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Assessing the Productivity and Socioeconomic Feasibility of Cocoyam and Teak Agroforestry for Food Security

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Abstract: Limited agricultural land areas combined with increasing demands for food require breakthroughs in land use development using agroforestry systems. Intercropping root crops with trees could be an alternative for food production in forest areas. This study aimed to assess the feasibility of cocoyam (*Xanthosoma sagittifolium* (L.) Schott) farming on dry land within 12- and 42-year-old teak (*Tectona grandis* L.f.) forests to support local food security. The feasibility assessment took into account both productivity and socio-economic aspects. The agroforestry land productivity was measured using the land equivalent ratio (LER), and our analysis of the cocoyam farming within the teak stands was carried out using the revenue/cost ratio (R/C) at the demonstration plot scale. Furthermore, we also surveyed farmers' perceptions of the production of cocoyam for food security. The results showed that the R/C values of cocoyam tuber production in agroforestry systems were lower than 1. However, the production rates of cocoyam tubers in the 12-year-old teak stand (48.3% light intensity) and the 42-year-old teak stand (62.5% light intensity) were 2.64 and 2.76 tons/ha, respectively. The overall yields from the teak and cocoyam agroforestry systems were more profitable than those of the monoculture system, as indicated by the LER values of 1.61 and 1.85. Cocoyam production was socially acceptable (77% of respondents) as a smallholder subsistence agroforestry practice to meet food demand. Increasing cocoyam productivity in teak forests requires the adoption of agroforestry silvicultural technology to achieve food security for rural communities. To increase their farming production and income, farmers could apply intensive silvicultural practices. Governmental support that could be provided includes encouraging product diversification and providing assistance for the processing and marketing of cocoyam products.

Keywords: agroforestry; community forest; food crops; feasibility

Citation: Winara, A.; Fauziyah, E.; Suhartono; Widiyanto, A.; Sanudin; Sudomo, A.; Siarudin, M.; Hani, A.; Indrajaya, Y.; Achmad, B.; et al. Assessing the Productivity and Socioeconomic Feasibility of Cocoyam and Teak Agroforestry for Food Security. *Sustainability* **2022**, *14*, 11981. https://doi.org/10.3390/su141911981

Academic Editor: Teodor Rusu

Received: 15 July 2022
Accepted: 19 September 2022
Published: 22 September 2022

1. Introduction

Population growth leads to increases in food demand and creates huge challenges for food production [1]. The low carrying capacity of agricultural land is one of the challenges facing food security [2]. At the same time, food production programs through crop cultivation also face fierce competition for land, water, energy, and efforts against the negative effects of food production on the environment [3,4]. Efforts to achieve food yield targets using conventional agricultural methods have caused extensive environmental and societal damage [5,6], while multifunction agriculture could be an option to improve food production that is socially and environmentally positive [7]. Therefore, multifunction agriculture practices are expected to support the achievement of the sustainable development goals (SDGs) [7,8]. The relationship between agriculture and food security is important for farming households in villages that are facing land degradation, water shortages, and climate change [9]. Farmers with limited resources can cultivate food crops within tree stands using a sustainable intensification approach called agroforestry [6,10].

Agroforestry involves smallholder agroecosystems and aims to increase income, food security, and ecosystem services in a sustainable manner [11,12]. By intercropping crops and trees, agroforestry practices have significantly contributed to the livelihoods of village communities [13]. An additional critical element of agroforestry systems is resilience to climate change and its impacts, which can trigger significant famine crises [14]. Agroforestry also improves plant resistance to the possible consequences of climate change, including drought and higher temperatures, as it increases water infiltration and accumulation and reduces evaporation and extreme temperatures [14–16]. Agroforestry also boosts livelihood resilience by reducing dependence on trees alone, anticipating limited product markets in remote areas, and providing ecosystem services [14]. Additionally, increases in yields can be highly sustainable (secure), as agroforestry retains soil fertility and can reduce land degradation [14,17,18].

Food production through agroforestry farming can begin with the regulating of species composition. Agroforestry is able to increase yields, depending on crop selection, local conditions, and the level of expertise/management, to benefit farmer organizations and the environment [19,20]. The optimization of land productivity within tree stands for the production of shade-tolerant tubers can provide medium-term benefits for both forestry and food for local populations [21]. Tuber species such as *Dioscorea alata* L., *Dioscorea esculenta* (Lour.) Burkill, *Colocasia esculenta* (L.) Schott, *Xanthosoma sagittifolium* (L.) Schott, *Canna edulis* Ker Gawl., *Maranta arundinacea* L., and *Amorphophallus campanulatus* Decne are among the potential species to be developed within forest stands in agroforestry systems [22,23] and as commodities for the diversification of carbohydrate-rich foods other than rice [23–25]. Most tubers grow naturally, while some are deliberately planted by communities [26].

Agroforestry farming by intercropping cocoyam (*Xanthosoma sagittifolium* (L.) Schott) and trees can be a potential alternative for food production in forest stands. Cocoyam is among the world's top six most important root and tuber crops [27]. This plant has been cultivated in a wide geographical distribution including Oceania, Africa, and Asia [28]. Cocoyam can be cultivated in agroforestry systems [29]. This crop is generally grown by small-scale farmers who operate in subsistence economies [30] for household food security, especially when production is unprofitable [31]. Cocoyam is a food crop that is well adapted to agroecological zones in Sub-Saharan Africa and is ranked third after cassava and sweet potato out of the root crops that are cultivated and consumed by people in West and Central Africa [32]. In Nigeria, farmers grow cocoyam on well-drained coastal sand plains, and yields are optimal when it is planted in fertile soil with good water retention capacity [30]. Households grow cocoyam as a cash crop and sell at least half of their yearly production [33]. In Ghana, people cultivate cocoyam around lakes as a food crop [34]. Cocoyam can be used for food supplies during disaster conditions [35].

Cocoyam is a viable food commodity that has an appreciable nutritional profile and higher productivity and better storability than other indigenous roots and tubers, as well as having potential for development as a sustainable food security measure [28,36] because it is not tied to the seasons [37]. Further, cocoyam is a potential substitute for rice because it is rich in carbohydrates [38] and has a low glycemic index (54/100 g) [28], as well as containing antioxidants [39]. Cocoyam has a nutritional value that is comparable to that of potato and higher than those of cassava and sweet potato [40,41]. This plant is known to have higher carbohydrate and lower protein contents than potato [42], as well as being high in lipids [43], fiber, and vitamin C [44] and having low glycemic levels [45]. This native American plant was introduced in Africa and became a staple food [28]. In Africa, cocoyam tubers are used as an indigenous food for human consumption, and the leaves are used for animal feed [30]. In Indonesia, this tuber is a staple food in certain marginal areas and is eaten as a snack in East [46] and Central Java [26]. As well as being consumed as they are, cocoyam tubers can also be processed into flour [47–49] to be used as a base for making noodles/pasta [50–53], biscuits/cookies [54–56], meat analogs [57,58], yogurt mixes [59,60], food thickeners [61], bioplastics [62,63], and edible films [64]. The leaves and stems of this plant can also be used as animal feed, wound medicines [65], painkillers [66], diabetes medicines [39], antileukemia medicines [67], and biofuel [38,68,69]. It can be grown as a monoculture [70,71] or intercropped with other crops. Research on intercropping teak with other crops has been conducted, including *Amorphophallus* [72], maize [73], peanut [74], soybean [75], arrowroot (*Maranta arundinacea* L.), canna (*Canna edulis* Ker Gawl), and yam (*Dioscorea esculenta*) [21], but studies on intercropping teak with cocoyam are still limited in number.

