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Intercropping Tuber Crops with Teak in Gunungkidul Regency, Yogyakarta, Indonesia

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Abstract: The adoption of agroforestry system aims to combine food production enhancement to compensate population growth with the improvement of agricultural marketable products to increase household income. The diversification of food crop products requires more effective land use. In Gunungkidul, high-density teak (*Tectona grandis*) plantation has dominated many private forests. The area under the tree crown has received low light intensity, where only shade-resistant plants can survive. Tuber crops, i.e., arrowroot (*Maranta arundinacea*), canna (*Canna edulis*) and yam (*Dioscorea esculenta*) are shade-tolerant crops, which were planted in tree understory for supplementary food production and income generation. The cultivation under teak stand has been overlooked due to uncertainty in tuber productivity. To address this knowledge gap, the effect of teak shade (5- and 7-year teak) on the growth and yield of the three tuber crops was examined. The results indicated that both teak trial areas (with RLI 45.13% and 38.76%) were suitable for canna production (LER > 1), while management options were recommended for enhancing arrowroot and yam production. The LER of intercropped three-tuber crops under 5 years' teak were >1, while of those under 7 years' teak, only canna reached >1. Canna is the preferred option to be mixed in teak agroforestry systems with low light intensity due to its consistent yields, whether planted in open area or under teak shade. Silvicultural management, pruning and thinning are recommended to increase the growing space and resource sharing for intercropped plants. Land optimization in private forest understory using shade-resistant tubers will offer medium-term benefits, provided that proper silvicultural procedures are applied.

Keywords: *Maranta arundinacea* L.; *Canna edulis* Kerr.; *Dioscorea esculenta* L.; *Tectona grandis* Linn

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1. Introduction

Population growth has caused food demand to exceed food availability [1]. Food availability depends on food production and arable land availability. Arable land for food crops is projected to decrease due to population growth and economic pressures [2,3]. The decline in the production capacity of agricultural lands becomes a barrier in achieving food security [4]. Efforts to achieve food yield targets with conventional agriculture have caused extensive environmental and social damage [5,6]. The conversion of forests to agricultural land has seriously impacted water availability, changing the energy balance on land surface and climate from local to global scale [5]. Unsustainable agriculture [7] can be changed toward sustainable agroforestry [8].

Agroecological practices are essential in producing food in ways that are environmentally friendly and provide ecosystem services, unlike conventional agriculture [9].

Agroforestry as a sustainable land use system is practiced globally for economic benefit [10], social benefit [11] and ecological benefit (soil conservation, habitat and carbon sequestration) [12]. Agroforestry improves plant resistance to the possible consequences of climate change, including drought and rising temperatures, increasing water infiltration and accumulation, and escalating evaporation [13,14]. Moreover, increases in yields can be achieved, as agroforestry retains soil fertility and can reclaim degraded lands [15].

Local food commodity can play an important role in achieving food sustainability [16]. The outsourcing of staple food production to local commodities has enhanced income security as a basis of food security in forest margin communities [17]. Tubers (arrowroot/*Maranta arundinacea* L., canna/*Canna edulis* Kerr, yam/*Dioscorea esculenta*) have the potential as functional food ingredients and flour industry and human health nutraceutical ingredients [18]. Arrowroot, canna and yam can be rice substitutes due to their high carbohydrate value. The three tubers are edible, and even yam is the staple food in Africa [18]. Arrowroot has high yield potential, high-quality starch and multiple benefits for the treatment of autism, diabetes or digestive disorders [19]. Arrowroot starch is used in the food and non-food industry, alongside corn, potatoes, cassava and wheat flour [20]. Canna rhizome has the potential as a functional ingredient for food and pharmaceutical industries. Canna can be utilized as an alternative food source and as the basic ingredient of instant noodles and biscuits [21]. Yam, apart from being a carbohydrate source, can be used for various industrial and medicinal purposes [22,23]. Yam flour can be mixed into popular food products, such as cookies [24]. Yam has a carbohydrate content (22.5–31.3%) similar to rice. Therefore, it has the potential to be the staple food source as a rice substitute [25] and can be consumed with simple preparation.

The intensification in agriculture planting patterns has occurred because of the increased land use in agriculture [26,27]. Intercropping in teak private forests plays a role in providing short-term (food), medium (livestock) and long-term (wood) needs for smallholders [26,27]. Teak has been the dominant tree in Gunungkidul private forests [28,29]. There were three land use systems, namely home garden, *tegalan* and *kitren* [29,30]. Home garden and *tegalan*, with relatively open conditions, were often intercropped with agricultural crops, while the *kitren* tended to have higher tree density and was managed as teak monoculture [28]. In *tegalan* and *kitren*, teak species had the highest importance value index [29]. In Gunungkidul, many farmers intercropped their teak systems (mainly in *tegalan*) with agricultural crops: cassava (26.6% of intercropped parcels), peanuts (23.8%), upland rice (18.0%), soybeans (8.1%) and long beans (2.9%) [28]. Most agroforestry patterns that have been successfully established were food crops in *tegalan* and home garden systems, with relatively high light intensity (border trees system). Transforming *kitren* (monoculture) into intercropped systems is an effort to optimize land use. Reducing tree density (thinning) is the first requirement to provide space for intercropping. However, farmers are reluctant to thin the teak, resulting in low light intensity and limited space in the understory [30]. Therefore, it is necessary to select low light-resistant tuber species under teak shade (>5-year teak) for food productivity and optimization of understory space in *kitren*.

Optimizing land with food crops is expected to increase food production [31]. In general, many types of food crops are cultivated in open areas, but some tuber species (arrowroot, canna and yam) are able to grow under the tree shade from 30% to 70% [18–22]. Tubers (arrowroot, canna and yam) are usually planted in agroforestry system under the trees by the local community [23]. This tropical and perennial tuberous plant was underutilized despite its potential as an alternative food source [24,25]. Arrowroot is a low-light adaptive plant [32,33]. Arrowroot survives poor light environment and infertile land, characteristics that are required for a shaded place [19]. Yam grows at 60–70% light intensity [34], while canna is drought resistant and suitable for cultivation under shaded area with low light intensity [35]. The highest production of canna tubers was in 50% shade [36]. The ideal management of annual and perennial crops in an agroforestry system varies by biophysical, economic and social conditions [37].

Gunungkidul, a regency in the Yogyakarta Province, Indonesia, has a 1485.43 km^2 area with 64,382.50 ha of private forest land [38]. Limited cultivation has been effectuated due to the high percentage of rock on soil surface, making farming on rocky dry land more challenging [4]. The competition between annual and perennial plants is a potential obstacle in adopting agroforestry in private forests for food crop production [32]. This study aims to determine the adaptability of three species of tuber plants (arrowroot, canna and yam) under the teak shade (5 years and 7 years). The specific objectives of the research are to: (i) evaluate the potential of the three tuber species as understory crops for teak intercropping and (ii) provide farmers with recommendations about tuber species selection to be planted under teak shade. This research is expected to improve the development of agroforestry as an option to provide local food from private forests, facilitate food security for villagers and contribute to sustainable environmental management.

2. Materials and Methods

2.1. Research Site and Time

The research was conducted in private forests in Semin Village, Gunungkidul Regency, Yogyakarta Province, Indonesia (Figure 1). The coordinates of the research location were 7°53′57.2″ S–110°44′36.1″ E. Three shade-resistant tuber species were planted in December 2019 and harvested in September 2020. Harvesting was carried out when the age of tubers reached nine months. The site's elevation was 230 m a.s.l. up to 325 m a.s.l. In 2020, the average daily temperature was 26.65° C, ranging from 17.3 °C to 35.5 °C; the average air humidity was 82.17%, ranging from 79 to 84%; the rainfall was 2327 mm/year, with a 5-month dry season [38]. The precipitation changed every year in the range of 1.175–2.489 mm/year (2010–2020) [38]. The research site still received low-intensity rain until June 2020. In general, the Gunungkidul area has low rainfall, but in 2020, it rained almost all year round, except for only 1 rainy day in July [38]. Semin Village is located in the lowland dry agro-ecosystem with dry climate and has type D climate, according to the Schmidt–Ferguson classification [39]. Agroforestry pattern has been cultivated on dry land in private forests with rocky soil and highly rainfed with no irrigation. During the dry months, the teak turns deciduous, while the tuber plants turn dormant with wilting leaves. Those are the signs of tuber readiness for harvest (ripeness). Some areas of southern Gunungkidul are covered by karst bedrocks with thin solum and have been deforested since the 1800s. It has caused the area to become critical [40].

2.2. Research Method and Data Collection

This research began with focus group discussion with the farmer community (Forest Farmer Group) in the research location (Semin village) to determine the preferred tuber species, select the land patch (*kitren*) as the trial plot candidates and discuss the planting–maintenance–growth measurement harvesting techniques and schedule. The smallholder farmers performed teak agroforestry farming activities using labor from family members. Occasionally, like the farmers' local cultures in other areas [41–43], they reciprocally exchanged labor with neighbors in mutual cooperation to reduce the burden of labor cost. In general, traditional agroforestry is subsistent and applied to relatively narrow land with minimum and non-intensive silvicultural treatments and maintenance [30,44,45].

Land management was performed manually using hand plows, hoes, machetes, sickles, etc. The plot areas were owned by the farmers–members of the forest farmer group. Planting, plot development and growth measurement were conducted together with the community. Three tuber species were planted under the teak stands aged 5 years, 7 years and in open area as control. The 5-year stand was planted with 3 m × 3 m spacing, and the 7-year stand was planted with 2 m × 3 m spacing. In both teak stands, there had been no thinning and pruning. In private forests, the teak understory has not yet been utilized for intercropping. Arrowroot and canna were selected by the farmer group because they are widely accessible on the market for the local flour-making industry. Yam was selected because it is a local subsistence crop with a high local market demand.

