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Productivity of Arrowroots and Taro Grown Under Superior Teak Clones with Several Levels of Stand Density

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Abstract. Perum Perhutani has an important role in providing food and wood for people. Diversity and diversification of food will reduce the need for one type of food, namely rice as a staple food. Some tuber and rhizome are source of alternative foodstuffs, such as taro and arrowroot. This study aimed to determine the suitability and productivity of arrowroot and taro planted under old superior teak clones with several levels of stand density. Arrowroot and taro were planted under 13-year-old teak stands with 4 levels of density. Both plants were planted in the form of an array, measuring of 3m x 15m, with a spacing of 75cm x 75cm between plants. They were arranged in Randomized Completely Block Design (RCBD) placed in 4 blocks of observation as replications. The results showed that under superior teak clone had the potential to be planted with arrowroot and taro. Teak stand density influenced significantly some characteristics of arrowroot (leaves number, leaves area, stem height, stem diameter, root length) and taro (stem diameter, tuber diameter). Arrowroot productivity per hectare increased with low density of teak stands, accounted for 55, 59, 80, and 88 kg respectively. Meanwhile, taro productivity from very high to low teak density were 365, 301, 523, and 426 kg/ha. The novelty of this study is that there is no record of intercropping studies on old superior teak clones, so this is among the first studies. The benefit of this research result, it could be employed by Perhutani to support the Indonesian government in the national food security program.

Key words: agroforestry; arrowroot; stand-density; taro; superior teak-clones

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INTRODUCTION

Rice is mainly the staple food for Indonesian as carbohydrates source. As a tropical country, Indonesia actually has a lot of carbohydrates sources in plants other than rice such as Cerealia (corn, sorghum, *jawawut*, etc.), bulb, rhizome or tuber (cassava, sweet potato, taro, sago, *ganyong*, arrowroot, *gembili*, *gadung*, etc.), and fruits (breadfruit, banana, pumpkin, mangroves fruit, etc.). Those food sources of carbohydrates available because they grow well in mostly soil type in Indonesia. Traditionally, they are consumed as a basic food as well as snacks. However, rice is still the main staple foods of most Indonesian and demand on rice has been rising year by year. It resulted in rice importation from other countries to fulfill the demand (Widarjono, 2018).

Efforts has been made by Indonesian government to reduce people dependency on rice. One effort to reduce the need for rice as a staple food is the diversification of food source. Some food sources that have potency to be cultivated include annual plants such as tubers and rhizomes. Some types of those plants turn out to have high economic value, so that many have been cultivated by farmers since hundreds of years (Widarjono, 2018). Two type of foodstuff that can be used as carbohydrates sources are arrowroot (*Marantha arundinacea)* and taro (*Colocasia esculenta*). Arrowroot and taro have high carbohydrate content which can reduce carbohydrate source dependence on rice. Arrowroot tuber is a starch source with the potential of starch production accounted for 1.92 – 2.56 t/ha (Djaafar et al., 2010). Meanwhile, taro can produce starch up to 80% of its harvested wet weight (Rahmawati, 2012). Taro has also become a substitute food ingredient (leaves, leaf stalks, and tubers), besides that it is also useful as a medicine to lower blood pressure and diabetics in some areas of Indonesia (Oktavianingsih et al., 2017; Rahayu & Andini, 2019).

Arrowroot and taro starch can be used as a substitute for flour, food ingredients with a percentage of 50% to completely as a substitute for flour (100%) (Suhartini & Hadiatmi, 2011 ; (Simsek & El, 2012). Therefore, both starches have potency to reduce the import of wheat which have been reached 4.2 million metric ton/year (Ross et al., 2018). Arrowroot and taro are healthier compared to other foodstuff as carbohydrates sources because they have low glycemic index than the other roots, such as *gembili*, *kimpul*, *ganyong*, and sweet potato (Simsek & El, 2012). Moreover, the low glycemic index of both starches, their high carbohydrate content, high quality of flour and can replace the position of wheat flour as food material for industry (Suhartini & Hadiatmi, 2011; Simsek and El, 2012). Arrowroot and taro starch can be used for the chemical industry, for example cosmetics, fertilizers, liquid sugar, glue, and drug mixtures in capsules. Starch that is usually used in the food and non-food industry comes from corn, potatoes, cassava, and wheat (Yazid et al., 2018). The starch of arrowroot and taro are obtained from the tubers that are 8-12 months old.