Developing agroforestry as a viable alternative for farmers in diverse ecological and socioeconomic conditions is a very challenging issue [76]. Future research on timber-based agri-silviculture systems must link food security issues [77] and incorporate both productivity and socioeconomic assessments. Previous studies have indicated that some tubers, such as canna (*C. edulis*) [78], arrowroot (*M. arundinacea*) [79], and yam (*D. esculenta*) [80], are economically feasible to cultivate [78–80]. In Indonesia, farmers' perceptions of the benefits of agroforestry practices are varied: some are high, e.g., in Wonosobo, Central Java [81], and Malang, East Java [82,83], while others are low, e.g., in Lampung [84,85] and Ciamis, West Java [86]. In Lampung, people's perceptions of agroforestry management were found to be low because only a few of the farmers understood the benefits of non-timber forest products (NTFPs) [85]. In Ciamis, West Java, farmers' perceptions of private forest value were found to be positive [87] but their motivation to apply agroforestry practices was low [86]. However, studies on the socioeconomic aspects of tuber-based agroforestry that have focused on the cocoyam species are still very limited.

Intercropping food crops, such as corn, peanuts, and cassava, in between rows of teak trees has been practiced for more than a century in Java [88]. The purpose of teak agroforestry has advanced from reforestation into more diverse goals, such as environmental protection [89], the enhancement of ecosystem services [90], carbon sequestration [91], flora–fauna biodiversity conservation [92], poverty alleviation [93], and food security [77]. In Indonesia, teak-based agroforestry is combined with various companion food crops, such as maize (*Zea mays* L.) [94,95], porang (*Amorphophalus mulleri* Blume) [96], arrowroot (*M. arundinacea L.*), taro (*Colocasia esculenta* L.) [97], soybean (*Glycine max* (L.) Merr) [75], suweg (*Amorphopallus paeoniifolius* (Dennst.) Nicolson) [72], arrowroot-yam (*Dioscorea esculenta* L.), edible canna (*Canna edulis*) [21], a combination of maize and cassava (*Manihot utilisima*), peanut (*Arachis hypogaea* L.), rice (*Oryza sativa*), sorghum (*Sorghum bicolor*) [98], durian (*Durio zibethinus*) [99], ginger [100], and a combination of maize and peanut [74].

Agroforestry systems have been developed in Gunungkidul Yogyakarta, Indonesia, as adaptations to marginal land and dry environmental conditions [101]. Farmers in Gunungkidul have limited land (<0.25 ha), with teak (*Tectona grandis* L.f.) as the main tree species [102]. The limited availability of fertile land and insufficient water supplies due to the short rainy season (4–5 months) encourage farmers to select drought-resistant plants that can be harvested during the dry season, such as tubers [103]. For this, the farmers need land in the state forest (community forest/*hutan kemasyarakatan*) to cultivate food crops. The Forest Management Unit/*Kesatuan Pengelolaan Hutan* (FI/KPH) of Yogyakarta, which covers 13,826 ha, is planning to increase the productivity of the dry rocky land using teak stands that are over five years old and root crops [104]. A previous study by Roshetko et al. [105] showed that farmers applied intercropping systems in Gunungkidul using less-than-five-year-old teak stands and several shade-intolerant species, such as cassava, peanuts, upland rice, soybeans, and long beans. Cocoyam is one species of tuber plant that can be cultivated in dry land within ten-year-old teak stands in Indonesia [106] and within five-year-old oil palm stands in Nigeria [107]. It should be planted in 40–50% shade to grow optimally [93,108–111]. Cocoyam that was cultivated within teak stands that were 3–5 years old was able to produce 32.92–33.28 tons/ha of tubers, while production within teak stands that were aged <10 years decreased by 37% [106]. However, the productivity of cocoyam tuber cultivation within >10-year-old teak stands with dry rocky soil conditions is not yet known.

Since location and light intensity both affect tuber growth and productivity [112], and farmers' perceptions and motivation can affect the adoption of agroforestry practices [113], it is necessary to carry out comprehensive studies covering the productivity and socioeconomic aspects of intercropping cocoyam with teak to examine the possibility of cultivating tuber species within tree stands. Therefore, this study evaluated the feasibility of cultivating cocoyam tuber crops as an intercropping species within 12- and 42-year-old teak stands that are on marginal soils in the Gunungkidul community forest. The specific objectives of the research were to (i) assess the productivity of intercropping cocoyam tuber crops within teak stands on marginal land in the Gunungkidul community forest, (ii) analyze the profit value of cocoyam tuber crops as an option for farmers, and (iii) evaluate the perceptions of the farming community regarding the use of teak intercropping in the community forest. We assumed that tree shading would decrease the productivity of tuber crops but that the positive perceptions of farmers and the economic value of cocoyam tuber products would make the application of a cocoyam and teak agroforestry system feasible.

2. Materials and Methods

This study was driven by the increasing demand for food, as the availability of land is becoming increasingly limited. Forest land could be an alternative for food production using agroforestry farming systems that combine tree stands and food crops. The idea of using forest land to cultivate trees and food crops was adapted to the specific conditions at the research site and took the results of previous studies into account. The previous studies were traced from various online databases with themes related to land productivity in tuber crops, marginal land farming, agroforestry practices related to food security, and social acceptance. The previous studies were reviewed to find out the research gap. This study focused on assessing the feasibility of using cocoyam and teak cropping systems to achieve food security in marginal areas. The feasibility assessment covered land productivity and a financial analysis, as well as farmers' perceptions. The conceptual framework of this study is presented in Figure 1.

2.1. Location

The research was conducted from April 2018 to December 2019 in the Giriharjo and Girisuko villages in the Panggang District, Gunungkidul Regency, Yogyakarta Province, Indonesia (Figure 2). The objects of this research were agroforestry systems that used teak and cocoyam on a plot scale and the community around the research plots. The plots were located in the forest of the FMU Yogyakarta, which is at 08°00′13.7″ S 110°25′52.0″ E and 333 m above sea level.

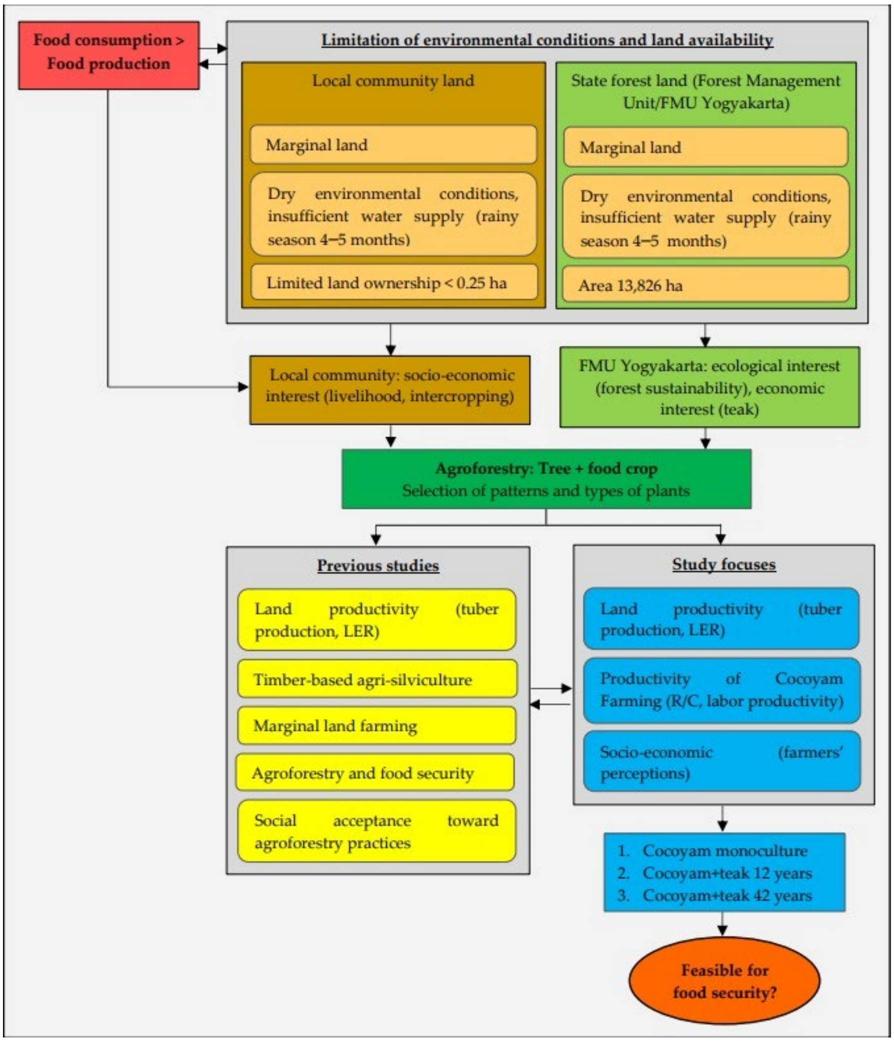

Figure 1. The conceptual framework of this study.