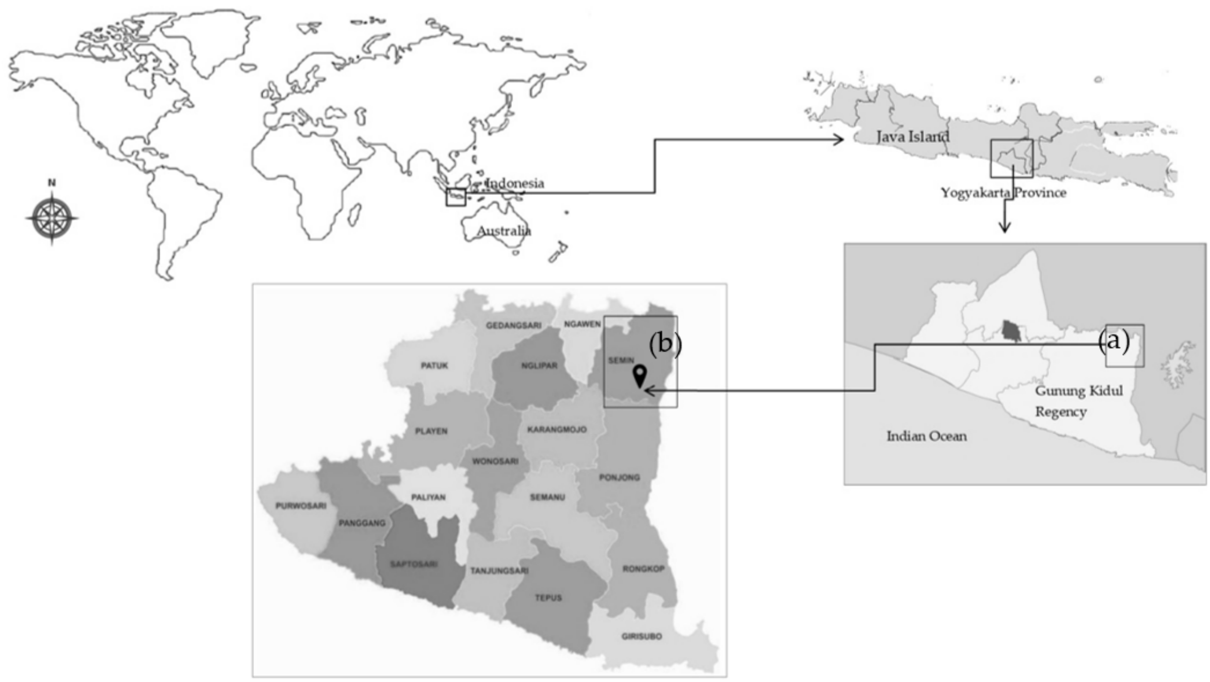


Figure 1. Research location in Gunungkidul Regency, Yogyakarta Province, Java Island, Indonesia (**a**), Trial location in Semin District (**b**).

Site preparation was conducted by tilling the soil to 20 cm depth to construct ridges. The ridges were 30 cm wide × 20 cm high; the distance between the ridges was 20 cm; and the distance between the ridges and trees was 50 cm (Figure 2a). Plant spacing between tubers was 50 cm, while the planting holes of 20 cm × 20 cm width × 10 cm depth were made on the ridges. Each planting hole received 50 g (2 Mg/ha) of manure as basic fertilizer. Rhizome seed, of average weight between 20 to 40 g, was planted in each hole. The excavated soil was returned to the planting hole until the rhizome seeds were completely buried. Weeding and mounding as routine maintenance were conducted monthly for the first 4 months. Yams were staked at 1 month after planting or before vines started crawling on the ground. This study used split-plot design with three cropping patterns (open area, intercropping tubers in 5-year teak and 7-year teak) as the main plots. Sub plots consisted of three tuber crops, namely arrowroot, canna and yam. The tuber rhizome seeds were local varieties from several home gardens of rural community villages in Gunungkidul. Therefore, there were 27 experimental units (3 main plots × 3 subplots × 3 replications), with 900 tuber plants/species with a total 2700 tuber plants (Figure 2a). However, those plots were still located in one village landscape (Figure 2c). Open area was the area without teak stand that accepted full sunlight and often cultivated rainfed food crops, whereas the 5-year and 7-year teak stands represented the area in the understory layer of respective age of the teak stands (Figure 2b).

Data on microclimate and teak growth variables were obtained from direct measurement (Table 1). Data on microclimate included sunlight intensity, air temperature and relative humidity. Air temperature (°C) and relative humidity (%) were measured using a thermo-hygrometer. This tool was systematically placed on the imaginary points on the ground representing the condition of each main plot (4 corner points and 1 middle point). Light intensity measurement for each main plot was undertaken by placing the luxmeter systematically under the trees (3 replications), between 2 trees (3 replications), on the intersection point of quadrilateral between 4 trees (3 replications) and in the open area (3 replications). The different age of teak stands results in different tree shade and relative light intensity. Relative light intensity (RLI) represents the shade level in the three cropping patterns as the main treatments (open area, 5-year teak and 7-year teak). Light intensity was measured before tuber planting. Meanwhile, the soil characteristics derived from the analysis result in the soil laboratory. The data of soil characteristics consisted of soil texture and macro nutrient content. Soil samples were taken compositely from each plot with 5 systematic points representing the plot area (4 points in the corner and 1 point in the middle). Soil samples were taken at 10–20 cm depth.

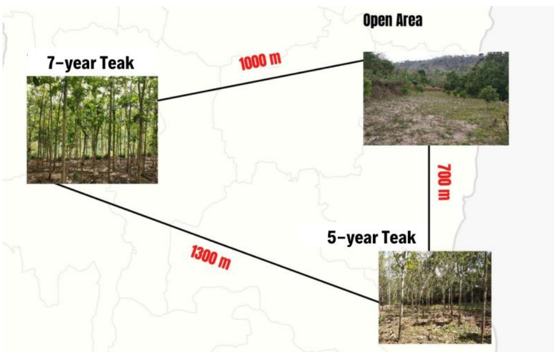
Experimental design
(a)

Open area

Under 5-year teak

Under 7-year teak

Land condition in 3 treatments
(b)



Sketch of the distance between the trial plots

(c)

Figure 2. (**a**) Experimental design of three shade-resistant tuber species (Ma: *Maranta arundinacea*, Ce: *Canna edulis* and De: *Dioscorea esculenta*) in three planting patterns (A = 7-year teak; B = 5-year teak; and C = tuber monoculture or open area); X = teak monoculture); (**b**) field condition before planting and (**c**) sketch of the distance between trial plots.

Table 1. Microclimate, soil properties and teak dimensional variables at the research site.

Variables	Plots				
	Open Area	Teak (5 Years)		Teak (7 Years)	
		BP	AP	BP	AP
Microclimate					
Relative light intensity (%)	100	45.13	-	38.76	-
Day temperature (°C)	32.73	31.81	-	30.09	-
Day relative humidity (%)	48.19	49.39	-	52.67	-
Physical and chemical properties of the soil					
Texture (%)					
Sand	36.50	7.78	-	50.33	-
Silt	32.78	38.56	-	25.83	-
Clay	30.72	53.67	-	23.61	-
pH (H_2O)	6.56 (n)	6.61 (n)	-	6.25 (n)	-
C-organic (%)	1.53 (l)	1.62 (l)	-	1.73 (l)	-
N-total (%)	0.10 (l)	0.09 (vl)	-	0.09 (vl)	-
K-available (ppm)	193.72 (vh)	127.22 (vh)	-	239.83 (vh)	-
P_2O_5-potential (mg/100 g)	27.94 (h)	83.11 (vh)	-	29.83 (h)	-
Dimension of teak					
Tree height (m)	-	8.35	8.78	12.21	13.26
Bole height (m)	-	2.91	3.04	4.65	5.28
Tree diameter (cm)	-	7.44	8.24	11.76	13.00
Crown diameter (m)	-	2.29	2.65	2.71	3.4
Teak spacing	-	3 m × 3 m	3 m × 3 m	3 m × 2 m	3 m × 2 m
Crown width (m^2)	-	32.43	38.57	60.64	86.11
Volume (m^3/ha)	-	34.44	43.61	225.05	240.46

Remarks: BP = Before Planting; AP = After Planting; n = neutral; l = low; vl = very low; h = high; vh = very high.

The data of teak dimension were total height, bole height, stem and crown diameter, crown width and tree volume (m^3/ha). The total height (m) and bole height (m) were measured using a meter stick. The total height was measured from the ground surface to the tip of the crown, and the bole height was measured from the ground surface to the first branch. Stem diameter, or DBH (cm), was obtained from the ratio of the circumference of the tree stem and Pi (3.146). Stem circumference was measured using tape measure at breast height (1.37 m). The crown diameter (m) was measured using tape measure by measuring the length of the widest and narrowest crown. The stand density of 5-year teak was 1111 trees/ha, while the 7-year teak was 1667 trees/ha. Growth measurement of teak was conducted before and after planting the tuber crops. Overall measurement, namely relative light intensity (%), stem diameter (cm), crown diameter (m), crown area (m^2) and tree volume (m^3/ha) were calculated using the following equation:

$$RLI = \frac{TLI}{OLI} 100\% \tag{1}$$

$$BA = \pi \left(\frac{DBH}{2} \right)^2 \tag{2}$$

$$CA = \pi \left(\frac{Crw}{2} \right)^2 \tag{3}$$

where

RLI = Relative light intensity (%)
TLI = Light intensity under the teak trees
OLI = Open area light intensity (%)
BA = Basal area (m^2)
CA = Crown area (m^2)
$\pi = 3.146$

DBH = Diameter (m)

$$Crw = \frac{longest\ crown\ diameter + shortest\ crown\ diameter}{2}\ (\text{m})$$

Tree volume was calculated using a general formula, viz.:

$$V = \frac{1}{4}\pi \times \left(\frac{D}{100}\right)^2 \times H \times f \quad (4)$$

$$V_{ha} = V_i D_0 \quad (5)$$

where

V = Tree volume (m^3)
D = Diameter (cm) (breast height is 1.37 m)
H = Tree height (m)
f = Form factor = 0.7 [46]
V_{ha} = Volume per ha (m^3/ha)
V_i = Average volume
D_0 = Initial seedling density (n/ha)

The observed tuber crop growth variables were plant viability (%), plant height, stem diameter, number of shoots and number of leaves. Tuber plants were measured at 1 and 6 MAP (Months after Planted). The growth data were collected from 30 plants from each plot, with total number of plants measured as much as 270 samples. Plant height (cm) was measured using a meter stick, starting from the base of the stem at above ground level to the tip of the longest plant leaf or the longest vine (for yam). The stem diameter of arrowroot, canna and yam (cm) was measured using a caliper at 5 cm above the ground. The number of shoots was measured by counting the total number of shoots or leafy stems that grow on a tuber plant. The number of leaves was calculated by counting the total number of leaves that grow on a plant clump (Figure 3).