Arrowroot and taro has much valued in the food industry for its easily digestible starch. Due to its high (＞85%) starch content, arrowroot and taro has been used in the food industry as thickeners and stabilizers in puddings, sauces, jellies, cakes, and for therapeutic use in broths, as well as a supplement for infants and invalids (Simsek & El, 2012). On the other hand, arrowroots and taro can be consumed directly by boiling the tubers. It can also be preserved by making the tubers into crackers.

Another advantage of arrowroot and taro plant among others, they tolerate to shading so it can grows under trees or shading up to 30-70% shade intensity, grow on various types of soil, grown in different soil types both fertile and critical or nutrient-poor soil, grow both from waterfront to the mountainous region with an altitude of 900 m above sea level, and they don't require specific treatment so that easily cultivated and preserved (Oktafani et al., 2018). According to Deswina & Priadi (2020), arrowroot and taro can be grown in a shaded place without lowering its quality.

Forest land that has been planted with woody plants, has different environmental characteristics from agricultural land or open area fields. The difference is partly due to the shade originating from forest stand canopy. Forest floor that gets a limited amount of sunlight makes not all types of plants can grow well because of their shade tolerance. Some types of plants that are tolerant or able to live in the shade are tubers (Gommers et al., 2013).

Intercropping between crop plants and tree is called agroforestry. Many agroforestry systems have been implemented by the community and many recognize their superiority, especially in providing a variety of community needs, both wood as a forest product and food crops as an agricultural product. There have been many studies related to the relationship between crops and woody plants (Gao et al., 2013). Arrowroot (*Marantha arundinacea*) and taro (*Colocasia esculenta*) are two plants that are usually planted by the community in an agroforestry system under the trees (Batoro et al, 2017). However, both plants are underutilized tropical and perennial tuberous plant which can grow well under shaded area.

Perum Perhutani, a state forest enterprise, managed the majority of forests in Java, with an area approximately 1.5 million ha of production forest (Ekawati et al., 2015). Teak (*Tectona grandis*) is the main tree species planted by Perum Perhutani. Since hundreds of years ago, agroforestry has been practiced on the island of Java, teak are planted intercrop with crop plant. Meanwhile, Perum Perhutani started establishing clonal forestry in 2010 by planting most of their area with superior clone material (Prehaten, et al., 2018). There are few or almost none of information on arrowroot and taro productivity planted under moderate old genetically superior teak with levels of stand density. This study aimed to determine the suitability and productivity of arrowroot and taro planted under old superior teak clones with several levels of stand density.

Some of the benefits that can be taken from the results of this study are: 1. Understanding the potential of intercropping under old superior clone teak stands. 2. Knowing which types of intercropping plants are appropriate for planting under superior clone teak stands and as result increase the productivity of forest land. 3. Farmers around the forest can use the space under the superior clone teak stands for intercropping and increase their income. 4. Perhutani benefits from the maintenance and fertilization of intercropping plants as well as supporting food security programs.

METHODS

Study Site

The study was conducted in compartment 25, Begal Forest Resort, Ngawi District in East Java. Annual rainfall is 1,436 mm/year with rainy days of 104 days / year (Tania et al., 2019), with the elevation of 132 - 197 m above sea level. Teak stand was planted in 2005 (13 years old), organic fertilizer (manure) as much as 3 kg and inorganic fertilizer (NPK) 50 g/planting hole were applied. The research plot had characteristics flat to choppy topography, there were several creeks that pass through the plot. Rough material of soil consisted of small, large sized stones to rock outcrops.

