A study of agroforestry farming for tropical peatland conservation and rehabilitation in Central Kalimantan, Indonesia

Adi Jaya[1], Andrie Elia[2], Emmy U. Antang[1], Merrisa Octora[3], Gusti I. Ichriani[4], Salampak Dohong[1], Yustinus Sulistiyanto[1]

Faculties of [1]Agriculture, [2] Economics and [3] Social & Political Affairs, University of Palangka Raya, Indonesia
[4] Faculty of Agriculture, University of Lambung Mangkurat, Banjarbaru, Indonesia

SUMMARY

Current studies on tropical peatlands in Indonesia focus mostly on the environmental effects of management practices. Studies on the efforts of farmers to conserve and rehabilitate degraded tropical peatlands by operating agroforestry systems have been limited. We addressed this research gap by conducting a qualitative survey with semi-structured interviews and field observations of agroforestry systems in the villages of Tumbang Nusa and Kalampangan in Central Kalimantan. The results showed that the main motivation of farmers establishing agroforestry systems was the understanding that trees would otherwise become scarce in the future, and combining intercrops with planted trees would provide adequate income that would meet the economic needs of their families. Farmers who chose intensive intercropping options followed market demand, whereas others preferred crops that did not require intensive management. Communities in both study villages need further knowledge and training on agroforestry, which can provide a source of income in conjunction with conservation and rehabilitation of degraded tropical peatland. In particular, Government support is important, especially when initiating peatland rehabilitation using agroforestry. More guidance and support than is currently available is needed. Restoring degraded peatland through agroforestry utilising local tree species, such as *Dyera polyphylla*, *Shorea belangeran*, *Alstonia scholaris*, *Combretocarpus rotundatus* and *Alseodaphne* sp., has strong potential. All of these species grew well and could be managed by agroforestry farmers; their growth provided greater vegetation cover which increased humidity, lowered temperatures and reduced fire risk. The role of farmer institutions should be maximised to support more sustainable use of the peatland.

KEY WORDS: degraded peat, fire, local communities, restoration, sociology

INTRODUCTION

Peatlands occupy only 3 % of the global terrestrial surface (Vitt & Short 2020) and are important ecosystems for biodiversity conservation, climate regulation (Joosten 2015) and human well-being (Wildayana 2017). Some 31–46 Mha of peatland (10–12 % of the global peatland area) is found in tropical countries (Maltby & Proctor 1996) such as those in Southeast Asia, South America, Africa, Central America and the Caribbean, Mainland Asia, Australia and the Pacific (Rieley & Page 2016). Amongst these countries Indonesia contains the largest area (around 13.43 Mha) of tropical peatland (Immirzi *et al*. 1992, Rieley *et al*. 1996, Page *et al*. 2011, Anda *et al*. 2021), located mainly on the islands of Sumatra, Kalimantan (Borneo) and Papua (Purnomo *et al*. 2019). In their natural condition these peatlands provide environmental services of global importance, especially in the context of climate change, because of their huge carbon (C) storage capacity (Page *et al*. 2011).

For local communities in peatland areas, the ecosystem is primarily a source of livelihood. The use of Indonesian peatland by local communities is long-established, mainly for traditional cultivation activities in the areas with shallow peat (0.5 m) alongside large rivers (Najiyati *et al*. 2005, Osaki *et al*. 2016). However, since the 1970s, substantial areas with deep peat in Sumatra and Kalimantan have been opened for development (Noor 2012). The largest contiguous area identified for conversion into agricultural land (> 1 Mha in Central Kalimantan) was opened in 1995, but works were discontinued in 1999 because they caused significant environmental problems related to the drying of peat (Subagio *et al*. 2015). More generally it appears that, although technical aspects of peatland development are well

understood (Direktorat Rawa 1992), in practice it is seldom successful because many negative effects can be linked to peatland drainage (Widyati 2011).

Poor peatland management can lead to degradation of the land, and peatland degradation generally has detrimental consequences. Tropical peatland, especially in Indonesia, has experienced much degradation as a result of inept land management, such as the use of fire for land clearing and excessive drainage, as well as forest and land fires (Purnomo *et al*. 2021c). Prolonged dry seasons have seen increased fires in both forest and peatland, especially since 1997 (Page *et al*. 2009). Nowadays there are severe forest and peatland fires in Central Kalimantan almost every long dry season, and the worst conditions experienced to date occurred in 2015 (Huijnen *et al*. 2016, Miettinen *et al*. 2017). Fire-related air pollution has caused problems at both local and national/international levels, including significant economic losses (Tacconi 2003), health problems, and ecosystem damage (Uda *et al*. 2019). Kiely *et al*. (2019) stated that fire also emits substantial amounts of trace gases and aerosols, resulting in serious air pollution episodes.