Figure 3. Plot conditions (6 MAP) and measurement process of the growth and yield of three shade-resistant tuber crops (canna, arrowroot and yam).

The variables of tuber production were number of tuber/plant (piece), tuber weight/piece (g), tuber weight/clump (g), tuber weight/ha (Mg/ha), tuber length and diameter (cm), and tuber starch content (%) (Figure 3). The number of tubers was obtained by calculating the number of tubers produced per plant. Tuber weight/piece was obtained by weighing fresh tubers using digital scale, one by one. Tuber weight per clump was the total weight in one plant. Tuber weight/ha was the result of converting tuber weight per plot area to ha. Tuber length (cm) was measured using tape measure, and tuber diameter (cm) was measured using caliper. Tuber starch content was analyzed in the laboratory at the Food Technology and Agricultural Products Examination Laboratory, Faculty of Agricultural Technology, Gadjah Mada University.

2.3. Data Analysis

The effect of cropping pattern, which was represented by the RLI, on tuber species growth and yield was then analyzed using a one-way analysis of variance (ANOVA), while the effect on the starch content was analyzed using two-way ANOVA. Significant results were further analyzed using the Duncan Multiple Range Test. Data analysis was conducted using SPSS 20 [47].

The LER (Land Equivalent Ratio) was calculated only for one cycle of the tubers intercropping (9 months). The LER approach [48] was used to determine the effect of species' interactions in agroforestry, with the following equation:

$$LER = \frac{C_i}{C_s} + \frac{T_i}{T_s}$$

where

LER = Land Equivalent Ratio
C_i = production of tubers in agroforestry
C_s = production of tubers monoculture
T_i = production of teak in agroforestry
T_s = production of teak monoculture.

3. Results

Effect of Cropping Pattern on the Growth and Yield of Tuber Plants

The RLI values were 100%, 45.13% and 38.76% for the open area, under 5-year teak and 7-year teak, respectively. Cropping pattern or RLI had significant effects on tuber growth and yield (Table 2 and Appendix A Table A1), especially on arrowroot height and diameter at 1 and 6 MAP. The RLI difference only caused substantial effect on canna diameter at 1 MAP and on the number of leaves at 1 and 6 MAP. Yam had a notable difference in height at 6 MAP and in the leaves number at 1 and 6 MAP.

The height of arrowroot under 7-year teak shade at 1 MAP was the highest compared to other treatments on arrowroot. Nevertheless, at 6 MAP, the highest value was reached by the arrowroot in open area. The diameter of arrowroot plant was the highest at open area in both measurements. On average, the values of arrowroot plant growth variables in open area were higher compared to both shaded areas (5- and 7-year teak), except for the plant height at 1 MAP under 7-year teak shade. The values of arrowroot growth attributes under 7-year teak at 6 MAP were the lowest compared to other treatments.

The height of canna plant was not affected by RLI. Canna plant height reached 16.96–21.66 cm in the three treatments at 1 MAP and 25.22–39.97 cm at 6 MAP. The RLI only had considerable effect on the diameter of canna plant at 1 MAP. The diameter of canna plant in open area reached the highest value 1.44 cm) compared to canna diameter under teak shaded areas (0.96 and 1.14 cm). The number of canna leaves in open area at 1 MAP was the highest (5.13 sheets) compared to teak shaded areas (4.19 and 4.32 sheets on 5- and 7-year teak, respectively). On the contrary, the number of canna leaves in shaded areas at 6 MAP was higher than in open area. The variables of growth in canna plants are different from other tuber species.

Table 2. The effect of RLI on the average growth variables of tuber plants at 1 and 6 MAP.

Variables and Treatments	Species					
	Arrowroot		Canna		Yam	
	1 MAP	6 MAP	1 MAP	6 MAP	1 MAP	6 MAP
Plant viability (%)						
Open area	100.00	100.00	100.00	25.56 a	100.00	23.33 a
5-year teak	100.00	100.00	100.00	43.33 ab	100.00	100.00 b
7-year teak	100.00	100.00	100.00	100 b	100.00	21.11 a
Plant height (cm)						
Open area	27.16 ± 9.26 b	83.92 ± 26.43 c	17.00 ± 5.56 ns	25.22 ± 16.25 ns	120.33 ± 66.11 ns	191.33 ± 36.62 a
5-year teak	22.93 ± 5.41 a	68.36 ± 13.85 b	16.96 ± 5.93	25.99 ± 19.87	92.58 ± 28.06	247.52 ± 67.75 b
7-year teak	30.43± 8.68 c	34.65 ± 12.02 a	21.66 ± 6.20	39.97 ± 23.52	132.70 ± 86.17	177.83 ± 71.04 a
Diameter (cm)						
Open area	1.23 ± 0.38 b	10.24 ± 1.84 b	1.44 ± 0.36 c	8.98 ± 2.86 ns	0.34 ± 0.13 ns	0.25 ± 0.05 ns
5-year teak	0.78 ± 0.20 a	5.63 ± 1.45 a	0.96 ± 0.26 a	8.07 ± 2.80	0.33 ± 0.06	0.29 ± 0.08
7-year teak	0.82 ± 0.27 a	5.67 ± 1.57 a	1.14 ± 0.36 b	8.55 ± 2.62	0.29 ± 0.11	0.23 ± 0.04
Number of shoots (pieces)						
Open area	1.88 ± 1.25 ns	5.85 ± 2.36 ns	1.65 ± 0.75 ns	1.85 ± 0.93 ns	1.40 ± 0.76 ns	2.06 ± 1.66 ns
5-year teak	1.53 ± 0.94	3.08 ± 1.76	1.73 ± 0.75	1.75 ± 1.10	1.46 ± 0.69	1.87 ± 0.78
7-year teak	1.61 ± 1.06	2.09 ± 1.17	1.60 ± 1.01	1.64 ± 0.99	1.64 ± 0.87	1.48 ± 0.69
Number of leaves (sheets)						
Open area	6.40 ± 1.47 c	8.07 ± 2.64 ns	5.13 ± 0.82 b	1.89 ± 1.07 a	33.27 ± 28.93 b	105.10 ± 52.74 b
5-year teak	5.69 ± 1.18 b	6.83 ± 2.36	4.19 ± 0.74 a	2.83 ± 1.10 b	15.62 ± 8.56 a	112.68 ± 54.83 b
7-year teak	4.97 ± 0.98 a	6.04 ± 2.91	4.32 ± 0.95 a	3.01 ± 1.07 b	33.40 ± 28.71 b	24.93 ± 18.75 a

Remarks: Numbers followed by different letters in the same column are significantly different, according to Duncan Multiple Range Test ($p < 0.05$). MAP = Months After Planted; RLI = Relative Light Intensity.

The yam plants gained a notable highest height (247.52 cm) at 6 MAP under the 5-year teak shade, despite negligible effects at 1 MAP. The number of yam leaves under 7-year teak at 1 MAP was the highest (33.4 sheets), even though it was not significantly different to the height of yam plants in open area (33.27 sheets). The 6 MAP measurementof yam leaves number showed an opposite result where the yam under 7-year teak reached the lowest number of leaves (24.93 sheets) compared to open area (105.1 sheets) and 5-year teak (112.68 sheets). At 6 MAP, the average growth variables of yam under 5-year teak shade reached the highest values, except for the number of shoots.

Appendix A Table A2 shows the ANOVA result for tuber production and dimension variables. RLI had significant effect on tuber production variables of arrowroot and yam, while for canna, it only had an effect on the diameter of tuber variable (Table 3). Moreover, the RLI had considerable effect on starch content (Figure 4). Starch content is one of the parameters of tuber quality. The weight of tubers/piece and the number of tubers/clump on the canna were not recorded because the tubers are fused as one rhizome and cannot be observed.

The dimension variables of arrowroot and yam tubers in open area were the highest compared to other treatments, except for the yam diameter under 5-year teak. For canna, the weight of tubers/clump and diameter of tuber under 7-year teak (59.71 g and 2.98 cm) were the highest compared to other treatments.

Table 3. The effect of RLI on average tuber crop yield variables.

Variables and Treatments	Species of Tuber Plants: Arrowroot	Canna	Yam
	Tuber weight/clump (g)		
Open area	665.97 ± 182.45 b	26.58 ± 28.03 ns	587.30 ± 185 b
5-year teak	235.19 ± 73.76 a	39.97 ± 39.97	213.80 ± 87.14 a
7-year teak	111.36 ± 39.78 a	59.71 ± 22.86	115.91 ± 38.84 a
	Tuber weight/piece (g)		
Open area	75.74 ± 12.41 c	-	103.85 ± 69.10 b
5-year teak	47.93 ± 13.60 b	-	31.33 ± 10.97 a
7-year teak	28.81 ± 6.40 a	-	28.81 ± 24.74 a
	Tuber weight/Ha (Mg/ha)		
Open area	26.64 ± 1.61 b	1.06 ± 0.25 ns	23.49 ± 3.45 b
5-year teak	6.21 ± 1.91 a	1.06 ± 0.70	5.65 ± 1.76 a
7-year teak	2.94 ± 0.56 a	1.58 ± 0.51	3.06 ± 0.39 a
	Tuber length (cm)		
Open area	19.52 ± 1.73 b	7.22 ± 5.60 ns	7.38 ± 1.99 b
5-year teak	14.27 ± 2.40 a	8.57 ± 8.57	4.75 ± 1.08 a
7-year teak	12.96 ± 1.74 a	12.24 ± 1.60	4.40 ± 0.70 a
	Diameter of tuber (cm)		
Open area	2.96 ± 0.15 ns	1.02 ± 0.64 a	3.57 ± 0.83 ns
5-year teak	2.33 ± 1.21	1.60 ± 1.60 a	3.62 ± 2.41
7-year teak	2.42 ± 1.57	2.98 ± 2.58 b	3.18 ± 1.41
	Number of tubers/clump (pieces)		
Open area	9.10 ± 2.06 b	-	7.45 ± 2.46 ns
5-year teak	5.04 ± 1.73 a	-	6.79 ± 2.26
7-year teak	3.96 ± 1.68 a	-	4.67 ± 1.43

Remarks: Numbers followed by the same letter in the same column are not significantly different, according to Duncan Multiple Range Test ($p < 0.05$); MAP = Months After Planted; RLI = Relative Light Intensity.