Soils

Soil types are classified as Vertisol dan Alfisol (USDA, 1999). Soil thickness varied from very thin (15 cm) to thick (> 100 cm) with soil pH ranging from 5.2 to 6.3, while the sand, dust, and clay content respectively were 5-46%, 26-49%, and 18-71%. Organic C content ranged from 0.4 - 2.4% (very low - moderate), while the total N as 0.05 - 0.2% (very low-low). The P content available was 1-34 ppm (very low-moderate), while the K content was 0.02 - 0.2 me / 100 g (very low - low). Meanwhile, the Ca and Mg content were 4.4-13.8 me / 100g (low-high) and 1.4 - 4.3 me / 100 g (medium-high), respectively. Cation Exchange Capacity (KPK) had a value of 11-38 me / 100 gr (low-high).

Research Design

Arrowroot and taro seedling were planted under 14-year-old teak stands in February 2018. Teak stand comprised of superior teak clones with initial space 6m x 2m. They had been thinned in 2016 with 4 levels of intensity. Randomized completely block design (RCBD) was applied with 4 level of teak density, namely very high density (667 trees/ha =A), high density (583 trees/ha =B), moderate density (417 trees/ha = C), and low density (250 trees/ha =D), with light intensity of 17.66%, 19.63%, 33.69%, and 44.57% respectively and 4 blocks as replication. Therefore 16 plots in total were measured.

Arrowroot and taro were planted in the form of an array, in a plot, measuring of 3m x 15m, with a spacing of 75cm x 75cm between plants, thus there were 100 arrowroots and taro seedlings in each plot (10.000 plant. ha^{-1}). Plots were placed in 4 blocks of observation as replications, so there were 16 observation plots. Arrowroot and taro were harvested after 9 months of age (in November 2018).

Harvested arrowroot and taro were then separated based on leave, stem, root, and tuber. Measurements was conducted on amount and area of leaves, stem's diameter and height, number of tiller (arrowroot), root's length, tuber's length and diameter, and fresh tuber was also measured for its weight. Dry biomass of leaf, stem, and tuber were obtained by putting samples into oven with 70º C until reached zero weight loss.

Light intensity was measured in a representative block using lux meter in each plot and an open area at the same time. Light intensity percentage was obtained through dividing data inside plot by data at open area. Measured data was then analyzed by ANOVA and post hoc test with Duncan Multiple Range Test (DMRT) using IBM SPSS Statistic 21.

RESULT AND DISCUSSION

The light intensity measurements showed differences between teak stands. The stands that were very dense have a low light intensity, on the other hand, sparse teak stands have a higher light intensity (Table 1).

Table 1. Light intensity of teak stand

Teak Density (Tree/ha)	Density Category	Light Intensity (%)
667	(very high = A)	17.66 ± 1.79
583	(high = B)	19.63 ± 3.90
417	(moderate = C)	33.69 ± 3.65
250	(low = D)	44.57 ± 16.49

One way to find out the suitability of plants planted on a certain land is by looking at the percentage of its live. Arrowroot ability to survive under various teak stands density until they were harvested was different as compare to taro's, arrowroot had a higher survival ability. In addition, the ability to survive of arrowroot did not show a clear trend. Whereas taro's life percentage shows a fairly clear trend, it was better to survive in more light conditions (Figure 1).

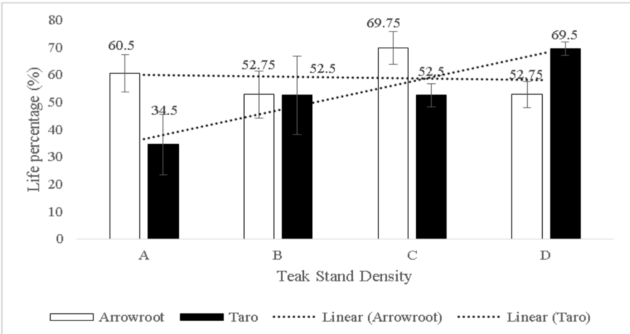

Figure 1. Life percentage of Arrowroot (white bar) and Taro (dark bar)