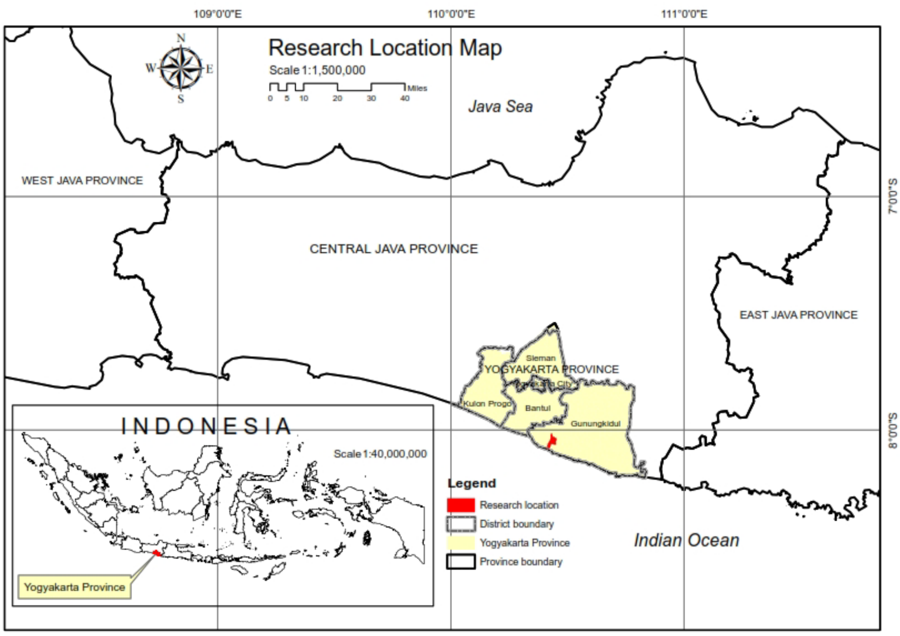

Figure 2. The location of the study area.

The teak and cocoyam agroforestry plots were established within a 12-year-old teak plantation (not thinned), a 42-year-old teak plantation (remaining logging stands), and an area of open land. All three plots were located within the same landscape. The slope of the research plots was flat to slightly steep (5–43%). The relative light intensity under the 12-year-old teak stand was 48.3%, and it was 62.5% under the 42-year-old stand. The soil was classified as clay (79–86%), with a neutral pH, medium C-organic matter, medium total N levels, very low total P, and very low total K levels (Table 1).

Table 1. The microclimate and soil properties of the agroforestry research plots before cocoyam planting.

Variable	Open Land	Teak Stand (12 Years Old)	Teak Stand (42 Years Old)
Microclimate Properties			
Relative Light Intensity (%)	100.00	48.30	62.50
Daytime Temperature (°C)	31.73	27.83	28.10
Daytime Relative Humidity (%)	59.07	70.53	69.50
Soil Properties			
Sand (%)	7.00	6.00	5.00
Silt (%)	14.00	9.00	7.00
Clay (%)	79.00	85.00	86.00
pH H_2O	7.40 (neutral)	6.80 (neutral)	6.80 (neutral)
C-Organic Matter (%)	2.24 (medium)	2.31 (medium)	2.05 (medium)
Total N (%)	0.23 (medium)	0.23 (medium)	0.21 (medium)
C/N	10 (low)	10 (low)	10 (low)
P_2O_5 HCl 25% (mg/100 g)	15.12 (low)	13.65 (very low)	10.09 (very low)
P_2O_5 Olsen (ppm)	6.6 (very low)	3.8 (very low)	4.3 (very low)
K_2O (mg/100 g)	12.72 (low)	12.68 (low)	9.78 (very low)
Ca (cmol (+)/kg)	50.40 (very high)	40.60 (very high)	35.34 (very high)
Mg (cmol (+)/kg)	1.94 (medium)	2.30 (high)	2.16 (high)
Na (cmol (+)/kg)	0.12 (low)	0.10 (low)	0.13 (low)
CEC (cmol (+)/kg)	44.10 (very high)	42.70 (very high)	33.98 (very high)

2.2. Research Procedures

The research was conducted at the plots and covered all three aspects of the study, namely, the productivity of the teak and cocoyam agroforestry systems, an analysis of farming business, and the perceptions of farmers around the plots. The research was carried out using a participatory action research method, which involved forest farmer groups and the FMU Yogyakarta when deciding on the type of tubers to be planted within the teak stands, the location of the plots, and the implementation of the cultivation activities. The process of establishing the research plots began with identifying and mapping the actual location of the community forest within the FMU Yogyakarta and then continued with selecting appropriate teak stands, i.e., old teak stands with high levels of shade and marginal soil conditions that were not being used by communities around the forest. Cocoyam was selected by the farmers and the managers of the FMU Yogyakarta as the food crop to be planted in the research plots.

The research plots were established within teak stands and open land. There were three cropping systems, namely, monoculture cocoyam (open land), intercropped cocoyam within a 12-year-old teak stand, and intercropped cocoyam within a 42-year-old teak stand (Figure 3). Each system was repeated three times. Cocoyam was planted with as many as 40 plants/plot at a spacing of 1 m $\times$ 1 m. The cocoyam seeds came from tubers with an average weight of 250–300 g. The technical treatment of the cocoyam was conducted through manual land preparation, planting, the maintenance of weeds, and harvesting. Fertilization and pest and disease control were not carried out on the cocoyam during the study. The planting was carried out in November 2018, and the harvesting of the cocoyam tubers was carried out in August 2019. The technical treatment of the cocoyam was performed by adopting the habits of the communities around the forest when planting cocoyam.