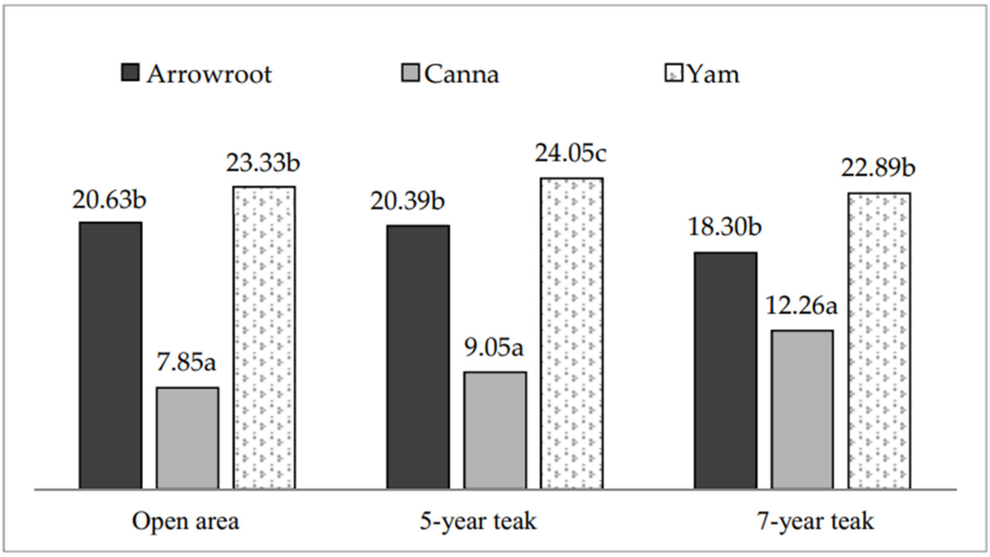


Figure 4. The effects of RLI on starch content (%) of three tuber species. Columns followed by the same letter are not significantly different ($p < 0.05$).

The starch contents of the three tuber species under three RLI treatments were significantly different. The interaction between RLI and the species of tubers resulted in notable difference in starch content (Appendix A Table A3). On further DMRT test result (Figure 4), yam under 5-year teak shade obtained the highest percentage of starch (24.05%). Yam also had the highest starch content compared to other tested tubers when planted in open area (23.33%) and under 7-year teak (22.89%).

The possible causes for the difference in starch content in the three species of tubers were the genetic factor of the tuber species and the size of the rhizome seeds [49]. The research on rice also showed that different varieties of rice produced varied starch content [50]. Furthermore, plant spacing (represented by RLI in this article) contributed to influencing some variables of the chemical composition of the starch, such as starch percentage, ash, ether concentration, gluten and carbohydrate content [51].

In terms of assessing the suitability of land management with tuber-based agroforestry systems, LER calculations were carried out (Table 4). The LER values > 1 were found in the teak agroforestry cropping pattern of arrowroot (1.65), canna (2.65) and yam (1.27) under 5-year teak shade (RLI 45.13%). Furthermore, the greater shade of 7-year teak (RLI 38%) resulted in LER below 1, i.e., arrowroot 0.69 and yam 0.73. Unlike arrowroot and yam, canna had the highest LER value under 7-year teak (2.01). According to [48], a mixed cropping pattern with an LER value < 1 indicates that the combination is not profitable or has low compatibility.

Table 4. LER (Land Equivalent Ratio) of intercropping teak and tubers.

No.	Treatments	Land Equivalent Ratio		
		Arrowroot + Teak	Canna + Teak	Yam + Teak
1	Teak 5 years	1.65	2.65	1.27
2	Teak 7 years	0.69	2.01	0.73

4. Discussion

In general, the private forests that were utilized as research location were not managed intensively [30]. The private forests received no fertilization for teak [52], no weeding [45], no pruning and were rainfed [45,52]. Thinning meant harvesting big trees [53], and the tree selection was cut down when farmers experienced financial hardship [53,54]. The normal rotation for teak harvesting is 2–3 decades [28]. In general, the tree spacing of teak stands on private forests is 3 m $\times$ 2 m or 3 m $\times$ 3 m. With relatively small crown cover, young-aged teak (0–3 years) can be intercropped with seasonal crops. Without thinning and pruning, the crown and tree density are expanding. It causes the light intensity under the stand to get lower and means the annual crops cannot be cultivated. Most farmers in Gunungkidul do not practice intercropping in the private forest/*kitren*. However, intercropping was applied in home gardens and *tegalan* [28,29]. In practicing intercropping, the farmers carried out soil preparation, weeding and fertilizing the seasonal crops. As a consequence, those had a good impact on the growth of teak. A share of 72% of the smallholder of teak private forests in Gunungkidul have used seeds from natural sapling [30], so the teak timber quality was low [45].

4.1. Growth and Yield of Arrowroot (Maranta arundinacea L.)

The growth performance of arrowroot in open area was the highest compared to under teak shade (Table 2). Arrowroot plants require more light, so that under 5-year teak (45% light intensity) and 7-year teak (38% light intensity) growth and tuber production will decrease. However, the plant's height at 1 MAP under 7-year teak was the highest compared to the plant's height at 1 MAP under 5-year teak and in open area. Low light intensity (RLI 38%) triggered auxin activity to elongate the plant's height [33]. Under the shade, the light intensity for photosynthesis decreased, which affected the development of arrowroot tubers, such as biomass and starch content [55]. The weight of cultivated arrowroot tubers is higher than those that grow naturally. This is because the shade is denser in a natural environment [56]. However, arrowroot is able to adapt to low light intensity of 30.56–56.05% (Table 5) [56]. The optimal growth is the result of photosynthesis in the leaf area index in the form of the dry weight production of plants [56]. In nursery scale, the average number of arrowroot leaves was the highest under artificial shade of 31%, while the lowest was under 51% shade [33]. Variations in morphological and physiological adaptations, tuber yield and starch content of arrowroot are interdependent and controlled by genetic and environmental factors, especially climate and soil [55].

This study attests arrowroot suitability at elevation of 230 m a.s.l., with rainfall of 2300 mm/year and dry rocky soil (without irrigation). Water greatly affects plant metabolic processes, either directly or indirectly [57]. In Madura Island (Indonesia), with very low rainfall (1202 mm/year) and very low soil nitrogen content, the potential of arrowroot production is only 2.65 Mg/ha [58]. Arrowroot has been planted in Indonesia a long time ago, with a production variation of 7–47 Mg/ha [59]. The low productivity of arrowroot in Gunungkidul is mainly caused by dry land; therefore, it depends on rainwater [60]. Arrowroot tuber is a starch, with starch production potential equaling to 1.92–2.56 Mg/ha [61]. In this study, arrowroot production was relatively high in the open area (26.64 Mg/ha) and had limited production under 5-year teak (6.21 Mg/ha) and below-the-standard production under 7-year teak (2.94 Mg/ha). Arrowroot productivity will be lower along with higher teak density [62]. The carbohydrates content on arrowroot tubers in teak dense places is similar to open areas. Physicochemical and nutrient content of arrowroot is not significantly different between monoculture and intercropping [63]. Although a previous study indicated that arrowroot was a shade-resistant species productive at light intensity of 30–56% (Table 5), in this study its growth and tuber production decreased under the teak shade. The limiting factor for arrowroot production was light intensity.

4.2. Growth and Yield of Canna (Canna edulis Kerr.)

In this study, the highest (but statistically insignificant) survival and productivity of canna was under 7-year teak shade (Tables 2 and 3). Leaves number growth in canna will increase with the lower sunlight intensity or the greater teak shade. This has implications for the production of tuber (weight, tuber diameter and tuber length), which improves with the increasing shade of teak, although it is not significantly different. The productivity of canna plants was not significantly different, but the highest average was under 7-year teak. Growth is influenced by the leaf area and leaf assimilation [64]. This indicates that canna can adapt to low light intensity under 7-year teak (38%). The high light intensity, which is received by the chlorophyll, will damage the leaves, turning them yellow and causing them to wither [65]. On dry land, the presence of trees will produce a microclimate that is more conducive to understory production. Lower light intensity will reduce evaporation and micro temperature. Decreased light intensity has insignificant effect on photosynthesis rate in resistant shading species. As long as the plant can adapt, it will not have any effect on the production. Shade intensity and harvest age have a significant effect on canna plant height [36]. The growth of canna plants under *Neolamarckia cadamba* stands with a spacing of 3 m $\times$ 3 m was better than under *Falcataria mollucana* with a distance of 2 m $\times$ 2 m [66]. Shade treatment also has a significant different effect on the weight of canna tubers, with the highest average being under 50% shade [36].

The growth of canna on *Falcataria mollucana* shade (42%) was higher than in the open area on the parameters of plant height, leave length, leave width and plant biomass, but the treatment of shading did not significantly affect the tuber weight [35]. Tuber production in 75% light intensity was higher than in the open area [65]. In another study, 50% light intensity resulted in higher tuber growth and production than in the open area and 30% light intensity [36]. Under the stand with 62% light intensity, it resulted in better tuber production than in the open area with a slight decrease in the carbohydrate and protein content of the tubers [66]. Several studies showed that 38% to 75% of light intensity resulted in better tuber production than in the open areas. In addition, the results of this study showed that intercropping with teak resulted in higher canna carbohydrate content, although it was not significantly different. In another study, the chemical content of canna tubers (carbohydrates, fiber, fat, protein) was more influenced by genetic factors and the duration of harvesting canna [36]. Increasing the productivity of canna can be applied by administering organic and inorganic fertilizer and by a more intensive maintenance of agroforestry crops. Intercropping canna as understory of private forest is technically feasible for increasing the community food availability [66].