Amount of leaves on arrowroot grown under various teak density different significantly, more leaves were intact in more open area compared to more shaded area (Table 2). However, it's not the case for taro, which were no different on taro's number of leaves between high density and lower teak density (Table 3). Plants grown under shaded area tend to shed their leaves in order to have less leaves to increase the photosynthetic activity (Rezai et al., 2018). However, number of leaves showed clear trend and negative interaction with teak stand density, it means that number of leaves increased when teak density decreased. Sunlight is relatively abundant under low density of trees compare to those of higher density. This causes arrowroot to grow more leaves due to the higher availability of sunlight.

Leaf area of arrowroot grown under less dense teak stand were significantly higher than those under denser teak stand. Meanwhile taro's leaf area grown under less dense teak stand did not show a significant difference compared to the denser teak stand. However, there appears to be a trend that taro leaf area is higher in more exposed areas. Previous studies stated that shade-plants develop larger and thinner leaves to increase light harvest (Zervoudakis et al., 2012).

Table 2. Arrowroot performance grows under different teak stand density

Arrowroot		Teak stand density				P (0.05)
		Very High	High	Moderate	Low	
	Leaves number	4.862 ± 0.165 ^{a}	5.622 ± 0.167 ^{bc}	5.887 ± 0.165 ^{c}	5.200 ± 0.162 ^{ab}	0.000*
	Leaves area (cm^2)	87.318 ± 6.424 ^{a}	123.134 ± 6.931 ^{b}	104.595 ± 6.498 ^{a}	100.745 ± 6.612 ^{a}	0.003*
	Stem's height (cm)	22.402 ± 0.913 ^{a}	26.197 ± 0.925 ^{b}	21.453 ± 0.913 ^{a}	22.303 ± 0.901 ^{a}	0.002*
	Stem’s diameter (cm)	0.825 ± 0.041 ^{a}	0.945 ± 0.041 ^{ab}	1.054 ± 0.041 ^{b}	0.937 ± 0.040 ^{ab}	0.002*
	Tiller number	1.089 ± 0,063	1.124 ± 0.054	1.050 ± 0.049	1.115 ± 0.051	0.726
	Root's length (cm)	18.161 ± 0,930 ^{a}	24.307 ± 0.942 ^{b}	20.707 ± 0.930 ^{a}	20.325 ± 0.918 ^{a}	0.000*
	Tuber's length (cm)	7.318 ± 0,444	7.579 ± 0.490	7.569 ± 0.425	8.056 ± 0.444	0.695
	Tuber's diameter (cm)	1.213 ± 0,660	1.242 ± 0.740	1.403 ± 0.640	1.383 ± 0.670	0.104
	Tuber’s weight (g)	55.000 ± 16.000	59.000 ± 16.000	80.000 ± 16.000	88.000 ± 16.000	0.422
Dry weight	Leaves (g)	8.763 ± 1,842	14.310 ± 1.842	12.995 ± 1.842	12.110 ± 1.842	0.246
	Stems (g)	6.072 ± 1,227	9.882 ± 1.227	8.200 ± 1.227	9.437 ± 1.227	0.195
	Tuber (g)	11.638 ± 2,511	11.294 ± 2.511	13.160 ± 2.511	17.900 ± 2.511	0.287
Dry biomass	(g)	26.472 ± 4.781	35.485 ± 4.781	34.355 ± 4.781	39.447 ± 4.781	0.335

Description: Value in rows followed by the same letters are not significantly different in DMRT of 0.05 levels. Values with an asterisk marked in column P (0.05) represent significant differences.