In Southeast Asia, land-use conversion on around 10 Mha of peatland results in C emissions of 132–159 Mt yr^{-1} from peat oxidation and increased incidence of peat fires which not only augment GHG emissions but also threaten human health and livelihoods (Marlier *et al*. 2013, Miettinen *et al*. 2017). In addition, loss of peat through oxidation and fire results in land subsidence and an increased risk of flooding (Hooijer *et al*. 2012, Evers *et al*. 2016, Evans *et al*. 2019). Subsidence may also occur on drained peatland due to a combination of consolidation and decomposition (Wösten *et al*. 1997, Hooijer *et al*. 2010, Hooijer *et al*. 2012).

The Indonesian state has made numerous attempts to address the problems related to peatland degradation. Presidential Regulation No. 1 of 2016 established the Peatland Restoration Agency *Badan Restorasi Gambut* (BRG) to conserve and restore degraded peatlands (Agustiyara *et al*. 2021, Purnomo *et al*. 2021b). The terms restoration and rehabilitation are often used in the context of improving peatland ecosystems, and it seems that the improvement is directed mostly towards rehabilitation. Restoration is the process of assisting the recovery of ecosystems that have been degraded, damaged or destroyed, while rehabilitation is a management action that aims to restore a level of ecosystem function in degraded locations that will renew and sustain ecosystem services other than the biodiversity and integrity of the original reference ecosystem (Gerwing *et al*. 2021). The BRG has sought to implement an integrated approach to the conservation and restoration of degraded peatlands which involves hydrological restoration (rewetting), revegetation and revitalisation of livelihoods alongside more immediate fire prevention measures. Rewetting programmes that aim to hydrologically rehabilitate a peatland to a near-natural state involve canal blocking, canal backfilling and construction of deep wells (Dohong 2019, Sutikno *et al*. 2019). Revegetation is carried out by replanting endemic species in forest areas and peat swamps but, in general, the success rate in propagation and cultivation of local species is limited (Mishra *et al*. 2021). Therefore, it will be necessary to develop rapid-propagation cultivation techniques capable of generating endemic tree seedlings at a sufficient rate to meet the government's peatland restoration targets. Initiatives for revitalisation of livelihoods have twofold goals: i) to increase income and welfare for local communities by creating various livelihood alternatives, and ii) to improve the participation of local people in operating and maintaining the infrastructure installed to effect rewetting of the peatland (Dohong 2019). Economic empowerment of the community involves efforts to encourage people to desist from activities that cause forest and peat swamp land degradation, and even to protect forest areas, by stimulating new enterprises such as cultivation, fish farming and beekeeping. Putiksari *et al*. (2014) found that community income is the main factor that significantly affects deforestation.

Revegetation may be a less attractive restoration activity locally because it requires long timescales and does not provide obvious economic value to the community. Planting trees, especially for timber production, is a long-term investment with little or no intermediate return because a long time period must elapse before harvesting age is reached (Kallio *et al*. 2011). The alternative of agroforestry has been proposed as a farming system that can provide social, economic and environmental benefits by integrating trees with other crops (Purnomo *et al*. 2021a, Maftu'ah *et al*. 2021). There are indications that agroforestry improves soil quality, agricultural production and ecosystem sustainability, as well as income (Neupane & Thapa 2001, Jose 2009). For example, Yuwariah (2016) states that production is higher and more evenly distributed throughout the year in agroforestry than in monocultures; also, that the risk attached to failure of one crop is reduced, and losses due to market price fluctuations for one crop can be offset by sales of other crops. Some researchers have found that, in addition to making a significant contribution to environmental sustainability and biodiversity (Paembonan *et al*.

2018), agroforestry can help address the problem of poverty (Barnes *et al*. 1982, Foley & Barnard 1984, Gregerson 1988, Jordan 1988, Namwata *et al*. 2012, Moriarty *et al*. 2014, Suharti 2015, Kholifah *et al*. 2017).