4.3. Growth and Yield of Yam (*Dioscorea esculenta L.)*

The highest survival of yam plant was found under 5-year teak (100%). The growth of yam in 5-year teak stands (RLI 45%) was the highest compared to 7-year teak (RLI 38%) and open area (height, diameter and number of leaves) (Table 2). Yam plants had the highest average number of leaves under 25% paranet shade and the lowest under 50% shade [67]. In this study, the production decreased as the light intensity decreased due to the teak shade. The effect of shade treatment on the weight of yam tubers was significantly different, with the highest average under 50% shade [67]. There is a tendency that optimizing the light will boost plant growth, but not tuber productivity. Yam's growth and production will give better results in open areas, although it still produces quite good growth in 30–50% shade (RLI 50–70%) (Table 5) [52]. In heavy shade (75% or RLI 25%), yam is not adaptable, which is indicated by the production of fewer stolons and tubers [67]. An optimal plant height of yam was found in treatment without shade [67]. The height of yam plants can reach 10.90 m under the planting pattern with trees along the border, where the average relative light intensity reaches 66.94 % [68]. In other shade-resistant tuber species, such as konjac/*Amorphophallus muelleri*, the percentage of crown closure also has a significant effect on the number of konjac's bulbil [69]. However, this is not only influenced by the shade of the teak but also the suitability of the requirements for where each type of tuber grows with the physical environmental conditions of the study site (soil type, elevation, soil pH, relative air humidity, rainfall and temperature) (Table 5). Yam in Kudus (Central Java) can grow at 29–34 °C temperature, 50–79% humidity and 25,500 lux–67,800 lux light intensity, together with other species, such as *D. hispida*, *D. bulbifera*, *D. alata* [70].

In this study, teak stands (RLI 38–45%) produced 115–213 g/plant of a yam tuber weight. This result is greater than other research results under *Acacia mangium, Euchaliptus* and teak [71]. The different species of tree stands had a significantly different effect on tuber wet weight of yam [71]. The wet weight of tubers was under Eucalyptus pellita (RLI 46.98%), which was 46.75 g/plant, under *Acacia mangium* (RLI 40.64%), which was 39.96 g/plant and under teak (31.62%), which was 19.39 g/plant [71]. These RLI data show that greater intensity of light induces larger productivity of yam (up to 46.98% of RLI). Furthermore, the qualification to maintain production was achieved at RLI 50–70% [34,70].

Table 5. Requirement of physical environmental conditions for the growth of three tuber species.

Site Characteristics	Soil Type	Elevation (m a.s.l.)	Light Intensity (%)	Soil pH	Relative Air Humidity (%)	Rainfall (mm/Year)	Temp. (°C)
Site trial	Litosol	230–325	5-year teak (45.13) dan 7-year teak (38.76)	5–6.5	79–84	2.327	17.3–35.5
Maranta arundinacea	Grumusol [72]	605–1.351 [32]	30.56–56.05 [55] 58 [35]	6.7 [72]	50–75 [55]	1.202 [58]	25–34 [55]
Canna edulis	Alluvial, Yellow-red podzolic [73] Ultisol, Sandy-Clay [74]	0–250 [36] 250–300 [75]	75 (for tuber weight) and 50 (for vegetative propagation) [65] 30–40 [35] 50 [36] 42 [76]	4.5–8 [74]	80.2 [35] 68–80.2 [36]	1120–2664 [36] Resistant to dry land and efficient in the use of N [77]	28.3 [35] Resistant to various air temperatures in the tropics [76]
Dioscorea esculenta		500–2000 [34] 103–240 [70]	50–70% [67] 60–70% [34]	5.5–6.5 [34] 6.8 [70]	40% [34] 50–79% [70]	1.000–1.500 [34] 1.970–3.425 [70]	20–30 [34] 29–34 [36]

4.4. Enabling Smallholder of Agroforestry Practices

The LER value of the intercropping of the three types of tubers with 5-year teak showed more than 1 (arrowroot (1.65), canna (2.65) and yam (1.27), but under 7-year teak, LER > 1 was only produced at intercropping with canna (2.01) (Table 4). The cropping pattern of intercropping tubers and teak is expected to be a recommendation for farmers. This research only studied the growth and yield of shade-resistant tubers in one cycle. The adoption of this planting pattern will provide the farmers with middle-term income, since the tubers can be harvested every 9 months. Intercropping arrowroot, canna and yam tubers under 5-year teak was profitable, while under 7-year teak, it was only recommended for canna. Although there are still limitations linked to growing annual crops under teak stands, as indicated by lower levels of production and growth of arrowroot and yam, the contribution of agroforestry (combination of the two crop commodities) in land utilization is more suitable than monoculture. Similar to the results of intercropping jackfruit with eggplant tubers, where LER > 1, the eggplant tuber production decreased due to low light intensity, and jackfruit growth increased due to the effect of understory maintenance [78]. Eucalyptus + corn has LER > 1, while Eucalyptus + soybean has LER < 1 [79].

At the research location, the tuber crops are harvested every year because tubers are the raw material for the home industry, which produces tuber flour, especially arrowroot and canna. Wheat flour processing industry is still operating manually by women farmer group. The selling price of arrowroot flour at the time of the study was IDR 50,000 to IDR 100,000. The results of the financial analysis of canna cultivation in Malang, East Java, results in an R/C ratio = 3.05 [80], arrowroot cultivation in Malang, East Java, results in an R/C ratio = 2.07 [81] and yam cultivation in Merauke results in a B/C ratio = 1.92 [82]; therefore, those are feasible to be cultivated. The agroforestry cropping pattern in Lumajang Regency, East Java, has succeeded in further raising income (3 million to 10 million rupiah) from various seasonal crops, namely cassava, corn, rice, cardamom and ginger [83].

However, agroforestry is still more profitable because it enables tuber and wood production. Based on the planting pattern of teak and tubers, this study considers it still necessary to require other silvicultural treatments for more optimal results. Crops that were planted near trees had a reduced annual crop production [84], whereas wider tree spacing would reduce competition. The maintenance of wood in the agro-plantation system aims to increase the production and quality of wood and maintain the tillage area for seasonal crops [85]. Thinning is recommended for reducing tree density at 4–6-year teak (40–60% of thinning intensity) [85–87]. Thinning enhances the growth of residual teak stand and food crop in intercropping, and it provides income for the tree grower [85]. Light settings in an intercropping pattern can be adjusted by removing dead trees and diseased tree branches, manipulating the crown size and shape by pruning, maintenance to anticipate the competition with the understory, singling and thinning [88]. In other studies, pruning has proven to be effective at improving crop productivity in teak + cassava [89], gmelina + corn [90], soybean + pine [91], and trees + seasonal plants [92]. Pruning can be started when the teak reaches three years of age and applied at the beginning of the rainy season (before planting the understory crops) [93].

Water, light and nutrient competition in agroforestry systems can be minimized by intensifying silvicultural treatments and intensifying agriculture in agrosilviculture patterns in order to remain multifunctional (food and pro-environment). Although the rate of decomposition of half teak leaves is slow [94], leaf litter can be used as organic fertilizer and a substitute for chemical fertilizers [95], and it can create a mulch for soil microclimatic conditions [96]. The need for water and nutrients is anticipated by employing a more intensive fertilization treatment (mainly organic fertilizer) to meet the needs of the two constituent plants [74]. Arrowroot can yield 10 Mg/ha of tubers, provided that it is fertilized with 100 kg/ha of Urea, 200 kg/ha of SP36 and 50 kg/ha of KCl [97]). Plant height and fresh tuber weight of arrowroot can be improved with the application of 3.5 Mg/ha KCl [98]. The combination of 2 Mg/ha manure, 40 kg/ha urea, 50 kg/ha KCl, 50 kg/ha SP36 during planting and 90 kg/ha urea, 100 kg/ha KCl at 3.5 MAP resulted in a significant difference in canna growth and tuber yield [99]. The combination of 25% shade treatment and 30 kg/ha manure resulted in higher number of leaves and tuber weight of canna [65], while a combination of 75 kg/ha N, 30 kg/ha P_2O_5 and 100 kg/ha K_2O applied to yam produced high tuber weight of 0.71 kg/plant [100]. It is feasible for farmers to increase food production by optimizing the land under the teak stands. Intensification of agroforestry will bring several advantages: (1) tuber crops will generate mid-term income; (2) pruning will improve teak timber quality and increase the productivity of tuber crops; and (3) thinning will increase residual teak stand growth and food crop productivity. The contribution of timber and non-timber products in the agrosilviculture system shows a harmonious balance between plant diversity and income generation [101].

5. Conclusions

The intercropping trial on three shade-resistant tuber species with teak resulted in different growth and productivity rate of tubers. The starch content of the three types of tubers was not significantly affected by the RLI. This indicates that the quality of tuber production under different treatments was similar. The production of canna tubers was most consistent, regardless the RLI. Canna is recommended as the most shade-resistant understory crop for teak agroforestry with RLI values of 38% and 45%. In previous studies, canna remained productive at 50% of light intensity. The tuber weight of arrowroot and yam was affected by the RLI, as the tuber weight decreased alongside a decrease in RLI percentage. However, tuber productivity is influenced by various factors, namely light intensity, soil conditions, climate, cultivation methods (agriculture intensification + teak silviculture) and cultivar varieties. This study provides a useful initial evaluation of the effect of 5-year teak shade (45% of RLI) and 7-year teak shade (38.76% of RLI), with unthinned and unpruned teak, on the productivity of three shade-tolerant tubers. Planting three shade-tolerant tuber species to optimize the land use of the 5-year teak stands understory in dry land of private forests (LER > 1) is a potential practice for generating annual income and producing alternative food sources for rural farming communities. The contribution of agroforestry to smallholder livelihoods is greater than monoculture (LER > 1). Further research is needed to measure the effectiveness of: thinning and pruning on teak at several spacings; crop maintenance intensification on increasing the productivity of food-producing tubers in smallholder teak system.