Table 3. Taro growth performance under different teak stand density

Taro		Teak stand density				P (0.05)
		Very High	High	Moderate	Low	
Fresh	Leaves number	2.050 ± 0.088	2.200 ± 0.088	2.050 ± 0.088	2.073 ± 0.089	0.5720
	Leaves area (cm^2)	124.099 ± 17,578	120.157 ± 17,578	182.643 ±18,612	152.855±17,578	0.0620
	Stem's height (cm)	26.165 ± 1.111	26.370 ± 1.111	28.180 ± 1.111	28.921 ± 1.125	0.2240
	Stem’s diameter (cm)	1.229 ± 0.045 ^{ab}	1.148 ± 0.045 ^{a}	1.407 ± 0.045 ^{c}	1.338 ± 0.045 ^{bc}	0.0004*
	Root's length (cm)	16.447 ± 1.250	17.404 ± 1.215	18.244 ± 1.197	20.657 ± 1.213	0.0950
	Tuber's length (cm)	3.559 ± 0.182	3.763 ± 0.176	4.210 ± 0.174	3.781 ± 0.176	0.0700
	Tuber's diameter (cm)	3.329 ± 0.146 ^{a}	3.063 ± 0.142 ^{a}	3.910 ± 0.140 ^{b}	3.486 ± 0.142 ^{a}	0.0005*
	Tuber’s weight (g)	365.000 ± 80.000	301.000 ± 67.000	523.000 ± 67.000	426.000 ± 67.000	0.1990
Dry weight	Leaves (g)	3.148 ± 1.138	2.813 ± 1.138	3.965 ± 1.138	2.905 ± 1.138	0.8850
	Stems (g)	6.053 ± 1.203	3.873 ± 1.203	6.353 ± 1.203	5.203 ± 1.203	0.4990
	Tuber (g)	65.520 ± 17.326	49.156 ± 17.326	10.331 ± 17.326	80.165 ± 17.326	0.2620
Dry biomass	(g)	74.720 ± 16.450	55.840 ± 16.450	110.648 ± 16.450	88.273 ± 16.450	0.1900

Description: Value in rows followed by the same letters are not significantly different in DMRT of 0.05 levels. Values with an asterisk marked in column P (0.05) represent significant differences.

Arrowroot stem grew higher under high dense teak stand significantly than those under less dense teak. It suggests that a growth hormone, auxin more accumulated under less light, therefore in low light intensity auxin activity is high so that the plant becomes taller (Yang et al., 2019). However, compared to the other study, stem height in this study was less high (Setyowati, 2012; Oktafani et al., 2018). On the other hand, although not significantly different, taro’s stem tends to grow higher under less dense teak, than those grew under more dense teak.

Stem diameter of arrowroot grow bigger significantly under less dense teak compared to the highly dense. Meanwhile taro’s stem were the opposite cases, they were grown bigger under less dense teak stand than those grow under denser teak stand. Arrowroot stem increased with the decreased of teak density, it can be assumed that much of photosynthate materials used to form bigger stem of arrowroot. Light supply under low density of teak stand was enough for physiological processes, as result, the stem diameter increased as teak density decreased. However, what happened to taro was that the growth and development reduced the height because higher plant height increases the rate of plant lodging under shading conditions (Feng et al., 2019).

There were no differences in amount of arrowroot tiller grown under less or denser teak stand. This finding also corroborated with other study which stated that tiller do not influenced by spacing and depth of planting (Qodliyati etal., 2018).

Root length of arrowroot different significantly between arrowroot grown under dense teak stand and those grown under less dense teak. However, the length of the taro roots did not differ significantly between levels of teak density, but there was a tendency, the denser the teak stands, the shorter the roots.

Tuber length of both arrowroot and taro were not significantly different but there was a trend tuber length go along with the less dense teak stand. The length of arrowroot tuber increased as teak density decreased, however the root length had another story, it has positive correlation as it decreased when the density of the teak also decreased. Patola et al., 2017 suggested that to increase the tuber length can be done with fertilizer application.

The diameter of the arrowroot tubers was not significantly different between the levels of teak density, but there was a tendency for the tuber diameter to increase when the density of the teak decreased. However, taro has a tuber diameter that differs significantly between the teak densities, the lower the density the larger the tuber diameter.

