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INTERCROPPING OF SHORT ROTATION TREES SPECIES WITH THE OIL PALM (*Elaeis guineensis* Jacquin) PLANTATIONS: LESSON LEARNED FROM SMALLHOLDER FARMERS IN INDONESIA

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ABSTRACT

The development of Oil palm plantations in Indonesia is often related to the deforestation issue because the expansion of plantations usually utilizes an area from native forest conversion. From a land coverage perspective, the total vegetation coverage after conversion is relatively unchanged on one hand, but conservationists insist that the environment quality is degraded on the other hand. Until recently, this issue remains debatable and the research which elaborates has not satisfied yet both parties. This paper aims to review theoretical arguments which support the implementation of Oil palm agroforestry practice as an alternative strategy geared towards economic growth and environmental maintenance. Equally important, the study is expected to enrich the references of future research concerning the dilemma between Oil palm and forest plantations industries or a combination of both trees and Oil palm intercrops. The study indicated that the Oil palm agroforestry system can create a balance between the conservation of the environment, community needs, economic benefit, and viability by designing a proper landscape. For Indonesia's condition, a community involvement scheme is likely more proper to implement but needs government support such as a regulation. This model is recommended as a transitional option that can alleviate the poverty of communities in a neighboring plantation, at the same time can minimize environmental degradation.

Keywords: Environment; farmers; intercropping; oil palm; poverty.

1. INTRODUCTION

The rate of development of large-scale oil palm plantations is currently increasing along with the increasing need for palm products as food, cosmetics, and biofuel industries [1]. The results of the study by [2] estimated that until 2025 the world's demand for Oil palm (*Elaeis guineensis* Jacq) continues to increase and Indonesia has the opportunity to fill the CPO market demand between 6.31 to 7.51 million tons. This opportunity also opens the potential for expansion of the planting area to 1.80 – 2.15 million ha, thus leading to controversial views on environmental and social changes in rural communities.

For the government and some stakeholder groups, oil palm is a magic crop that provides income to local

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communities and is promoted as a potential resource for tackling climate change through bioenergy production and restoration of degraded lands [3]. However, for environmentalist groups, Oil palm (*Elaeis guineensis* Jacq) poses a serious threat to forest conservation, decrease plant diversity, and poor access to resources by communities, since these plants do not only affect land rights [4,5] but also traditional livelihoods [6,7]. Therefore, the development of Oil palm plantations which display characteristics close to the character of natural forests is an intermediatory way to bridge between economic and environmental interests. Enrich with selected tree species and proper arrangement of cropping patterns can maintain oil palm productivity and stabilize the environment. This condition can be obtained by applying the concept of Oil palm (*Elaeis guineensis* Jacq)-based agroforestry. The management of Oil palm with a monoculture cropping pattern and with a wide spacing has great potential if it is optimized using an agroforestry system, especially during the early period of plantation establishment. The agroforestry system is expected to be able to provide ecological, economic, and social benefits for Oil palm farmers and entrepreneurs.

Community concerns about large-scale oil palm development in terms of negative impacts on the environment need to be addressed carefully so that development goals do not face social barriers. Depletion of water supply and clean air is the biggest environmental impact of oil palm development [8]. Demographic characteristics do not always affect the perception of local communities because in general, they are more likely to expect new jobs from the project. Thus, the program can run as long as the community is involved in local economic activities.

The benefit of the Oil palm agroforestry system has not been fully able to encourage small-scale farmers and large-scale companies to implement the system in their Oil palm plantations. The Oil palm monoculture system remains more attractive, possibly because of market certainty and practicality of management. Oil palm plantations still dominate farmers' land, especially in Sumatra Island, because they consider profit and do not require a lot of laborers. The limited manpower is indeed a problem for farmers in managing a large area. However, species richness was lower in Oil palm plantation habitats compared to secondary forests habitats [9]. Therefore, to encourage the agroforestry system, a more suitable business climate is needed, especially in the marketing of timber forest products (TFP) and non-timber forest products (NTFP) which are intercropped with Oil palm. The government needs to mediate to strengthen the market by providing friendly policies.