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Appendix A

Table A1. ANOVA results on tuber plants variables.

Variables	F-Calculated					
	Arrow Root		Canna		Yam	
	1 MAP	6 MAP	1 MAP	6 MAP	1 MAP	6 MAP
Plant Height (cm)	9.06 *	115.08 **	6.79 ns	3.73 ns	3.88 ns	11.51 *
Plant Diameter (mm)	24.35 **	46.62 **	11.39 *	2.44 ns	1.83 ns	5.73 ns
Number of shoots (pieces)	2.35 ns	16.51 ns	0.43 ns	0.44 ns	1.60 ns	1.25 ns
Number of leaves (sheets)	28.67 **	2.38 ns	8.72 *	12.19 *	15.85 *	17.44 *

Remarks: MAP = Months After Planted; * significantly different at <0.05; ** very significantly different at <0.01; ns = non-significant.

Table A2. ANOVA results on tuber productivity.

No.	Variables	F-Calculated		
		Arrow Root	Canna	Yam
1	Tuber weight/clump (g)	79.65 **	4.11 ns	32.46 **
2	Tuber weight/piece (g)	74.94 **	-	26.68 **
3	Tuber weight/ha (Mg/ha)	80.00 **	4.02 ns	32.15 **
4	Tuber length (cm)	44.96 **	3.57 ns	76.44 **
5	Tuber diameter (cm)	0.75 ns	24.49 **	0.43 ns
6	Number of tubers/clump (pieces)	26.38 **	-	6.22 ns
7	Starch content (%)	2.36 ns	2.31 ns	0.58 ns

Remarks: MAP = Months After Planted; ** very significantly different at <0.01; ns = non-significant.

Table A3. ANOVA two-way result on starch content of tubers—557.

F-Calculated Treatments		
Shades	Species	Shades × Species
0.28 ns	138.77 **	3.17 *

Remarks: * significantly different at <0.05; ** very significantly different at <0.01; ns = non-significant.

References

1. Mayrowani, H.; Ashari, N. Pengembangan agroforestry untuk mendukung ketahanan pangan dan pemberdayaan petani sekitar hutan. *Forum Penelit. Èkonomi* **2011**, *29*. [CrossRef]
2. Tan, Z.; Lal, R.; Wiebe, K.D. Global soil nutrient Depletion and yield reduction. *J. Sustain. Agric.* **2005**, *26*, 123–146. [CrossRef]
3. Amundson, R.; Berhe, A.A.; Hopmans, J.W.; Olson, C.; Sztein, A.E.; Sparks, D.L. Soil science. Soil and human security in the 21st century. *Science* **2015**, *348*, 1261071. [CrossRef] [PubMed]
4. Abdurachman, A.; Dariah, A.; Mulyani, A. Strategi dan teknologi pengelolaan lahan kering mendukung pengadaan pangan nasional. *J. Litbang Pertan.* **2008**, *27*, 43–49.
5. Ellison, D.; Morris, C.E.; Locatelli, B.; Sheil, D.; Cohen, J.; Murdiyarso, D.; Gutierrez, V.; van Noordwijk, M.; Creed, I.F.; Pokorny, J.; et al. Trees, forests and water: Cool insights for a hot world. *Glob. Environ. Chang.* **2017**, *43*, 51–61. [CrossRef]
6. Godfray, H.C.J.; Beddington, J.R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J.; Robinson, S.; Thomas, S.M.; Toulmin, C. Food security: The challenge of feeding 9 billion people. *Science* **2010**, *327*, 812–818. [CrossRef] [PubMed]
7. Bernard, F.; van Noordwijk, M.; Luedeling, E.; Villamor, G.B.; Sileshi, G.W.; Namirembe, S. Social actors and unsustainability of agriculture. *Curr. Opin. Environ. Sustain.* **2014**, *6*, 155–161. [CrossRef]
8. Van Noordwijk, M. Agroforestry as nexus of sustainable development goals. In Proceeding of the 3rd International Conference in Agroforestry—Adopting Modern Agroforestry toward Smart Social Forestry Program, Yogyakarta, Indonesia, 16–17 October 2019. [CrossRef]
9. Elagib, N.A.; Al-Saidi, M. Balancing the benefits from the water-energy-land-food nexus through agroforestry in the Sahel. *Sci. Total Environ.* **2020**, *742*, 140509. [CrossRef] [PubMed]
10. Ahmad, S.; Caihong, Z.; Ekanayake, E.M.B.P. Livelihood improvement through agroforestry compared to conventional farming system: Evidence from Northern Irrigated Plain, Pakistan. *Land* **2021**, *10*, 645. [CrossRef]
11. Quandt, A.; McCabe, J.T. "You can steal livestock but you can't steal trees." The livelihood benefits of agroforestry during and after violent conflict. *Hum. Ecol.* **2017**, *45*, 463–473. [CrossRef]

12. Essa, M.; Nizami, S.M.; Mirza, S.N.; Khan, I.A.; Athar, M. Contribution of agroforestry in farmers' livelihood and its impact on natural forest in northern areas of Pakistan. *Afr. J. Biotechnol.* **2011**, *10*, 15529–15537. [CrossRef]
13. Garrity, D.P.; Akinnifesi, F.K.; Ajayi, O.C.; Weldesemayat, S.G.; Mowo, J.G.; Kalinganire, A.; Larwanou, M.; Bayala, J. Evergreen agriculture: A robust approach to sustainable food security in Africa. *Food Secur.* **2010**, *2*, 197–214. [CrossRef]
14. Charles, R.L.; Munishi, P.; Nzunda, E.F. Agroforestry as adaptation strategy under climate change in Mwanga District, Kilimanjaro, Tanzania. *Int. J. Environ. Prot.* **2013**, *3*, 29–38.
15. Batish, D.R.; Kohli, R.K.; Jose, S.; Singh, H.P. *Ecological Basis of Agroforestry*; CRC Press: Boca Raton, FL, USA, 2007; ISBN 0-429-13914-4.
16. Samadhi, N.; Mallipu, A. A Reviving Local Food Achieving Sustainable Food System. *The Jakarta Post*, 16 October 2021.
17. Van Noordwijk, M.; Duguma, L.A.; Dewi, S.; Leimona, B.; Catacutan, D.C.; Lusiana, B.; Öborn, I.; Hairiah, K.; Minang, P.A. SDG synergy between agriculture and forestry in the food, energy, water and income nexus: Reinventing agroforestry? *Curr. Opin. Environ. Sustain.* **2018**, *34*, 33–42. [CrossRef]
18. Chandrasekara, A.; Kumar, T.J. Roots and tuber crops as functional foods: A review on phytochemical constituents and their potential health benefits. *Int. J. Food Sci.* **2016**, *2016*. [CrossRef] [PubMed]
19. Deswina, P.; Priadi, D. Development of arrowroot (*Maranta arundinacea* L.) as functional food based of local resource. In Proceedings of the 6th International Simposium of Innovative Bioproduction Indonesia on Biotechnology and Bioengineering (ISIBIO), Tangerang, Indonesia, 23–24 October 2019. [CrossRef]
20. Yazid, N.S.M.; Abdullah, N.; Muhammad, N.; Matias-Peralta, H.M. Application of starch and starch-based products in food industry. *J. Sci. Technol.* **2018**, *10*, 144–174. [CrossRef]
21. Lai, K.; Tsai, Y.; Wang, T. Studies on the edible canna in Taiwan: Botanical characteristics and economical use of edible canna. *J. Agric. Assoc. China* **1980**, 1–14.
22. Nugraheni, N.F.; Karyadi, J.N.W.; Tarwaca, S.N.; Indrasari, Y.P.; Albyan, R.; Setiyadi, I.; Ayuni, D. Effect of various drying methods on the physical characteristics of purple yam powder. In Proceeding of the International Conference in Agricultural Technology, Engineering, and Environmental Science (ICATES), Banda Aceh, Indonesia, 21 September 2020. [CrossRef]
23. Harijono, H.; Estiasih, T.; Saputri, D.S.; Kusnadi, J. Effect of blanching on properties of water yam (*Dioscorea alata*) flour. *Adv. J. Food Sci. Technol.* **2013**, *5*, 1342–1350. [CrossRef]
24. Prameswari, R.D.; Estiasih, T. Pemanfaatan tepung gembili (*Dioscorea esculenta* L.) dalam pembuatan cookies. *J. Pangan Agroind.* **2013**, *1*, 115–128.
25. Sabda, M.; Wulanningtyas, H.S.; Ondikeleuw, M.; Baliadi, Y. Karakterisasi potensi gembili (*Dioscorea esculenta* L.) lokal asal papua sebagai alternatif bahan pangan pokok. *Bul. Plasma Nutfah* **2019**, *25*, 25–32. [CrossRef]
26. Oktalina, S.N.; San Afri Awang, P.S.; Hartono, S. Strategi petani hutan rakyat dan kontribusinya terhadap penghidupan di kabupaten Gunungkidul. *J. Kawistara* **2015**, *5*, 221–328.
27. Seruni, A.P.; Aguilar, F.X.; Cai, Z.; Gold, M.A.; Roshetko, J.M. Parcelized cut-and-carry agroforestry systems for confined livestock. *Small-Scale For.* **2021**, *20*, 119–143. [CrossRef]
28. Roshetko, J.M.; Rohadi, D.; Perdana, A.; Sabastian, G.; Nuryartono, N.; Pramono, A.A.; Widyani, N.; Manalu, P.; Fauzi, M.A.; Sumardamto, P.; et al. Teak agroforestry systems for livelihood enhancement, industrial timber production, and environmental rehabilitation. *For. Trees Livelihoods* **2013**, *22*, 241–256. [CrossRef]
29. Sudomo, A.; Maharani, D. Aplication of plant diversity through coplex agrofresty on three land use system. In *Advant in Environement Research*; Nova Publisher: New York, NY, USA, 2020; pp. 55–77.
30. Sabastian, G.E.; Yumn, A.; Roshetko, J.M.; Manalu, P.; Martini, E.; Perdana, A. Adoption of silvicultural practices in smallholder timber and NTFPs production systems in Indonesia. *Agrofor. Syst.* **2019**, *93*, 607–620. [CrossRef]
31. Food and Agriculture Organization of the United Nations. *OECD-FAO Agricultural Outlook 2019–2028*; Food & Agriculture Organization: Rome, Italy, 2019; ISBN 92-5-131374-1.
32. Rohandi, A. Productivity and quality of three varieties of ginger on many light intensity levels under stand of pine. *J. Agrofor. Indones.* **2018**, *1*, 1–13. [CrossRef]
33. Oktafani, M.B.; Supriyono; Budiastuti, M.S.; Purnomo, D. Performance of Arrowroot (Marantha arundinacea) in various light intensities. In Proceedings of the 4th International Conference on Sustainable Agriculture and Environment (4th ICSAE), Surakarta, Indonesia, 10–12 August 2017. [CrossRef]
34. Miller, J.H. *Nonnative Invasive Plants of Southern Forests: A Field Guide to Identification and Control*; Southern Research Station: Asheville, NC, USA, 2003; Volume 62.
35. Azis, S.N. Pengaruh Naungan Sengon (*Falcataria moluccana* L.) Dan Pemupukan Terhadap Pertumbuhan Ganyong Putih (*Canna edulis* Ker.). Bachelor's Thesis, Institut Pertanian Bogor, Bogor, Indonesia, 2013.
36. Utami, N.W.; Diyono, D. Respon pertumbuhan dan produksi 4 varian ganyong (*Canna edulis*) terhadap intensitas naungan dan umur panen yang berbeda. *J. Teknol. Lingkung.* **2016**, *12*, 333–343. [CrossRef]
37. Wu, J.; Zeng, H.; Zhao, F.; Chen, C.; Liu, W.; Yang, B.; Zhang, W. Recognizing the role of plant species composition in the modification of soil nutrients and water in rubber agroforestry systems. *Sci. Total Environ.* **2020**, *723*, 138042. [CrossRef] [PubMed]
38. Gunungkidul, B.P.S.K. (Ed.) Kabupaten Gunungkidul Dalam Angka 2021. © BPS Kabupaten Gunungkidul: Yogyakarta, Indonesia, 2021; ISBN 0215-5230.