There were no significant different on tuber fresh weight in both plants grew in various teak stand density. However, taro and arrowroot showed a tendency that the lower the density of the teak stands, the more tubers produced. This is because first; the higher light intensity can be captured by plants, the higher photosynthetic capacity, thus the higher photosynthate can be store in its tubers. Secondly, less dense teak stand imply that nutrients, water, and sunlight can be received optimally and the competition between teak and crop plant can be minimized, thereby enlarge the yield of plants in the form of arrowroot and taro's tubers (Qodliyati et al., 2018).

Arrowroots productivity resulted from teak stand with low, moderate, high and very high density was accounted for 55 kg. ha^{-1}, 59 kg. ha^{-1}, 80 kg. ha^{-1}, 88 kg. ha^{-1}, respectively. It can be classified as low productivity, because in open area where arrowroot get full of sunlight and mounded around plants, productivity of arrowroots tuber can reach 241.7 - 717.5 kg. ha^{-1} (Yudianto et al., 2015). Meanwhile for the similar condition, the taro's yields were 365 kg. ha^{-1}, 301 kg. ha^{-1}, 523 kg ha^{-1} and 426 kg. ha^{-1} respectively. This yield was lower as compared to taro yield in open area (4,104 kg. ha^{-1}). Lower yield in arrowroot and taro can be caused by no fertilizer application, no land preparation, and no weeding treatment and also because of less plant planted in a hectare (Vidigal et al., 2016). A research revealed that fertilizer increased relative growth rate of Arrowroot (Patola et al., 2017). Patola et al., (2017) also found that number of leaves of arrowroot was higher of those plant from seedling as compared to plant from tuber. This can fathom that fertile soil can also increase the relative growth rate of arrowroot.

Lower tuber production can also be caused by type of the soil, Filipovic et al., (2016) found that tuber of *Helianthus tuberosus* yield were high when it grows in lower clay content (23.8%-25.9%) as compared to those grow in higher clay content (43.5%). Clay, small size of soil particle can hamper the growth of tuber, as content of clay in study site is ranging from low (18%) to very high (71%) therefore it could be the cause of low productivity. Another possibility of low arrowroot productivity is due to soil pH and nutrient availability, Patola et al., (2017) found that soils with a neutral pH (6.7) produced higher arrowroot tubers than soil with a pH of 8.23 (alkaline). More nutrients are available to plants at neutral pH. Soil pH in this study ranging from 5.2 - 6.3 (acidic – slightly acidic), it could be the reason of low arrowroot productivity. Lower productivity in intercropping system could be also caused by interaction of plants. The interactions between trees (teak) and food plants (arrowroot and taro) can be negative for tree and food crop growth, as they compete for nutrients and water (Atangana et al., 2014).

The fulfillment of sunlight is a major factor in the growth and production of arrowroot and taro. The increase of some arrowroots and taro's characters is suspected because of the sunlight availability. In a shrub (*Vernonia amygdalina*), photosynthetic rates, stomatal conductance, transpiration rate, stomatal index, and stomatal frequency reduced linearly with increasing level of shade (Idris et al., 2018).

The results of this study showed that the growth of both arrowroot and taro, especially the characters of the leaves and stems, adjust to the conditions of sunlight availability. The novelty result of this study is the information on the suitability level of arrowroot and taro plants under Perhutani's superior clone teak stands. The implications and benefits obtained from the results of this study are that farmers live around the forest can still take advantage of the area under the superior clone teak stands, because they have the potential to be planted with both arrowroot and taro.

CONCLUSION

Arrowroot survival rate was more than 52% under all teak stand density, it means that arrowroot has higher suitability compared to taro which was only 43% in very high teak density. On the other hand, arrowroot productivity from very high to low teak density was lower (55, 59, 80, and 88 kg/ha, respectively) as compared to taro (365, 301, 523, and 426 kg/ha, respectively).

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