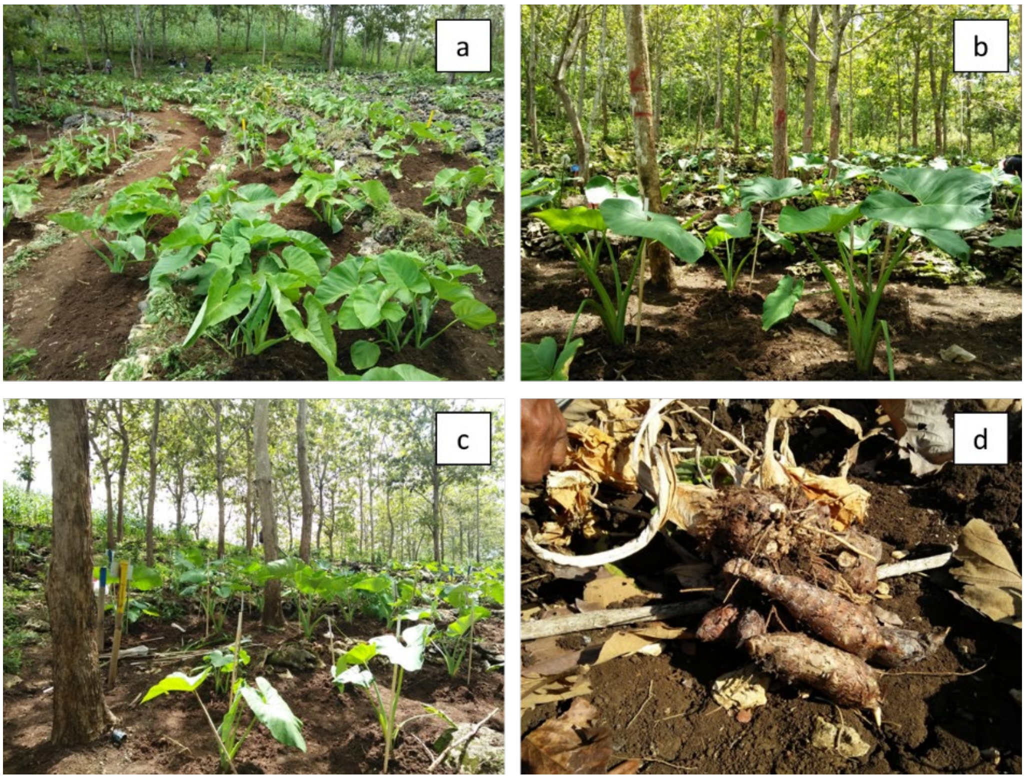

Figure 3. The research plots of cocoyam plants: (**a**) in open land; (**b**) within the 12-year-old teak stand; (**c**) within the 42-year-old teak stand; (**d**) a cocoyam tuber.

The data on the land productivity of teak and cocoyam agroforestry were obtained from our calculations of the land equivalent ratio (LER) for teak and cocoyam agroforestry. To calculate the LER, the cocoyam tuber production of 15 plants from each plot was measured over 1 harvest season (1 year), the diameters of the teak trees in each plot were measured including monoculture teak plots, and the volumes of the teak trees were calculated using the Gunungkidul teak volume table [114].

The data that were collected regarding the productivity of cocoyam farming included information on the production inputs that were used to make the cocoyam agroforestry plots, such as land area (m^2), the number of seeds (kg), herbicides (liter or kg), and the number of working days (HOK). In addition, supporting data in the form of the unit values of the production inputs were obtained through interviews with various sources of information, such as forest managers, heads of farmer groups, and institutions, who provided the production facilities around the research plots.

The characteristics and farmers' perceptions of the cocoyam cultivation within the teak stands were obtained directly through interviews with 30 respondents. The respondents were chosen with simple random sampling from a total (population) of 50 farmers who were members of farmer groups and were directly or indirectly involved in developing the cocoyam agroforestry plots. In addition to meeting the representativeness of the population (with a sampling intensity of 60%), the number of 30 respondents was considered to meet the requirements of a normal distribution, according to [115]. Moreover, this number of respondents was projected to reach saturation [116]. Before conducting further analysis, initial data analysis was carried out with a normality test, a homoscedasticity test, and a multicollinearity test (see Appendices A–D). The normality test showed that the data plot was close to the diagonal line, which indicated that the variable met the requirements. The homoscedasticity test also indicated from the scatter plot, which was evenly distributed, with an even distribution of data, that there was no homoscedasticity. Furthermore, to determine whether there was multicollinearity, VIF values were analyzed. Values that were less than 10 also indicated inadequate multicollinearity between variables as a condition for their analysis. We also used Kolmogorov–Smirnov for normality tests, and the results showed that the significant value was 0.200 greater than 0.05, which means the data were normally distributed. The perception data consisted of 15 questions (as presented in the Supplementary Materials). Every question was rated on a three-point Likert scale (1 = disagree, 2 = do not know, and 3 = agree).

2.3. Plant Origin

This research used cocoyam (*Xanthosoma sagittifolium*) samples and teak (*Tectona grandis* L.f.) stands. The cocoyam tuber rhizome seeds that were used were local species from several home gardens/moors within rural community villages (Ngudi Rukun Farmer Group) that are located in the Gunungkidul Regency. The cocoyam species that was studied in this research is abundantly found in the wild and is not mentioned on the IUCN red list. The samples were analyzed purely to obtain information related to tuber productivity.

The teak stands were under the management of the Forest Management Unit (FMU) of Yogyakarta. Those teak stands were utilized for the agroforestry systems via intercropping with cocoyam. The use of cocoyam and teak involved neither cell line methods nor plant experimental research related to taxonomy, genetics, rare plants, and/or mutants.

2.4. Data Analysis

The agroforestry land productivity was calculated using the land equivalent ratio (LER), according to Mead et al. [117]. Land is defined as more productive when the LER value is more than 1 [118–120].

$$\text{LER} = \frac{\text{Production of tubers on agroforestry}}{\text{Production of tubers monoculture}} + \frac{\text{Production of teaks on agroforestry}}{\text{Production of teaks monoculture}} \quad (1)$$

In this study, farming activities were assumed to be carried out by families/farmer groups. Therefore, farming costs were divided into explicit costs (i.e., those that were actually paid) and implicit costs (i.e., those that were not actually paid). Farming revenue was calculated by multiplying the amount of production by the selling price, farm income was calculated as the difference between the revenue and the incurred explicit costs, and farming profit was calculated as the difference between the revenue and the total farming costs (both explicit and implicit).

The collected data were then processed descriptively and quantitatively to establish the structure of costs, revenue, and income for cocoyam farming. The revenue/cost ratio (R/C) and labor productivity were then calculated to determine farming productivity [121,122]. Farming productivity was classified as good when the corresponding attributes met the following criteria: R/C was higher than 1, and labor productivity was higher than the standard daily wage for farming.

$$Total\ cost = explicit\ cost + implicit\ cost \quad (2)$$

$$Revenue = Production \times Price \quad (3)$$

$$Income = Revenue - Explicit\ cost \quad (4)$$

$$Profit = Revenue - Total\ cost \quad (5)$$

$$\frac{R}{C} = \frac{Total\ Revenue}{Total\ Cost} \quad (6)$$

$$Labor\ Productivity = \frac{Income - Implicit\ cost\ beside\ value\ of\ family\ labour}{Total\ working\ day\ of\ family\ labour} \quad (7)$$

The category of perceptions was divided into three categories, namely, negative, neutral, and positive. Interval classes were determined using the following formula:

$$interval = \frac{max\ score - \text{minscore}}{number\ of\ category}$$

The lowest score was 15, the highest score was 45, and the number category was 3. Furthermore, the levels of perception were categorized: (a) a score of 15–25 (negative), (b) a score of >25–35 (neutral), and (c) a score of >35–45 (positive). A correlation analysis between the respondent characteristics and their perceptions was carried out using Spearman's correlation formula, which was processed using IBM SPSS version 27 for Windows with serial number: 20220718T011754Z-001.

3. Results

3.1. Land Productivity

The weight of tubers that were produced in the agroforestry systems (i.e., within the 12- and 42-year-old teak stands) was 50–53% lower than that of tubers that were produced in open land (monoculture) (Figure 4). This was caused by the light intensity under the 12- and 42-year-old teak stands, which was 48.3% and 62.5%, respectively. The decrease in light intensity affected the growth and production of the tubers [123].

