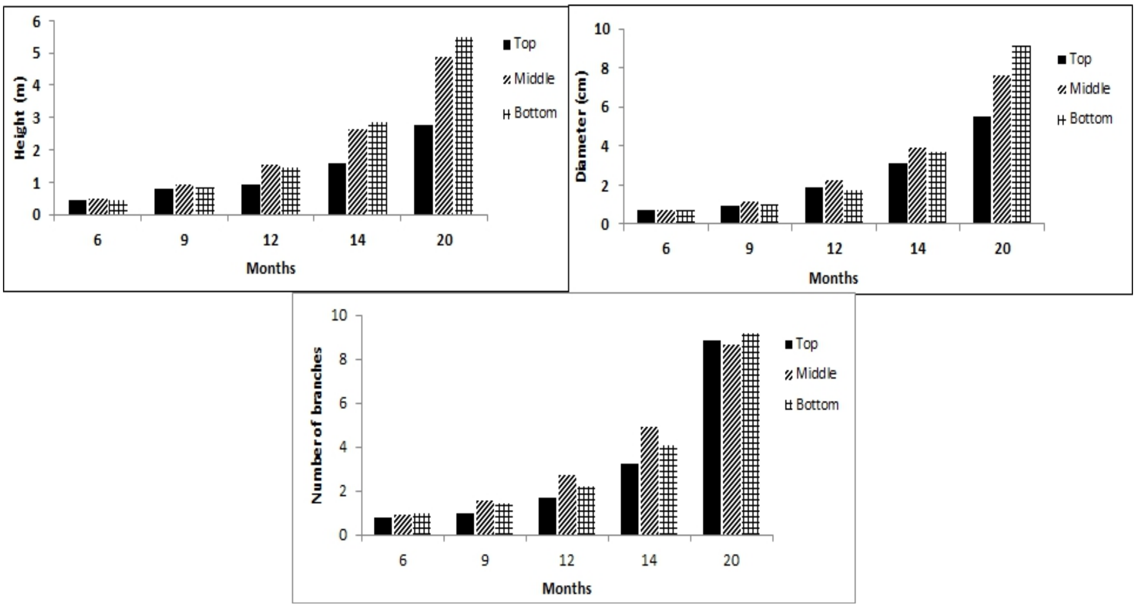

Figure 4. Mean growth performance under three different slope conditions.

3.1.4. Soil chemical properties
Soil samples from the trial plot were collected and analyzed in the soil laboratory to examine the soils' chemical properties. Table 6 shows that fertility in the study area is low, as indicated by low C-organic content and N-total content. The other indicator supporting low fertility in the area is low soil acidity (pH 4–5).

Table 6. Average soil chemical properties at the nyamplung trial plot in Bukit Soeharto Research and Education Forest.

Plot	pH H_2O	C-org (%)	N-Total (%)	C/N	P-Total (ppm)	Ca	Mg	K	Na	KTK	Base Saturation (%)
						(cmol$^{(+)}$/kg)					
1	4.48	1.46	0.19	7.51	44.37	0.59	0.43	0.20	0.05	14.28	10.01
2	4.49	1.14	0.21	5.47	21.09	0.15	0.31	0.06	0.05	8.08	6.69
3	4.27	1.13	0.20	5.59	39.16	0.15	0.15	0.14	0.05	7.36	7.47
4	4.93	1.13	0.23	4.98	29.35	0.30	0.30	0.11	0.04	42.23	1.59
5	5.14	1.32	0.22	6.06	10.18	0.28	0.28	0.16	0.04	41.40	1.99
Category	very acidic to acidic	low	low to moderate	very low to low	low to high	very low	very low to low	very low to low	very low	low to very high	very low

3.1.5. Landscape restoration and biodiversity
After two years of life as a plantation, the landscape had completely changed from degraded bare hills to a green landscape (see Figure 5). Nyamplung trees had already started to flower and fruit. Several bird species and insects, including bees and butterflies, had colonized the two-year-old trees. While flora and fauna surveying and analysis is not covered in this study, it is apparent that establishing bioenergy plantations on degraded land is a promising approach for land restoration and enhancing native biodiversity, while producing renewable energy.