In this article we examine sociological and economic aspects of agroforestry farming activities; especially those relating to production, distribution, exchange, consumption of goods, services and resources, and how people achieve prosperity (Elia 2019). We shall explore: (a) how communities practice agroforestry on peatlands and what motivates them to practice it; and (b) whether or not the practice of agroforestry provides financial benefits and contributes to the conservation and rehabilitation of peatland ecosystems. We focus primarily on agroforestry community actors, in order to identify commonalities in the informants' experience of peatlands, peat conservation, and matters relating to the implementation of agroforestry.

METHODS

Research setting

The research was conducted in Kalampangan Village (Sabangau District) including its newer part known as Kalampangan Misik, and Tumbang Nusa Village (Jabiren Raya District), which are both located within the Kahayan-Sebangau Peat Hydrological Unit (*Kesatuan Hidrologis Gambut* or KHG) in Central Kalimantan (Figure 1). Descriptions of the sites are presented in Table 1. These villages were selected purposively according to the research objectives, on the basis that KHG Kahayan-Sebangau is an area with peatlands where a large fire occurred in 2015, and a priority area for the BRG. Kalampangan Village was founded in 1979 to accommodate transmigrants (from Java) and lies entirely on deep peat (depth range 2–3 m). On the other hand, Tumbang Nusa Village is a long-established settlement alongside the Kahayan River, some of whose inhabitants have opened a new area on both sides of the Trans Kalimantan Road which now connects Palangka Raya in Central Kalimantan with Banjarmasin in South Kalimantan. This new residential area is located on deep (> 3m) peat and the community has established agricultural areas on the peat. Tumbang Nusa nowadays extends across a large and massive peat area that experiences fires every long dry season. Forest and peatland fires in Central Kalimantan, including the Tumbang Nusa Village area, have occurred since 1973 (Hoscilo *et al*. 2011) and even up to 2015 (Yulianti *et al*. 2020). As a result of the devastating fires in 2015, many of the natural tree species with high economic value - e.g. belangiran (*Shorea belangeran*), gelam (*Melaleuca leucadendra*), meranti (*Shorea leprosula*), gemur (*Nothaphoebe coriacea Kosterm*) and gerunggang (*Cratoxylon arborescens*) - have begun to disappear (Sutrisaputra & Hidayat 2018).