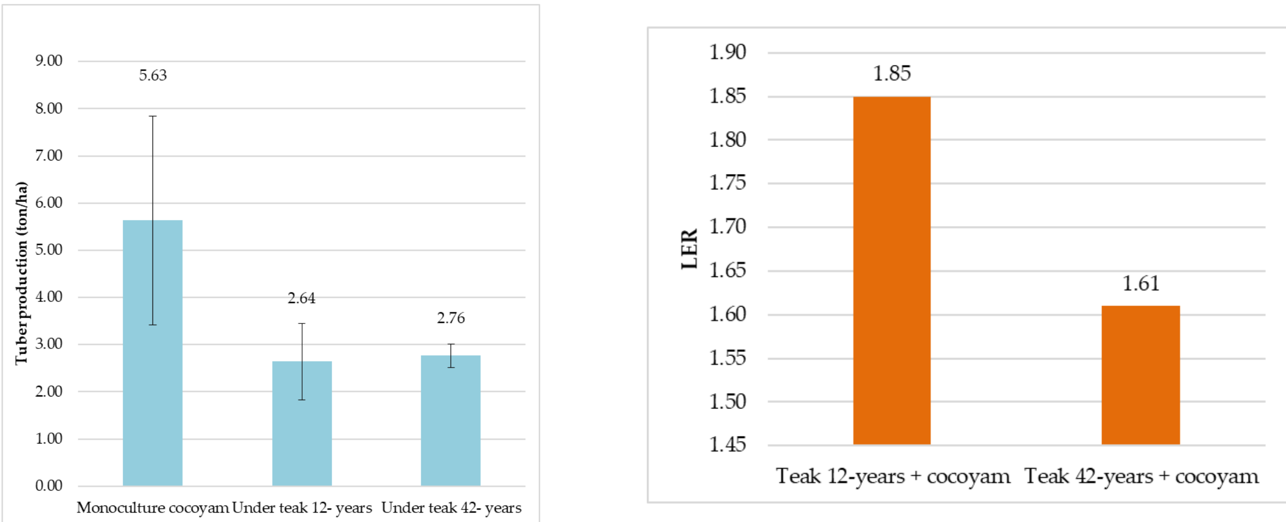

Figure 4. The production of cocoyam tubers and the LER values in the cocoyam and teak agroforestry systems.

The tuber productivity within the 12- and 42-year-old teak stands was 2.64 tons/ha and 2.76 tons/ha, respectively, while the tuber productivity in the cocoyam monoculture was 5.63 tons/ha (Figure 4). The tuber productivity within the 12- and 42-year-old teak stands was much lower than that within 3–5-year-old teak stands (23.3 tons/ha) [106]. Tuber production at the two locations was significantly different due to the differences in cultivation techniques and the location conditions. Within the 12-year-old teak stand, the cocoyam tuber production decreased by 37% compared to that in open land [106]. In addition, the lower production rate at the research site was due to the long dry season (6 months) in the research area. Tuber productivity decreases more when droughts occur during the tuber formation phase compared to when droughts occur during the vegetative phase [124]. The land conditions also contributed to the poor cocoyam production. There are thin soil sola in calcareous areas, such as the study site. At the same time, the presence of organic matter in the 0–30 cm layer plays an important role in tuber productivity. When the levels of organic matter are low, tuber productivity decreases [125]. Nitrogen influences several aspects of vegetative growth, such as apical shoot formation, increased levels of gibberellin hormones, elongation, and stolon growth [126], while potassium (K) is very important for tuber formation [127]. In fact, the average P (phosphorous) and K (potassium) contents were low at the research site. The K and P contents demonstrate strong interactions in soil [128] and are necessary for tuber production [129]. K is required for tuber-forming root growth, while P is involved in the assimilation translocation from leaves to the other parts of the plant [129]. Therefore, it is necessary to add P and K nutrients into soil, either through organic or inorganic fertilization, to increase cocoyam production. However, fertilization increases production costs. To overcome this, techniques that do not use tillage [130] or organic mulch are needed to produce higher tuber yields than tillage-based techniques [83]. Non-tillage techniques can reduce production costs and increase farm labor efficiency.

Managing tree shading by pruning is one of the initiatives that can boost cocoyam production within tree stands. Tree pruning increases light intensity and resource efficiency by adjusting the canopy of the tree stand [128]. In addition, the by-products of pruning serve as sources of nutrients for marginal soils. Many nutrients are stored in tree parts (roots, stems, branches, and leaves), which then decompose into soil after pruning or natural death [131]. As well as fertilization and pruning by-products, efforts to promote soil fertility must also address soil conservation by avoiding tillage-based techniques, improving harvest waste management, and using cover crops and crop rotation [130]. Another thing that needs to be considered is the harvesting technique. Cocoyam is grown in locations with thin soil sola; thus, it needs to be washed before harvesting so that soil is not removed [30].

The LER values of the teak and cocoyam agroforestry systems were higher than 1 (Figure 4). This indicated that the development of agroforestry with teak and cocoyam could increase the productivity of teak forest land. In 12-year-old stands, there are greater numbers of teak trees that are still in the process of rapid vegetative growth than in 42-year-old stands, which are starting to experience a decrease in vegetative growth. Teak cultivation has a high economic value when appropriate silvicultural measures are conducted, such as pruning and thinning [93]. Increasing the productivity of plants within teak stands can be achieved by maintaining the number of teak trees at 600 trees/ha and applying an alley cropping system with a corridor width of 10 m [132]. The differences in the age and shade levels of teak stands can be used as a basis for selecting the types of understory crops, based on their light requirements [133].

3.2. Productivity of Cocoyam Farming

The production of cocoyam tubers by the community around the FMU Yogyakarta was carried out naturally without fertilizers, so the production costs were relatively low. The farmers only purchased herbicides to kill weeds during land clearing. The cocoyam seeds that were planted also came from collections that belonged to the farmers. The land that was used was a state forest area that was managed by the community. The costs, revenue, and income for cocoyam farming are presented in Table 2.

Table 2. The structure of costs, revenue, and income for cocoyam farming at a 1 ha scale using three different cropping systems.

Number	Description	Cocoyam Monoculture	Intercropping with Teak Stand (12 Years Old)	Intercropping with Teak Stand (42 Years Old)
1	Production Costs			
	-Explicit Costs (IDR)			
	Herbicides	400,000	200,000	200,000
	-Implicit Costs (IDR)			
	Rent for Land	2,000,000	1,200,000	1,200,000
	Seeds	4,000,000	4,000,000	4,000,000
	Family Labor	9,500,000	5,000,000	5,000,000
2	Total Costs (IDR)	15,900,000	10,400,000	10,400,000
3	Production (kg)	5670	2640	2760
4	Price/kg (IDR)	3000	3000	3000
5	Revenue (IDR)	17,010,000	7,920,000	8,280,000
6	Income (IDR)	16,610,000	7,720,000	8,080,000
7	Profit (IDR)	1,110,000	−2,480,000	−2,120,000

The cocoyam farming costs were divided into two categories: explicit costs and implicit costs. The purchase of herbicides was included in the explicit costs category. Land rent, seed procurement, and family labor were included in implicit costs because these were not paid for in cash by the farmers. The labor costs made up the largest proportion of costs for cocoyam farming. Farmers used more family labor to reduce production costs [134]. The proportion could be more than half of the total production costs for cocoyam farming [29].

The cocoyam production in the monoculture system was higher than in the agroforestry systems. Similarly, farming income was higher from the monoculture system than from the agroforestry systems. However, cocoyam farming still generated positive income from all of the monoculture and agroforestry systems. This was in line with the results of previous studies, which have stated that cocoyam production is generally beneficial [135,136]. Community cocoyam production aims to meet the community's food needs and provide income [29]. Cocoyam productivity at the research site is presented in Table 3.

Table 3. The productivity of cocoyam farming at a 1 ha scale using three different cropping systems.

No.	Farming Feasibility Criteria	Cocoyam Monoculture	Intercropping with Teak Stand (12 Years Old)	Intercropping with Teak Stand (42 Years Old)
1	R/C	1.07	0.76	0.80
2	Labor Productivity (IDR/working day)	55,842	13,263	15,158

Cocoyam farming productivity in the monoculture system was more efficient than in the agroforestry systems, as their R/C values were less than 1, which meant that the productivity of cocoyam farming in those systems was not optimal. According to Soekartawi [137], R/C values of less than 1 indicate that farming is not economically efficient because any costs that are incurred do not result in a higher income. However, some results from the assessment of similar tubers, such as cassava [138–140] and sweet potato [141,142], have shown that R/C values of less than 1 can produce better business effectiveness. Further analysis is needed to determine which factors affect the productivity of cocoyam farming to achieve better economic performance.