This mini-review aims to identify the feasibility of trees and other seasonal crops which are intercropped with Oil palm plantations under agroforestry system by involving the neighboring communities which benefit farmers' income enhancement and creates better environmental quality.

2. AGROFORESTRY IN PRACTICE

The agroforestry system provides advantages for both the physical condition of the trees and the conditions of the site in which they grow. According to [10], the biological advantage of agroforestry systems is that roots in agroforestry systems produce a better soil structure and increase wind resistance when shallow root crops are mixed with deep root crops. In addition, the canopy space is better utilized and the cover is better, especially when tolerant plant species were interspersed with intolerant plant species.

Intercropping Oil palm with forestry crops has been widely practiced by the communities. The types of plants selected are usually diverse, adapted to the community's preferences and market attractiveness. The intercropping of Oil palm with large-scale forestry crops have even been practiced by one of the large Oil palm company in Jambi Province. Agroforestry was applied by combining Red Meranti (*Shorea leprosula*), Mahogany (*Swietenia macrophylla*), Jabon (*Anthocephalus cadamba* Miq), Rambutan (*Nephelium Lappaceum* L.), and Mango (*Mangifera indica*) plants with Oil palm. The company stated that in general, the agroforestry cultivation technique on Oil palm is relatively simple and has no significant obstacles because several cultivation practices have been directly integrated with Oil palm management.

Agroforestry management on Oil palm leads to higher fresh fruit bunches (FFB) productivity than monocultures [11]. This is caused by mixed die plant residues which are then decomposed into organic matter. It was revealed that if the management of Oil palm plantations is employed according to the technical instructions for planting, the agroforestry system in Oil palm, therefore, can be implemented. However, other information is still needed regarding appropriate planting time and spacing, up to the tolerance threshold of oil palm against the competition for growth factors with mixed crops.

To increase the rate of growth (productivity), mixing Oil palm plantations with legume crops has a very positive effect. For example, 3.5-year-old Oil palm mixed with *Centrosema pubescens* and *Pueraria phaseoloides* showed faster growth than monoculture one [12]. Mixing with legumes also produces more

FFB from Oil palms [13]. This is because legumes act as a stimulant for the development of oil palm roots. Legumes have two unique characteristics, namely having a high nitrogen content and increasing the ability to protect the soil. Another type of legume, namely Gamal (*Gliricidia*) can extract water from deeper soil layers, compared to cacao plants [14].

Oil palm agroforestry with maize, banana, and cassava do not harm oil palm growth [15]. Experimental agroforestry of timber plantations with oil palm has been tested in the Daling River using Rubber (*Hevea brasiliensis*), Teak (*Tectona grandis*), and Sentang (*Azadirachta excelsa*) trees species. It was reported by [16] that the presence of these types of trees with a density of 132-144 trees/ha on Oil palm plantations aged 6 years with a density of 138 plants/ha did not reduce FFB production. The results of this experiment may be used to conclude that the production of FFB oil palm up to the age of 8 to 10 years will not decrease. A slight decline will probably occur at the age of 10-12 years.

The results of experiments with Binuang trees (*Octomeles sumatrana* Miq.) also revealed that a normal planting distance of 9 m x 9 m (equivalent to a density of 135 plants/ha) is still recommended for planting patterns in Oil palm agroforestry. Rows of Binuang trees are planted along the centerline of the oil palm array, resulting in the same density of Oil palm and Binuang (135 plants/ha each). It is assumed that 110 mature Binuang trees are cut at the age of 10-12 years, the volume is estimated at 1.2 m^3/tree so that the total volume reaches 132 m^3. Financial derived income from trees depending on the price level when harvested. The inclusion of trees in Oil palm plantations does not significantly increase laborer for maintenance activities, because trees maintenance is carried out at the same time as Oil palm care. Besides financial benefits, here are some other advantages of Oil palm agroforestry with Binuang trees:

a. Better and efficient use of resources, especially sunlight. The use of sunlight before the Oil palm canopy closes is considered to have the same effect on livestock rearing in young oil palms [17]. However, raising cows or goats on oil palm plantations can only be done when the palm trunks are high enough (approximately 5 years old), while tree planting can be done simultaneously.
b. Reduced weeding costs can also be obtained after Binuang shade plays a role in suppressing weeds. Weeding is becoming more environmentally friendly because the frequency of herbicide use is also reduced.
c. A slight decrease in FFB production can be compensated for by timber production.
d. Mixing trees in Oil palm plantations becomes a kind of insurance for Oil palm crops in the event of a fall in the price of Oil palm or FFB, insect pests (root drillers), and disease (*Ganoderma*) attacks.
e. The use of Binuang as a local species has advantages from a conservation perspective, especially the conservation of native flora biodiversity.

In agroforestry practices, farmers must be supported by adequate and efficient crop management technology. For example, pruned palm leaves can be stockpiled along tree rows to provide nutrients and increase soil fertility. The Binuang cycle is only between 10-12 years or half the commercial production life of Oil palm. It was revealed by [16] that trees growing in agroforestry with Oil palm is faster than monoculture, and it is likely that Binuang harvesting can be achieved at the age of under 10 years, because of the positive interaction between tree species and Oil palm. At a wider spacing, the height growth is faster than that of Oil palm so that it can maximize land resources. Ideally, trees that are intercropped with Oil palm are those whose root system is dominated by taproots. The competition for nutrients from the soil between oil palms and trees, therefore, can be eliminated. In addition, considering that Oil palm is classified as a sun-loving plant, then the type of trees which are developed in the Oil palm plantations should have a light canopy (letting in a lot of sunlight), or shed their leaves regularly. However, tree species with such ideal characteristics are somewhat impossible to find in one type of tree. Each type of tree always has disadvantages but also has many advantages. The important thing is, with the existing characters, trees can have a mutual symbiosis with Oil palm plants which generates greater synergy than if the Oil palms or trees were developed in monoculture.

The selection of suitable species to be developed in Oil palm plantations must refer to the consideration of clear market prospects, high timber prices, fast-growing, mutual symbiosis, simple technology. Thus, higher-income from the use of a plot of land by applying agroforestry can be obtained by farmers.

The agroforestry systems between wood-producing plants and oil palm trees have the following benefits:

a. *Economic value*: optimizing the carrying capacity of the land can provide dual products, namely oil palm and timber products. Expectedly, the future value of timber products can be equal to or even greater so interest people to cultivation Oil palm mixed with timber products trees in the form of agroforestry.

b. *Ecological value*: It can maintain the quality of the soil around the Oil palm plantation area. In Oil palm plantation land, soil fertility tends to be low and absorbs a lot of water so that the presence of trees between Oil palms can balance the nutrient cycle and water in the soil. The presence of trees will also increase carbon storage in the biomass. Flowers and fruit trees will attract the presence of insects and birds so increasing biodiversity.
c. *Conservation value*: many tree species in native lowland forests face high pressure from neighboring communities. Conversion of forested land into Oil palm plantations can threaten the sustainability of such species, so planting these endanger tree species as mixed crops in oil palm plantations can be a good alternative to conserve.

3. OPTIMIZATION OF AGROFORESTRY PRODUCTIVITY

Trees can be intercropped with Oil palm crops as long as the growth requirements can be met. Several factors need to be considered if Oil palm is to be developed in an agroforestry manner, including:

3.1 Spacing

Conventionally, the average leaf area is used to determine the optimal density of Oil palm plants under certain environmental conditions. However, since the size of the adult canopy has a photosynthetic effect during the bunch production period, the estimation of leaf area is only relevant for palms over the age of 10 years. Alternatively, to determine the optimal spacing, the leaf area index (LAI) is used, which is the level of competition for light between plants. In Oil palm plantations, LAI is measured by the production of the number of palms per ha, the number of leaves per tree, and the average leaf area. The optimal LAI value is the value that gives the highest bunch yield per ha, for Southeast Asia between 5.6 to 6.0. The [18] noted that when Oil palm plants were planted at standard densities (143 trees/ha), compared to the density in this experiment (135 trees/ha), the leaf area index (LAI) in the mature crown was 5.6 (Ekona); 5.4 (Nigeria), and 4.5 (Calabar). Since Calabar's LAI is far below the optimal range, the density can be increased to 160 trees/ha resulting in an LAI of 5.0. Information on the ideal planting distance of oil palm also inspires the inclusion of other plants by considering the ideal spacing. It was proven by [19] that with a spacing of 4 m, Gaharu (*Aquilaria malaccensis*) trees planted between oil palm plantations showed better growth than at a distance of 2 m and 3 m, with the growth percentage reaching 81%.

3.2 Planting Schedule

Planting time is the determination of the planting schedule that can reduce competition. For example, Oil palm plantations are planted in year 1, while trees if they are intolerant must also be planted when the Oil palm canopy has not closed. However, if the trees to be developed in agroforestry are tolerant, they can be planted in the 3rd or 4th year.

3.3 Root Pattern

Roots are the most important organ of plants because they capture water and nutrients for metabolic processes. The distribution of tree root systems is very important in the land used with agroforestry systems. The Sengon has roots that mostly spread horizontally so that it provides a great opportunity for competition for soil nutrients [20] with other species having similar types of roots. Therefore, optimal spacing between plants is the key to reducing competition between plants in agroforestry systems.

Root development is closely related to the physical and chemical conditions of the soil. Soil with a high-density level has little pore space which affects root penetration into the soil. Indirectly, the light intensity is also related to the response of the roots in absorbing water and nutrients. Low light intensity, due to the narrow spacing of trees, is expected to cause a decrease in environmental temperature. Meanwhile, low temperature according to [10] can inhibit metabolic growth and root maturation. However, the short root size allows roots between plants not to overlap, and the competition between plants in agroforestry systems is minimized.

Root depth is one of the variables that affect the growth of the tree. Deep roots are associated with root activity to find water and nutrients for growth. The direction of root movement follows the location of water and nutrients in the soil. According to [21], about 51% of the lateral roots of Sengon are concentrated in the soil layer at a depth of 10-20 cm. In a site with high nutrient competition, roots will move following the location of water and nutrients that are usually found in the deep soil. In the wet tropics, deep-rooted trees are generally more profitable because they can take advantage of leached nutrients and are usually more drought tolerant.

According to [22] there are 3 main factors limiting root growth, namely genetic, chemical (low availability of nutrients and soil organic matter content and high levels of certain nutrient poisoning), and physical factors. The number of roots affects the growth of the crown while the distribution of the crown determines the depth and breadth of the distribution of plant roots. According to the concept of plant physiology, root growth is based on the morphogenetic balance between roots and plant crowns. In other words, the longer and larger the number of roots, the better the crown growth [23].

3.4 Tolerance to Sunlight

In general, forest plants are grouped into three groups in terms of the need for light, namely tolerant (shade tolerance), intolerant (sun-loving), and semi-tolerant. The tolerance of a tree species is the ability of a tree species to compete against the need for sunlight and competition for the root system in its growth medium [23].

Not all seasonal crops can survive under the shade. Canopy density is one of the factors that need to be considered in the growth space utilization because tree canopy coverage defines the intensity of light that can penetrate the forest floor. A dense canopy will be the dominant competitor for seasonal crops in the agroforestry system. Information on the percentage of canopy coverage and light intensity can be taken into consideration in the selection of seasonal plant species in the agroforestry system.