Figure 5. Condition of the previously burned land trial site, before and after planting nyamplung

Figure 6. Bees, birds and butterflies colonize nyamplung trees.

3.2 Discussion

3.2.1. Survival rate and environment

Survival rate is an attribute that relates adaptation of a species to the planting environment [19]. Geographic variation is often the most important characteristic relating to survival and adaptability [12]. The survival rate of nyamplung at the trial site plots in Bukit Soeharto is over 90%. This indicates that nyamplung from the provenance seed stands in Wonogiri adapted well to the trial site in Bukit Soeharto, despite the locations having different characteristics (see Table 1). This survival rate is the same as nyamplung planted in Wonogiri as the seed source at 6 and 12 months after planting [17]. A study by Hani and Rahman [21] revealed that 4-year-old nyamplung had respective survival rates of 97.33% and 68.88% under agroforestry and monoculture systems on sandy soil in a coastal area of West Java. Meanwhile, among six Javanese provenance populations aged 5 years, planted in sandy soil on ex-situ conservation plots in Cilacap, Central Java, the survival rate ranged from 44–82% [22]. When comparing 2-year-old nyamplung trees on rocky land with thin topsoil in Gunung Kidul, where seeds came from 8 different Indonesian islands, the survival rate ranged between 77 and 86% [23]. Likewise, 12 months after planting, nyamplung had the highest survival rate (52.4–78.7%) of five species planted on former tin mining land [24].

By the final monitoring visit of this study (24 months after planting), nyamplung trees in the trial plot had already started flowering and fruiting. This is also an indicator of good adaptability for nyamplung from Wonogiri's provenance seed stand. The environmental and soil conditions (Tables

1, 6, 7 and 8) in the observation plots were not significantly different to those in Wonogiri, the source of the seeds. One noticeable difference was that of pH. Soil pH in the observation plot tended to be acidic, while in Wonogiri, pH was 7-8 (neutral) [20]. Nevertheless, this pH still meets the prerequisite for growing nyamplung, as it is tolerant to a pH range of 4–7.4 [25]. The mean NPK nutrient content (Table 8) was higher than that of Wonogiri (N = 0.08%; P = 1.86 ppm; K = 0.12) [20]. Fires on Ultisol soil can cause an increase in nutrients like N, P, K and organic matter, due to the addition of minerals found in ash and charcoal [23]. However, fires can also destroy on-ground vegetation, with the result that soil structures are damaged, triggering erosion in the rainy season [27].

The survival rate of nyamplung is relatively high because it can tolerate various soil types including clay, calcareous and rocky soils. Nyamplung is classified as a semi-tolerant plant but tends to be more suited to areas with full sunlight exposure [28]. In the coastal area of Bukit Soeharto Great Forest Park in East Kalimantan, nyamplung dominated at stand and pole stages, with 90.11% and 140.06% respectively [29]. This domination was likely connected to the physical environment, as the coastal forest offered an ideal habitat for nyamplung, with a temperature of 25.4–31.7^{0}C, humidity of 75–97 %, and average rainfall of 2000–2500 mm/year. The high survival rate of nyamplung in the trial plot indicated high sunlight exposure supported growth. Climatic conditions in the coastal area are under the same range as the nyamplung trial plot, although both areas have different soil type and acidity. The coastal area is sandier with high soil acidity, while the plot is Ultisol with low soil acidity. As such, it appears possible to expand the planting of nyamplung from the Wonogiri provenance seed stand to different types of lands and soils based on its evident survival in these environmental conditions.