39. Heryani, N.; Sawiyo, N. Pemberian irigasi suplementer pada lahan kering berbasis kearifan lokal untuk meningkatkan produktivitas lahan. In Proceedings of the Seminar Nasional Matematika, Sain, dan Teknologi, Yogyakarta, Indonesia, 9 November 2013; Volume 4, pp. D.58–D.71.
40. Wardhana, W.; Sartohadi, J.; Rahayu, L.; Kurniawan, A. Analisis transisi lahan di kabupaten gunungkidul dengan citra penginderaan jauh multi temporal. *J. Ilmu Kehutanan* **2012**, *6*, 89–102.
41. Nurlaela, N. Pemberdayaan masyarakat petani kakao melalui pengembangan kelembagaan (studi kasus di desa putat, kecamatan patuk, kabupaten gunung kidul). *J. AgroSainTa Widyaiswara Mandiri Membangun Bangsa* **2017**, *1*, 52–60.
42. Oktalina, S.N.; Awang, S.A.; Hartono, S.; Suryanto, P. Pemetaan aset penghidupan petani dalam mengelola hutan rakyat di kabupaten Gunungkidul (The farmer livelihood asset mapping on community forest management in Gunungkidul district). *J. Mns. Lingkung.* **2016**, *23*, 58–65. [CrossRef]
43. Bahri, S.; Julaikha, S. Nilai-Nilai Gotong-Royong Dalam Masyarakat Petani Padi Sawah Di Desa Sungai Siput Kecamatan Siak Kecil Kabupaten Bengkalis. *Jom FISIP.* **2014**, *1*, 1–13.
44. Maryudi, A.; Nawir, A.A.; Sekartaji, D.A.; Sumardamto, P.; Purwanto, R.H.; Sadono, R.; Suryanto, P.; Soraya, E.; Soeprijadi, D.; Affianto, A.; et al. Smallholder farmers' knowledge of regulations governing the sale of timber and supply chains in Gunungkidul district, Indonesia. *Small-Scale For.* **2017**, *16*, 119–131. [CrossRef]
45. Roshetko, J.M.; Manurung, G.E. Smallholder teak production systems in Gunungkidul, Indonesia. In Proceedings of the 2nd World Congress of Agroforestry—The Future of Global Land Use, Nairobi, Kenya, 24–28 August 2009.
46. Simon, H. *Metode Inventore Hutan*; Pustaka Pelajar: Yogyakarta, Indonesia, 2007; ISBN 978-979-1277-17-4.
47. Aqil, M.; Efendi, R. *Aplikasi SPSS Dan SAS Untuk Perancangan Percobaan: Aplikasi Pertanian, Aplikasi Peternakan, Aplikasi Kehutanan Dan Aplikasi MIPA*; Absolute Media: Yogyakarta, Indonesia, 2021; ISBN 602-1083-07-5.
48. Nair, P.K.R. *An Introduction to Agroforestry*; Kluwer Academic Publisher: Dordrecht, The Netherlands, 1993; ISBN 0-7923-2134-0.
49. De Souza, D.C.; Costa, P.A.; Silva, L.F.L.E.; Guerra, T.S.; Resende, L.V.; Pereira, J. Productivity of rhizomes and starch quantification in cultures of different vegetative propagules of arrowroot. *J. Agric. Sci.* **2019**, *11*, 419–425. [CrossRef]
50. De Souza, D.C.; Silva, R.D.J.; Guerra, T.S.; Silva, L.F.L.E.; Resende, L.V.; Pereira, J. Characterization of arrowroot starch in different agronomic managements. *Rev. Ceres* **2019**, *66*, 323–332. [CrossRef]
51. Wickramasinghe, H.A.M.; Noda, T. Physicochemical properties of starches from Sri Lankan rice varieties. *Food Sci. Technol. Res.* **2008**, *14*, 49–54. [CrossRef]
52. Wiyono, W.; Lestari, P.; Hidayat, R.; Oktalina, S.N.; Utomo, S.; Prasetyo, E.; Ngadianto, A.; Nugroho, P. Penerapan teknik silvikultur intensif pada pengelolaan hutan rakyat di kabupaten gunungkidul. *J. Pengabdi. Pengemb. Masy.* **2018**, *1*, 57–69. [CrossRef]
53. Rohadi, D.; Kallio, M.; Krisnawati, H.; Manalu, P. Economic incentives and household perceptions on smallholder timber plantations: Lessons from case studies in Indonesia. In Proceedings of the International Conference on Smallholder and Community Forest Management—Taking Stock of Smallholder and Community Forestry: Where do we go from here? Montpellier Conference, Montpellier, France, 24–26 March 2010; pp. 1–14.
54. Roshetko, J.M.; Astho, A.; Rohadi, D.; Widyani, N.; Manurung, G.S.; Fauzi, A.; Sumardamto, P. Smallholder teak systems on Java, Indonesia: Income for families, timber for industry. In Proceedings of the IUFRO 3.08.00 Small-Scale Forestry Conference 2012: Science for Solutions, Amherst, MA, USA, 24–27 September 2012; pp. 162–167.
55. Rohandi, A.; Budiadi, B.; Hardiwinoto, S.; Harmayani, E.; Sudrajat, D.J. Variability in morpho-physiology, tuber yield and starch content of several arrowroot populations in Garut district. *AGRIVITA J. Agric. Sci.* **2017**, *39*, 311–323. [CrossRef]
56. Lakitan, B. *Dasar-Dasar: Fisiologi Tumbuhan*; Raja Grafindo Persada: Jakarta, Indonesia, 2015; ISBN 979-421-377-2.
57. Purwaningrahayu, R.D.; Sebayang, H.T.; Syekhfani, S.; Aini, N. Resistance level of some soybean (*Glycine max* L. Merr) genotypes toward salinity stress. *Berk. Penelit. Hayati* **2015**, *20*, 7–14. [CrossRef]
58. Murniyanto, E.; Badami, K. Karakteristik agroekologi garut (*Marantha arundinaceae* L.) pulau madura. *Agrovigor J. Agroekoteknol.* **2009**, *2*, 59–66.
59. Sastra, D.R. Analisis Keragaman Genetik Dan Tanggap Tanaman Garut (*Maranta arundinacea* L.) Terhadap Intensitas Cahaya Matahari. Ph.D. Theses, Bogor Agricultural Institute, Bogor, Indonesia, 2002.
60. Miftakhussolikhah, M.; Ariani, D.; Ervika, R.; Angwar, M.; Wardah, W.; Karlina, L.L.; Pranoto, Y. Cooking characterization of arrowroot (*Maranta arundinaceae*) noodle in various arenga starch substitution [Karakteristik pemasakan mie garut (*Maranta arundinaceae*) pada variasi subtitusi pati aren]. *Berita Biol.* **2017**, *15*, 141–148.
61. Djaafar, T.F.; Pustika, A.B. Pengembangan budi daya tanaman garut dan teknologi pengolahannya untuk mendukung ketahanan pangan. *J. Penelit. Dan Pengemb. Pertan.* **2010**, *29*, 25–33.
62. Prehaten, D.; Hardiwinoto, S.; Naâ, M.; Supriyo, H.; Widiyatno, W.; Rodiana, D. Productivity of arrowroots and taro grown under superior teak clones with several levels of stand density. *Biosaintifika J. Biol. Biol. Educ.* **2021**, *13*, 51–57. [CrossRef]
63. Handayani, T.; Wijayanto, N.; Wulandari, A.S. Analisis pertumbuhan mindi (*Melia azedarach* L.) dan produktivitas umbi garut (*Maranta arundinacea* dan *Maranta linearis* L.) dalam sistem agroforestri. *J. Trop. Silvic.* **2018**, *9*, 144–150. [CrossRef]
64. Gardner, F.P.; Pearce, R.B.; Mitchell, R.L. *Fisiologi Tanaman Budidaya*; UI Press: Jakarta, Indonesia, 1991; ISBN 979-456-088-x.
65. Muhartini, S. Pertumbuhan dan hasil ganyong (*Canna edulis* Ker.) pada beberapa tingkat naungan dan takaran pupuk kandang. *Caraka Tani J. Sustain. Agric.* **2009**, *24*, 114–120. [CrossRef]