According to [24], in conditions of high light intensity, plants tend to increase photosynthetic activity to a certain level of light saturation. The high light intensity can result in better growth rates for tree height and diameter. But not all sunlight energy can be absorbed by plants, only visible light can affect plants in photosynthetic activities [25]. The greater the intensity of light, the greater the increase in diameter growth. In addition, [26] noted that the growth of plant diameter is closely related to the rate of photosynthesis and will be proportional to the amount of sunlight intensity received by the plant. Thinning treatment had a greater light intensity value so that the diameter growth of Jabon would be greater compared to without thinning. This also applies to growth in total and branch-free height which shows the same thing as diameter growth. The higher the light intensity, the larger the canopy of Jabon receives light from the sun which causes tree growing to be more productive (Table 1).

4. CHARACTERISTICS OF OIL PALM AND SEVERAL POTENTIAL TREES

Before explaining the characteristics of several tree species which are potential to be intercropped with Oil palm, it is necessary to convey the characteristics of Oil palm plants to obtain an overview of the suitability in the agroforestry system.

4.1 Oil Palm (*Elaeis guineensis* Jacq)

4.1.1 Climatic requirements

Oil palm requires high rainfall (between 200 to 300 cm/year), or at least 15 cm of rain per month without less than 10 cm of rainfall [27,28]. Water shortage greater than 30-40 cm/year will significantly reduce the production of fresh fruit bunches (FFB) [29]. The optimal temperature is between 220C and 330C, with the lowest temperature that is still conducive around 200C [29]. Daily sunlight is needed between 5 to 7 hours and at least 2000 hours per year. Relative humidity should be between 75 to 100 percent.

4.1.2 Soil requirements

Oil palm can grow on almost all types of soil and does not require high fertility, but the soil should not be very loamy that causes waterlogging because the drainage is hampered [30]. The suitable soil texture is sandy loam with a depth of more than 75 cm. Oil palm is not recommended to be cultivated at an altitude above 200 m MSL [31]. Plant spacing or stand density depends on the type of soil. For inland soils, Oil palm is planted in a triangular shape with a spacing of 8 x 8 m (148 trees/ha), while on coastal alluvial soils is 136 trees/ha, and on peat soils is 160 trees/ha [32].

Table 1. Summary of individual plant characteristics in oil palm-based agroforestry

No	Plant species	Root structure	Root radius (cm)	Canopy radius (m)	Light needed (%)	Elevation (MSL)	Rain fall (mm/year)
1	Oil palm (*Elaeis guineensis* Jacq)	Fibrous	200-250	8,0	>60	<500	2000-3000
2	Sengon (*Paraserianthes falcataria*)	Taproot	78-165	2,5-4,8	>80	0-800	2000-2700
3	Jabon (*Anthocephalus cadamba* Miq).	Taproot and lateral	25-200	-	>70	500	1500-3000

4.1.3 Nutritional requirements

If Oil palm is grown on inland soils, a quarter to a half of the NPK requirement must be met from inorganic fertilizers. In contrast, if they are grown on fertile soil, additional fertilizer is not required [33]. The response of the application of high K elements to inland soils causes a decrease in the ratio of oil to bunches. Meanwhile, the N application increased the number of bunches, bunch weight, and total oil production, while the P application only increases the weight of bunches.

4.2 Jabon (*Anthocepalus cadamba)*

Jabon is a large tropical tree with a wide and cylindrical shape canopy, straight trunk with an average height reaching 15 m. In favorable climatic conditions, Jabon tree can reach more than 20 m, with a clear bole can reach up to 9 m and diameter at breast height (dbh) can reach between 40 cm to 50 cm. Young trees usually have smooth bark, while older trees have coarser bark. Jabon trees are leaf-dropping so they are suitable to be combined with palms that need a lot of light (sun-loving). Jabon trees are leaf-dropping, so the shading effect is low, and they do not contain allelopathy, making them suitable for agroforestry [34].