In terms of productivity, monoculture cocoyam farming was more productive than agroforestry cocoyam farming, as indicated by the R/C values of less than 1. The labor productivity was greater than the average local wage of IDR 50,000/working day. Moreover, cocoyam farming in the agroforestry systems resulted in lower farm productivity. Furthermore, cocoyam that is planted within 10-year-old teak stands has potential productivity of up to 23 tons per ha, and higher productivity can be achieved within younger teak stands [106]. Thus, cocoyam productivity in agroforestry systems could be increased if production could be carried out more intensively by increasing the capacities of teak–cocoyam agroforestry farmers, including their cultivation, storage, processing, and marketing capacities [143]. Improvements in food processing and the accessibility of credit should be prioritized to generate more income for farmers and encourage cocoyam production [144]. In addition, choosing the right variety or type of cocoyam could also increase yields [29].

3.3. Farmer Characteristics, Knowledge, and Perceptions

Giriharjo village is one of the villages situated within the area of the FMU Yogyakarta. The farmers who manage the community forest in the FMU Yogyakarta and participated in this study were mostly male and they were mainly in the productive age category (15–64 years old), as presented in Figure 5. Despite most of the respondents (63%) having side jobs as farm workers, their main jobs were predominantly as farmers (83%). The burden on the head of the family to earn a living was significant due to the large number of family members (4–6 people). The education level of the respondents was low since most of them (63%) only had an elementary school level of education. Dry land farming was their primary source of income.

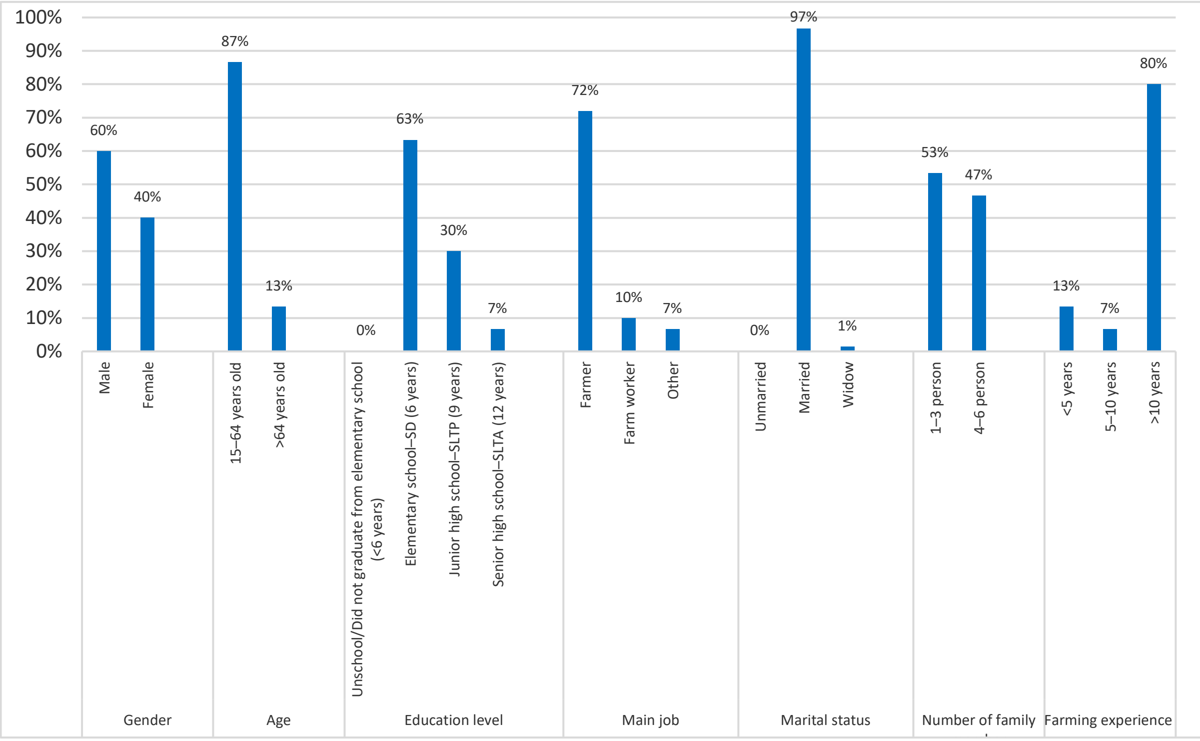

Figure 5. The characteristics of the respondents.

Most of the communities in the FMU Yogyakarta cultivate the land within teak and eucalyptus stands with various crops, especially rice, corn, cassava, beans, and soybean [145]. Additionally, they also plant grass for livestock feed on private land. Most farmers in the Giriharjo village who participated in this study worked on dry land, both on their own land and on state land. The main plants on their own land are teak, mahogany, acacia, and *sengon*, while teak dominates plants on the state land. Most farmers apply intercropping systems with upland rice, corn, peanuts, and tubers, such as cassava and cocoyam. Even in Nigeria, cocoyam is usually planted as a secondary crop and has output and consumption levels that are considerably lower than those of cassava and yams [146]. On the other hand, cocoyam is a staple food in regions of Ghana, Cameroon, and Gabon [146]. Cocoyam has been underappreciated due to its lack of competitiveness with other commodity crops in agriculture, but it has recently gained traction among smallholder farmers [146,147].

Farmers have a pretty good knowledge of cocoyam, particularly regarding its physical form, its utilization, how to process it, and how to cultivate it. Cocoyam has been known for a long time and is commonly planted by communities. Farmers, both those who have planted cocoyam and those who have never planted cocoyam, are familiar with this plant because it is consumed and served during certain events. Farmers grow cocoyam for consumption and sale. Cocoyam is usually eaten with other foods or as a snack at traditional events, thanksgiving, and other family events. In Giriharjo village, seven species of tubers are usually used in traditional ceremonies, one of which is *cocoyam*. Therefore, even though it has previously been said that cocoyam is of low value, the development of cocoyam in agroforestry is important because cocoyam plays a pivotal role and is an inseparable part of Javanese culture, especially for people in Gunungkidul.

According to farmers, all parts of the cocoyam plant can be utilized, including the stems, leaves, and tubers. However, the stems and leaves are only used for animal feed. Farmers' knowledge of processing for consumption is still limited. Cocoyam tubers cannot be consumed raw and must be processed first. Most people in Gunungkidul know how to process cocoyam by washing it and then steaming, frying, or processing it into chips (*ceriping*). Cocoyam can be further processed into flour, which can then be used for making bread and pastries [41]; however, the community around the FMU Yogyakarta does not yet have the knowledge or skills to process cocoyam tubers into flour.

Many farmers have knowledge and experience of planting cocoyam, but only at a small scale in their yards and not within teak stands. Farmers usually plant cocoyam on the edge of their land or under various types of trees, such as sengon, mahogany, fruit trees, coconut, and banana, among others. This knowledge is inherited from parents or neighbors who have experience in planting cocoyam. Small-scale and resource-poor farmers practice cocoyam farming with minimal input in most countries [148,149].

In this study, the farmers' knowledge of cocoyam influenced their perceptions of cocoyam cultivation within teak stands, and 77% of respondents had positive perceptions, as shown in Figure 6. The farmers assessed cocoyam as a prospective product in terms of cultivation (production), processing, and marketing. For them, cultivating cocoyam within teak stands would be a unique attraction if it provided good results. This was because they can take advantage of land that already has trees on it, especially teak trees. However, there were concerns that tuber production would be low because it was planted within teak stands. Cocoyam production is still at the subsistence level in major areas [29,32,150].