66. Sudomo, A.; Hani, A. Produktivitas talas (*Colocasia esculenta* L. Shott) di bawah tiga jenis tegakan dengan sistem agroforestri di lahan hutan rakyat. *J. Ilmu Kehutan.* **2014**, *8*, 100–107.
67. Lestari, P.; Utami, N.W.; Wawo, A.H. Adaptasi intensitas cahaya rendah gembili (*Dioscorea esculenta*) pada naungan atrtifisial [Adaptation on low light intensity of lesser yam under artificial shading]. *Pros. Semin. Nas. Masy. Biodivers. Indones.* **2019**, *5*, 374–382. [CrossRef]
68. Sawitri. Adaptasi anatomi dan morfologi tanaman gembili (Dioscorea esculenta) terhadap pola tanam dan intensitas cahaya relatif di hutan rakyat Kabupaten Sukoharjo. Bachelor's Theses, Universitas Gadjah Mada, Yogyakarta, Indonesia, 2015.
69. Budiman, B.; Arisoesilaningsih, E. Predictive model of Amorphophallus muelleri growth in some agroforestry in East Java by multiple regression analysis. *Biodivers. J. Biol. Divers.* **2012**, *13*, 18–22. [CrossRef]
70. Fatma, L.Y.; Jumari, J.; Utami, S. Keanekaragaman Dioscorea spp dan habitatnya di Kabupaten Kudus, Jawa Tengah Diversity and habitat of *Dioscorea* spp in Kudus, Central Java. *Bioma Berk. Ilm. Biol.* **2018**, *20*, 17–24. [CrossRef]
71. Maharani, D. Adaptasi Morfosiologi Dan Produktivitas Tanaman Gembili (Dioscorea esculenta (Lour.) Burk.) Di Bawah Jenis Tegakan Berbeda Di Wanagama I. Master's Theses, Pasca Sarjana Fakultas, Kehutanan Universitas Gadjah Mada, Yogyakarta, Indonesia, 2017.
72. Patola, L.N.P.; Supriyono, S.; Pardjanto, P. Effect use biofertilizer and differences type soil on growth and yield arrowroot. *SAINS Tanah-J. Soil Sci. Agroclimatol.* **2017**, *14*, 29–35. [CrossRef]
73. Fu, L.; Sun, H.; Sharma, R.P.; Lei, Y.; Zhang, H.; Tang, S. Nonlinear mixed-effects crown width models for individual trees of Chinese fir (*Cunninghamia lanceolata*) in south-central China. *For. Ecol. Manag.* **2013**, *302*, 210–220. [CrossRef]
74. Rosmiah, R.; Gusmiatun; Pebriana, P. Ganyong dan pupuk kandang. *Klorofil* **2014**, *IX-2*, 89–93.
75. Yulfia, Y.; Puji, H.; Prasetyo, P. Keragaan pertumbuhan ganyong (*Canna edulis* Kerr) pada berbagai ketinggian tempat bedasarkan ciri morfologi di kabupaten bengkulu selatan. *NATURALIS* **2012**, *1*, 85–88.
76. Lingga, P.; Sarwono, B.; Rahardi, F.; Rahardja, P.; Afriastini, J.; Wudianto, R.; Apriadji, W. *Bertanam ubi-Ubian*; Penebar Swadaya: Jawa Brat, Indonesia, 1986.
77. Hermann, M.; Quynh, N.; Peters, D. Reappraisal of edible canna as a high-value starch crop in Vietnam. *CIP Prog. Rep.* **1997**, *98*, 415–424.
78. Rahman, M.A.; Rahman, A.; Miah, M.G.; Hoque, M.A.; Rahman, M.M. Productivity and profitability of jackfruit-eggplant agroforestry system in the terrace ecosystem of Bangladesh. *Turk. J. Agric. Food Sci. Technol.* **2018**, *6*, 124–129.
79. Ceunfin, S.; Prajitno, D.; Suryanto, P.; Putra, E.T.S. Assessment of competition and the benefits of intercropping of maize-soybeans under eucalyptus stands. *Savana Cendana* **2017**, *2*, 1–3. [CrossRef]
80. Rachmadyanto, B. Analisis Usahatani Ganyong Dan Permasalahannya Di Desa Jatisari Kecamatan Tajinan Kabupaten Malang. Bachelor's Theses, University of Muhammadiyah Malang, Jawa Timur, Indonesia, 2011.
81. Baluk, M.S.N. Analisis Pendapatan Usahatani Garut Dan Nilai Tambah Pati Garut Di Desa Waringinanom, Kecamatan Poncokusumo, Kabupaten Malang. Bachelor's Theses, Widya Karya Malang Catholic University, Jawa Timur, Indonesia, 2021.
82. Tatay, P.; Widiastuti, M.M.D.; Untari, U. Analisis pendapatan budidaya dan pengolahan hasil gembili (*Dioscorea esculenta*) sebagai sumber pangan alternatif bagi keluarga di kampung yanggandur. *Musamus J. Agribus.* **2018**, *1*, 32–40. [CrossRef]
83. Nugroho, P.; Soedjoko, S.A.; Kusumandari, A.; Marhaento, H. Adaptasi dan mitigasi bencana tanah longsor melalui penguatan kapasitas masyarakat dan peningkatan produktivitas lahan melalui sistem agroforestri. In Proceedings of the Prosiding Seminar Nasional Agroforestri 2013—Agroforestry untuk Pangan dan Lingkungan yang lebih Baik, Malang, Indonesia, 21 May 2013; p. 381.
84. Dhyani, S.K.; Tripathi, R.S. Biomass and production of fine and coarse roots of trees under agrisilvicultural practices in north-east India. *Agrofor. Syst.* **2000**, *50*, 107–121. [CrossRef]
85. Ishii, H. Response of a clonal teak plantation to thinning and pruning in Java, Indonesia. *J. Trop. For. Sci.* **2017**, *29*, 44–53.
86. Seta, G.W.; Widiyatno; Hidayati, F.; Na'iem, M. Impact of thinning and pruning on tree growth, stress wave velocity, and pilodyn penetration response of clonal teak (*Tectona grandis*) plantation. *For. Sci. Technol.* **2021**, *17*, 57–66.
87. Kallio, M.; Kanninen, M.; Rohadi, D. Farmers' tree planting activity in Indonesia—Case studies in the provinces of central Java, Riau, and South Kalimantan. *For. Trees Livelihoods* **2011**, *20*, 191–209. [CrossRef]
88. Huxley, P. *Tropical Agroforestry*; Blackwell Science Ltd.: Oxford, UK, 1999; ISBN 0-632-04047-5.
89. Saptono, M. Growth and yield of cassava in agro forestry system using crown tree management: Crown pruning for optimization light interception. *AGRIVITA J. Agric. Sci.* **2011**, *33*, 22–31.
90. Bertomeu, M.; Roshetko, J.M.; Rahayu, S. Optimum pruning intensity for reducing crop suppression in a Gmelina-maize smallholder agroforestry system in Claveria, Philippines. *Agrofor. Syst.* **2011**, *83*, 167–180. [CrossRef]
91. Purnomo, D.; Sitompul, S.M. Irradiasi pada sistem agroforestri berbasis jati dan pinus serta pengaruhnya terhadap pertumbuhan tanaman kedelai. *Biodiversitas* **2006**, *7*, 251–255.
92. Suryanto, P.; Widyastuti, S.M.; Sartohadi, J.; Awang, S.A. Traditional knowledge of homegarden-dry field agroforestry as a tool for revitalization management of smallholder land use in Kulon Progo, Java, Indonesia. *Int. J. Biol.* **2012**, *4*, 173. [CrossRef]
93. Pramono, A.A.; Fauzi, M.A.; Widyani, N.; Heriansyah, I.; Roshetko, J.M. *Pengelolaan Hutan Jati Rakyat-Panduan Lapangan Untuk Petani*; Center for International Forestry Research (CIFOR): Bogor, Indonesia, 2010; ISBN 978-602-8693-19-6.
94. Cavalcante, V.S.; Dos Santos, M.L.; Cotta, L.C.; Neves, J.C.L.; Soares, E.M.B. Clonal teak litter in tropical soil: Decomposition, nutrient cycling, and biochemical composition. *Rev. Bras. Cienc. Solo* **2020**, *45*. [CrossRef]

95. Rahman, M.; Majumder, M.; Rahman, G.; Zaman, M.; Mojumder, M. Time of application of teak leaf litter and its effect on boro rice. *J. Agrofor. Environ.* **2008**, *2*, 1–6.
96. Al Mahmud, A.; Rahman, M.M.; Hossain, M.K. The effects of teak monoculture on forest soils: A case study in Bangladesh. *J. For. Res.* **2018**, *29*, 1111–1120. [CrossRef]
97. Triharyanto, E. Budidaya tanaman garut dalam upaya meningkatkan pendapatan petani. *Caraka Tani J. Sustain. Agric.* **2002**, *17*, 1–12. [CrossRef]
98. Fitria, R.; Supriyono, S.; Sudadi, S. Respon pertumbuhan dan hasil garut (*Maranta arundinacea*) terhadap pembumbunan dan pemupukan kalium. *Agrotechnol. Res. J.* **2017**, *1*, 46–50. [CrossRef]
99. Suhartini, T.; Rais, S.A.; Hadiatmi, L.H.; Dewi, N.; Setyowati, M. Rejuvenasi Dan Karakterisasi Morfologi Plasma Nutfah Tanaman Pangan. In Proceedings of the Prosiding Seminar Hasil Penelitian Rintisan dan Bioteknologi Tanaman, Bogor, Indonesia, 26–27 December 2001.
100. Sulistyono, E.; Marpaung, J. Studi karakter umbi dan kandungan *Nutrisi dioscorea* spp. *Indones. J. Agron.* **2004**, *32*, 39–43.
101. Duffy, C.; Toth, G.; Cullinan, J.; Murray, U.; Spillane, C. Climate smart agriculture extension: Gender disparities in agroforestry knowledge acquisition. *Clim. Dev.* **2021**, *13*, 21–33. [CrossRef]