Jabon tree has the following unique characteristics, i.e.:

a. It is easy to grow and does not need special treatments.
b. The rods of Jabon is cylindrical and perpendicular.
c. Branches can fall off by themselves (self-pruning) along with age and climate, so Jabon can optimize the growth and development of its trunk independently. The color of the wood is yellowish-white so that it meets the characteristic requirements of furniture raw materials.
d. The wood fiber is finely dense so it is very suitable for plywood or furniture.
e. Jabon has an optimal growth ecology at an altitude of 50 to 500 MSL so that it has a wider coverage of planting suitability than other woody plants.
f. Jabon can grow at a soil pH between 4.5 to 7.5, with rainfall of 1,500 to 3,000 mm/year, and the environmental temperature ranges from 14 – 40 C
g. Jabon cutting rotation age is relatively short, ranging from 5 to 8 years.

Due to sunlight requirement by both Sengon and Oil palm, the plant array in Oil palm-based Sengon agroforestry should stretch from East to West direction to ensure more sunlight. The Sengon tree has small leaves, so sunlight still penetrates the forest floor. This allows the land under the Sengon stand to

Fig. 1. Jabon (*Anthocepalus cadamba* Miq*)* intercropping [35]

Jabon is a type of tree that requires shade at a young age, but when mature requires light. Jabon may be intercropped with Oil palm plants when the Oil palm plants are 2 to 3 years old where the canopy of Oil plants can act as a shade for Jabon. Despite Jabon needing 1500 to 5000 mm of rain per year, it can also grow at 200 mm of rain per year. Jabon grows ideally at an elevation of 300 to 1000 MSL but they still can grow at an elevation of up to 1400 MSL. This plant likes loamy alluvial soil that is well-drained. Jabon is very well used for soil conservation, agroforestry, and land reclamation. Leaf fall can enrich organic carbon in the soil.

4.3 Sengon (*Paraserianthes falcataria*)

It is also recognized as a miracle tree and mentioned in the Guinness book of records as the fastest growing tree in the world. The Sengon not only needs sunlight but also needs protection from the wind. In suitable soil, Sengon can grow up to 7 meters in a year. Dropping leaves and twigs will enrich nitrogen, organic matter, and minerals in the soil. Its root system creates soil porosity which is useful for drainage and aeration. Sengon showed great growth in a suitable environment, as displayed in Table 2.

Table 2. The average of heigh and dbh growth by times

Ages (year)	Average	
	Height (m)	Diameter at breast height (Cm)
6	25.5	17
9	32.5	40.5
12	38	54
15	39	63.5

be planted with food crops, or other crops such as Cardamom (Fig. 2). Therefore, the combination of oil palm with Sengon and Cardamom is very possible.

Fig. 2. Agroforestry sengon (*Paraserianthes falcataria)* with cardamom *(Ammomum cardamomum* L.)

5. CONCLUSION

Intercropping short rotation trees with Oil palm under an agroforestry system is a promising opportunity due to potential economic and environmental benefits. Its development is relatively simple, it does not require a lot of additional inputs, because it is already integrated with the management of Oil palm itself. Oil palm intercropping with trees is feasible to develop as long as the management techniques apply good oil palm cultivation standards, especially in terms of intensive maintenance. What needs to be considered in the intercropping system of Oil palm with forestry plants is to design a planting schedule and spacing of forestry plants according to the tolerance threshold for growth factor competition. The selection of tree species to be intercropped with Oil palm plantations (agroforestry) also needs to consider the shape of the canopy, and the rooting system to avoid competition for sunlight and soil nutrients. However, the most important considerations are economic value and market availability without neglecting the environmental value.

To maximize the total agroforestry productivity, the relationship among plants intercropped should be harmonized. More sound-friendly Oil palm companies may be developed through the participatory scheme by involving neighboring communities which benefit on improving livelihood and sustainable environment. This scheme can be designed by splitting the plantation areas into several smaller blocks whose maintenance is the responsibility of the households surrounding the plantation. Trees and other crops could be planted as boundaries between blocks which enables farmers to easily recognize their plantation and increase additional incomes. Therefore, it is still possible to intercrop short rotation trees during the early stages of oil palm plantation growth in arrays or as boundary lines between smallholder-managed oil palm plantation blocks.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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