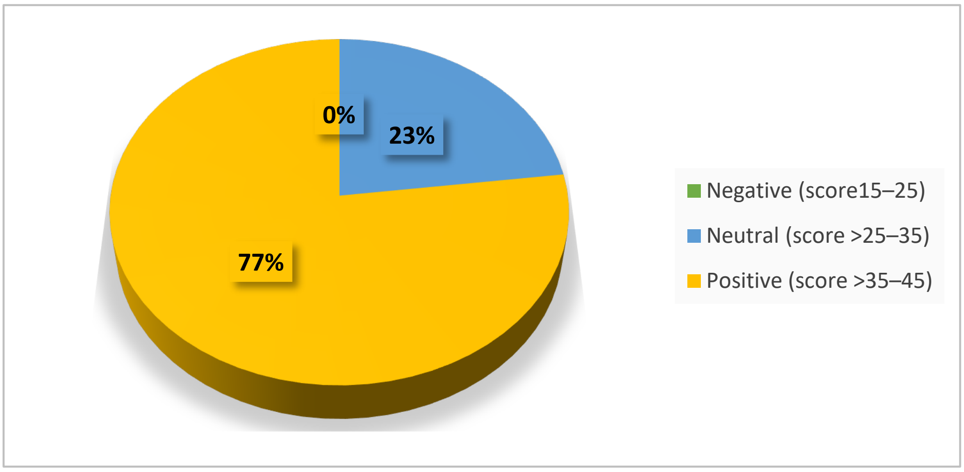

Figure 6. The farmers' perceptions of cocoyam cultivation within teak stands.

According to the respondents, cultivating cocoyam was simple, i.e., hoeing the soil and making planting holes or simply making planting holes and planting the seeds/seedlings directly. Most farmers rely on traditional farming tools to produce cocoyam [28]. The seedlings could develop into tubers or stems with tubers/roots and were usually obtained from neighbors or reproduced from previous plants. The farmers had positive perceptions of cocoyam planting. It was regarded as an easy plant to grow as long as it was planted in the rainy season. The farmers' perceptions of cocoyam plant maintenance were also positive. According to the farmers, cocoyam could grow well even without intensive maintenance. However, it grew better when weeding, fertilizing, and pruning were carried out. Farmers have limited capital to carry out intensive maintenance. Due to the presence of more significant problems, farmers tend to ignore pests and diseases, such as caterpillars. Harvesting and post-harvesting were also considered to be relatively easy. The farmers only used simple techniques and equipment to harvest cocoyam after 7–8 months.

Farmers' perceptions of processing and marketing were also positive. The processing of cocoyam into food ingredients was also considered to be fairly simple. However, slightly different from the other aspects, the marketing of cocoyam was still limited, although the farmers had no difficulty in selling the cocoyam tubers. This caused the farmers' motivation to cultivate cocoyam on a larger scale to remain low.

Many factors, including internal factors, influenced the farmers' knowledge and perceptions of cocoyam. The correlations between the respondent characteristics and their perceptions are presented in Table 4.

Table 4. The correlations between respondent characteristics and their perceptions of cocoyam cultivation within teak stands.

Number	Characteristics of Respondents	Correlation with Farmers' Perceptions		
		Correlation Coefficient	Sig. (2-Tailed)	Alpha
1	Age (years)	0.335	0.71	0.05
2	Gender	−0.470 **	0.09	0.05
3	Length of Stay in Village (years)	0.167	0.370	0.01
4	Education (years)	0.081	0.671	0.05
5	Main Job	0.019	0.919	0.05
6	Side Job	0.170	0.370	0.05
7	Farming Experience (years)	0.290	0.120	0.05
8	Number of Family Members (person)	−0.394 *	0.031	0.05
9	Land Ownership (ha)	−0.230	0.906	0.05

Note: ** Correlation is significant at the 0.01 level (2-tailed); * correlation is significant at the 0.05 level (2-tailed).

From the farmers' characteristics that were studied in this research, it was revealed that only gender and the number of family members were significantly negatively correlated with the farmers' perceptions of the cultivation of cocoyam within teak stands. The negative correlations between these two characteristics and the perception of cocoyam production could be rationally explained as follows: as the managers of their domestic/household affairs (99% of respondents were married), the women's workloads increased with the number of family members, so their activities were mostly centered around the home and yard. Thus, they preferred cocoyam cultivation to be carried out in their yards and to be mixed with various existing plants (as is their habit) as opposed to within teak stands, which could be located far from home and potentially cause them to neglect their responsibilities in household matters. Women's household responsibilities, in addition to the social expectations that agricultural land is prioritized for men, limit their contributions as agricultural workers [151].

Due to the easy management, the women preferred to cultivate cocoyam in the monoculture system. Cocoyam has greater appeal in Africa than in other areas of the world because it can be intercropped with any tree species [149,152,153]. As a shade-tolerant plant, it is commonly utilized as an understory crop in intercropping systems [146].

3.4. Policy Implications

Historically, Gunungkidul is regarded as a food-insecure area. The soil in Gunungkidul is infertile, with thin sola and many rocks, and low rainfall levels cause the suboptimal production of agricultural products. On the other hand, the increasing population in the area requires more and more food supplies.

The forestry sector needs to contribute more by providing food sources from the forest. The FMU Yogyakarta, which has the authority to manage the forest areas in Gunungkidul, provides land for the communities living around the forest to cultivate through FMU–community cooperation schemes and FMU–private company–community cooperation schemes with certain profit-sharing proportions. The Provincial Government of the Special Region of Yogyakarta issued the Regional Regulation (Perda) No. 4 in 2018 concerning the implementation of food reserves. This regulation set out local government strategies for providing and controlling regional food reserves, as well as anticipating and mitigating famine crises.

One type of plant from the forest that can be used as a food source is cocoyam. When cocoyam is considered as a "single" commodity, then it does not provide optimal benefits for farmers as a source of carbohydrates, food reserves, or income for the community economy. However, cocoyam should be considered as a part of the efforts to optimize land use by developing teak and cocoyam agroforestry systems. In addition, planting cocoyam within teak stands can produce two benefits: ecologically friendly weed management without the use of pesticides, and food security for farmers [154]. In this way, cocoyam can be considered as an attractive alternative food commodity because it has the characteristics of growing well within tree stands and being socially acceptable to the local community. Accordingly, farmers have a greater opportunity to utilize FMU land. The FMU and private sectors also benefit indirectly because the teak stands are maintained by the farmers during cocoyam maintenance activities.

The development and distribution of good cocoyam planting materials need to be established so that cocoyam production becomes competitive [29]. Efforts to upscale cocoyam production could be carried out through partnerships [117] between FMUs, the private sector, and the community that are supported by policies and investments, strong institutional capacities, innovative technologies [117], and research, advocacy, and innovation [29]. Alternative policies are needed to encourage farmers to access and intensify productive inputs [29].

Even though cocoyam production in community forests is not profitable (R/C < 1), it can constitute a subsistence business [155] for household food security [29] based on tuber production alone. However, in Africa, the production of cocoyam leaves through agroforestry generates larger incomes for farmers than that through monocultures [28]. Overall, the LER of teak and cocoyam agroforestry systems is higher than 1, so agroforestry is more profitable than monocultures. The application of agroforestry is related to local knowledge that is passed down from generation to generation, so it tends to be less intensive [156].

The commercialization of cocoyam cultivation within teak stands could be achieved by intensifying silviculture agroforestry to minimize competition for water, nutrients, and light as growth factors. In addition, there is a need for the further dissemination of knowledge regarding the utilization of other parts of the cocoyam plant. This needs to be supported by counseling and training for the processing and marketing of products other than tubers.