3.2.2. Implications of NPK fertilizer and slope gradient
At the beginning of the growth period, 50, 100 and 150g fertilizer dosage treatments had a significant effect on height, diameter and number of branches. However, the difference in growth performance became insignificant between plots and PMPs with the seedlings' increasing age. The first year (6-12 months) after planting is a critical phase for plants in terms of adapting from the nursery environment to the planting site in the field. Plants are more sensitive to external inputs, including fertilizer. Different doses of manure application also result in insignificant differences in height and diameter growth in teak plants [30]. Fertilizer doses only give fairly significant effects at the beginning of growth. This could be because the nutrient content in trial plot soils is sufficient to support growth, despite nutrient content being low (Table 8). At the operational scale, fertilizer application must be efficient as excessive fertilizer may not produce significant results and will increase the operational costs of cropping [30]. The results of different NPK fertilizer applications in nyamplung plants on the previously burned degraded land in Bukit Soeharto suggest that a lower dose (50g) of fertilizer is sufficient.

Slope conditions (top, middle, bottom) provide the same growth performance trend with the treatment of fertilizer doses, up to the age of 20 months. Slope as a treatment gives a real difference to the parameters of height, diameter and number of branches at the beginning of growth (6–12 months). At this stage, the greatest performance, diameter and number of branches were found at the bottoms of slopes (Figure 4) which may be due to the addition of nutrients that have leached from higher up the slope. At 14–20 months, the effect of slope gradient is not apparent, except on diameter. This insignificant difference could be down to the nutrient content, which is still sufficient to support plant growth until the age of 20 months (Table 5). Slope position also had no significant effect on the height and diameter of sengon at 4 months, in revegetated land on the former Berau coal mine in East Kalimantan [31].

3.2.3. Flowering and fruiting

Calophyllum inophyllum generally starts flowering seven years after it is first planted [32], however with intensive silviculture, *Calophyllum inophyllum* in Wonogiri's provenance seed stand in Central Java began to flower 18 months after planting [33]. In the previously burned trial plot in Bukit Soeharto Research and Education Forest, nyamplung was observed to start flowering and fruiting at the age of 24 months. This could be influenced by the low phosphorus (P) content in the soil (Table 5). The availability of water and P in the soil becomes a major limiting factor in the adaptability and growth of nyamplung in Wonogiri [20]. The reproductive cycle (flowering and fruiting) is one indicator of adaptation when a species is planted or developed in a particular location. As a comparison, in degraded peat swamps *Calophyllum soulatri* begins fruiting aged 3 years [34]. The reproduction process is influenced by many factors; the formation of fruit is affected by the amount of synchronization, the maturity of males and female flowers, pollinator effectivity, amount of sunlight, altitude, temperature, rainfall, site conditions and management practices [35,36,37].

3.2.4. Biodiversity and ecosystem services

There is ongoing concern and lack of agreement about the expansion of feedstock production for biofuels, and associated impacts on biodiversity and ecosystem services [38]. Depending on the location, previous land use, condition, planning and management, the establishment of biofuel crops may result in positive and/or negative impacts on the environment, including habitat, biodiversity, soil and water conservation [39]. In this case, the plantation of bioenergy crops in a degraded and previously burned landscape demonstrated positive results on land restoration and habitat quality. As the research site is just over two years old, however, it is too early to determine the full impact on biodiversity and habitat quality.

4. Conclusions

Bioenergy has huge potential for restoring degraded landscapes and supporting climate and development goals in Indonesia. With a huge landmass and variety of climatic conditions, a wide range of biofuel species can be grown on different site conditions. This study demonstrated growth performance of two-year old nyamplung trees on an extremely degraded and frequently burned landscape, revealing it as a feasible solution to restore the landscape while growing an alternative source of energy. Findings prove that nyamplung has high adaptability to different soil types. The research shows that nyamplung has potential to be taken from experimental scale to pilots and wider implementation in various parts of Indonesia. Research and development organizations need to engage with small and medium enterprises and community groups to develop projects and business models at appropriate scales and in suitable contexts. We would urge that bioenergy development avoids arable land and forest conservation sites, to avoid food-energy and environmental conflicts.

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