4. Conclusions

The application of teak and cocoyam agroforestry farming was feasible as an alternative method for food production within tree stands. This feasibility was mainly based on tuber productivity and farmer perceptions. The production of cocoyam tubers within the 12- (48.3% light intensity) and 42-year-old (62.5% light intensity) teak stands was 50–53% less than in open land. Consequently, the R/C values of cocoyam tuber production within the agroforestry systems were lower than 1. However, the overall yields from the teak and cocoyam agroforestry systems were higher than those from the monoculture system (LER 1.61–1.85 > 1). The farmers' perceptions of developing teak and cocoyam agroforestry systems for food security were positive because they were familiar with the cultivation, post-harvest processing, and marketing of cocoyam. Cocoyam was socially acceptable within the community and had become part of the daily culture for forest communities in rural areas. The teak and cocoyam agroforestry practices could provide food for the community and indirectly benefit the forest managers by maintaining teak plantations. The diversification of cocoyam products by using all parts of the plant (e.g., stem, leaves, and tubers) could be another option to maximize the benefits of cocoyam farming. The commercialization of teak and cocoyam agroforestry systems in state forests that involve local communities requires support for various parties, including the social, economic, policy, marketing, and technology adaptability aspects within forest community development. Nevertheless, teak and cocoyam agroforestry as a subsistence farming practice could play an important role in livelihood strategies and food security for communities in rural forest areas. This kind of farming practice also has the potential to contribute to food security measures within the forest sector to support the achievement of the Sustainable Development Goals (SDGs). Further research is needed to increase tuber productivity within teak stands using appropriate teak silviculture applications and tuber crop maintenance techniques through intensive agroforestry farming.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su141911981/s1.

Author Contributions: A.W. (Aji Winara), E.F., S. (Suhartono), A.W. (Ary Widiyanto), S. (Sanudin), A.S., M.S., A.H., Y.I., B.A., D.D., W.H., E.S., D.M., D.S., M., T.S.W., H.B.S.S., C.A., R.R., M.D. (Meksy Dianawati), C.S., D.G., A.R., Y.H.N., and M.D. (Muthya Diana) contributed equally as main contributors to the conceptualization, methodology, software analysis, validation, resource collection, writing, reviewing, and editing of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Our gratitude goes to the management of the Agroforestry Research and Development Institute and the Yogyakarta Forest Management Unit for facilitating this research. Our gratitude also goes to Asep Rohandi, Rd Dedi Herdiana, and Udin Saepudin who helping data collection.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Normality Test

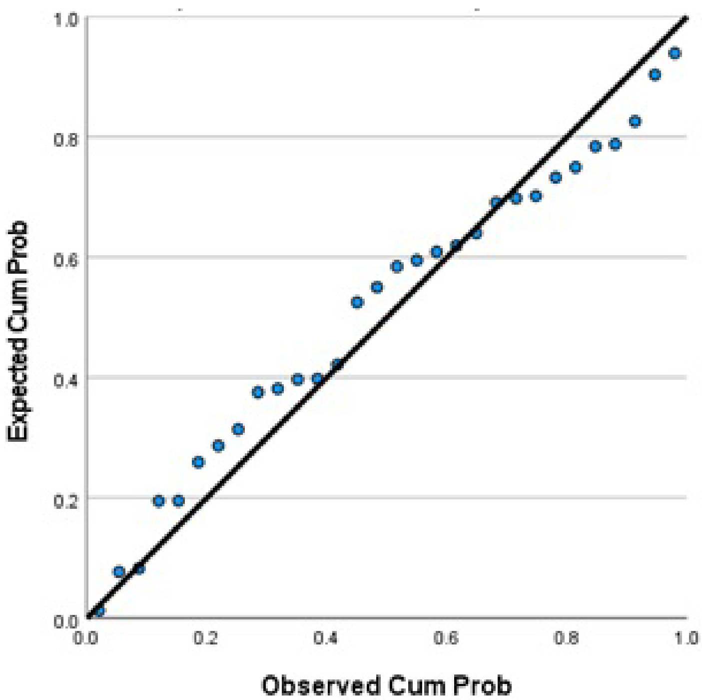

Figure A1. Normal distribution test result.

Appendix B. Collinearity

Table A1. Collinearity test result.

Coefficients [a]								
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	33.249	10.123		3.285	0.004		
	Age	0.170	0.207	0.442	0.824	0.420	0.115	8.719
	Gender	−2.165	1.867	−0.261	−1.159	0.260	0.649	1.541
	Length_of_stay	−0.065	0.097	−0.207	−0.674	0.508	0.348	2.870
	Education	0.433	0.533	0.180	0.814	0.425	0.675	1.481
	Main-job	−0.280	3.337	−0.019	−0.084	0.934	0.652	1.533
	Side_job	0.122	1.386	0.019	0.088	0.931	0.721	1.387
	Farming_experience	0.032	0.134	0.109	0.236	0.816	0.155	6.446
	Number_of_family_member	−0.205	0.350	−0.126	−0.587	0.564	0.718	1.392
	Land-ownership	−0.464	1.409	−0.074	−0.329	0.745	0.646	1.549

[a]. Dependent Variable: Perception.

Appendix C. Heteroskedasticity

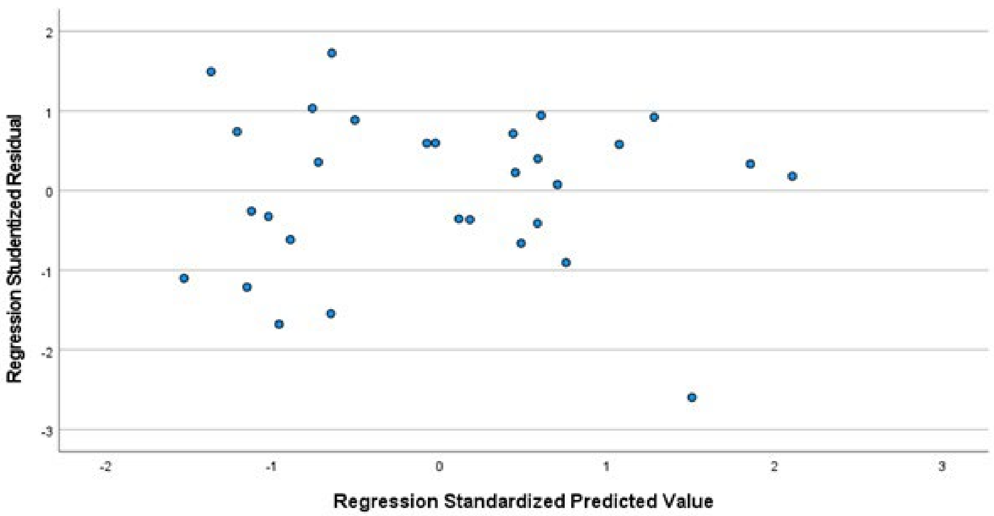

Figure A2. Heteroskedasticity test result.

Appendix D. Kolmogorov–Smirnov Test

Table A2. Kolmogorov-Smirnov test result.

One-Sample Kolmogorov–Smirnov Test		
		Unstandardized Residual
N		30
Normal Parameters [a,b]	Mean	0.0000000
	Std. Deviation	3.69465055

Table A2. *Cont.*

One-Sample Kolmogorov–Smirnov Test			
			Unstandardized Residual
Most Extreme Differences	Absolute		0.099
	Positive		0.070
	Negative		−0.099
Test Statistic			0.099
Asymp. Sig. (2-tailed) [c]			0.200 [d]
Monte Carlo Sig. (2-tailed) [e]	Sig.		0.616
	99% Confidence Interval	Lower Bound	0.603
		Upper Bound	0.628

[a]. Test distribution is Normal. [b]. Calculated from data. [c]. Lilliefors Significance Correction. [d]. This is a lower bound of the true significance. [e]. Lilliefors' method based on 10,000 Monte Carlo samples with starting seed 299,883,525.

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