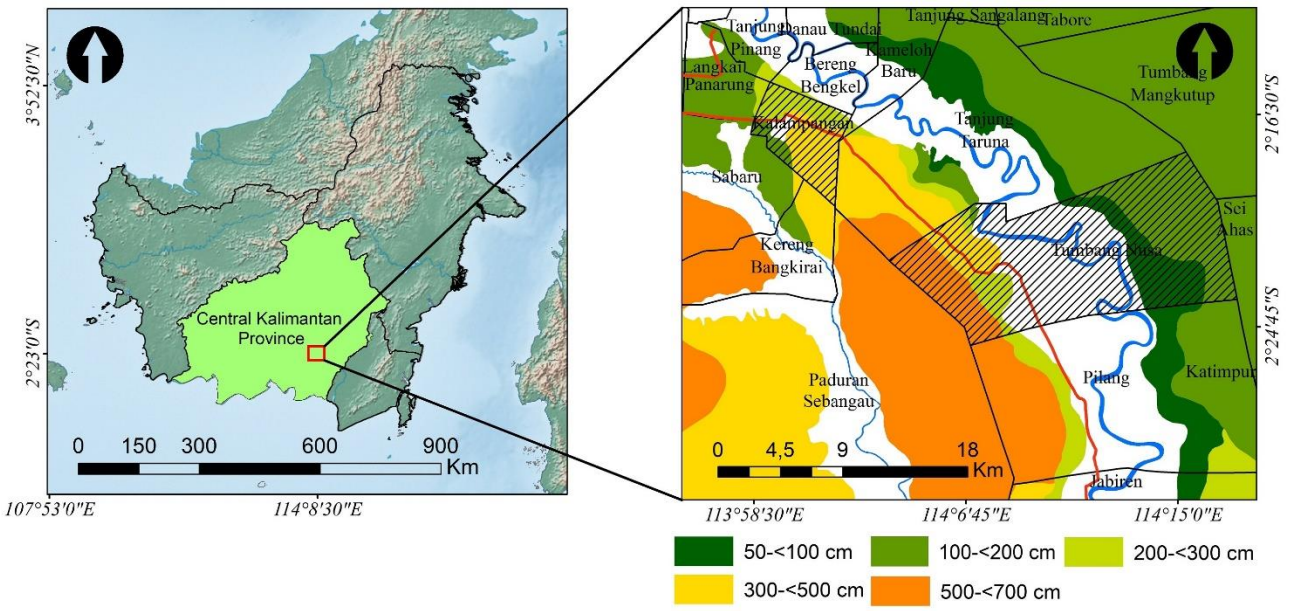

Figure 1. Maps showing the locations and extents of Kalampangan and Tumbang Nusa Villages (diagonal shading) in relation to the Kahayan river (blue line) and the Trans Kalimantan road (red line) (right-hand pane); and within Central Kalimantan (shaded light green) and the island of Borneo (Kalimantan) (left-hand pane). Peat depth data from BBSDLP (2019).

Informants and interviews

Informants were selected using the 'snowball' purposive sampling technique (Bloor & Wood 2006, Johnson 2014) on the basis of their knowledge of agroforestry, conservation behaviour and the role of institutions. We also considered their formal education levels and other training (non-formal education) relating to agroforestry management that they had attended. We interviewed a total of thirteen agroforestry farmers, six in Kalampangan and seven in Tumbang Nusa Village. Two of the farmers in Kalampangan and one farmer in Tumbang Nusa had worked closely with the authors on different research topics since 2017, and they provided us with information about other agroforestry farmers who were subsequently invited to contribute to this study.

Informants were interviewed in depth using a semi-closed interview questionnaire (see Appendix) as a means to obtain richer answers. Each interview was recorded and transcribed so that a large narrative was obtained from the interview results, then each transcription was coded according to the research aspects, namely: peat environment; agroforestry practices; and forest socio-cultural values, especially the meaning of trees in the farmers' lives. To facilitate data analysis, each transcription was then compiled and summarised on the basis of these codes (Bloor & Wood 2006). Observations were also made by visiting the agroforestry land owned by the informants (Figure 2). To cross-check information from the agroforestry farmer respondents, interviews were conducted with resource personnel from the forestry sector including staff from the Research, Development and Innovation Agency of the Ministry of Forestry and Environment, Banjar Baru Environmental and Forestry Research & Development Centre, the Environment Agency and the Provincial Forestry Agency of Central Kalimantan.

Data analysis

A narrative analysis approach was employed to capture information and dimensions of personal human experience over time, and take into account the relationship between individual experiences and the cultural context (McLeod 2011). This analysis was used to capture the informants' personal understanding and experience about agroforestry system practices in relation to social and cultural factors in the areas that they farmed. To this end the responses were carefully compiled, explained,

Table 1. Descriptions of Kalampangan and Tumbang Nusa Villages. Sources of information: *BPS 2020a; ** BRG 2018; *** BBSDLP 2019; ****data interview.

	Kalampangan	Tumbang Nusa
Area (km^2)*	42.29	200
When developed****	1978–1980	Originally a traditional riverside village, subsequently extended to encompass a trunk road.
Population*	4548	962
Number of households*	1215	228
Population density*	108 km^{-2}	5 km^{-2}
Main source** of livelihood	Agriculture (fruit and vegetables)	Fishing
Land***	The entire area is peatland with peat depth 2–3 m.	The river margins have alluvial soil, the remainder of the area is peatland with a peat depth of 0.5-7.0 m.
History of fire on peatland****	Most of the area was cleared by the government without burning; a small area was affected by the last peatland fire in 2015.	Most of the peatland repeatedly subject to peat fires, most recently in 2015.
Drainage history****	1978–1980	Drained by the community in the 1990s.

a  b 

c 

Figure 2. Examples of agroforestry practice in the research area:
(a) jelutung (2 years) with vegetable crops;
(b) silvopasture duck in jelutung plantation;
(c) stingless bee husbandry in jelutung plantation;
(d) jelutung (10 years) with vegetable crops;
(e) silvopasture cows in jelutung plantation.

d 

e 

analysed and interpreted to obtain an in-depth description of the informants' perspectives on landscape and peat conservation and the cultivation of their agroforestry systems.

Financial analysis was conducted to determine the feasibility of agroforestry farming on peatland with the plants and cropping patterns selected by the respondent farmers. The criterion used was Benefit Cost Ratio (BCR), calculated as the quotient of benefit and cost; agroforestry farming was considered feasible if BCR > 1 (Budiningsih & Effendi 2013).

RESULTS

Characteristics of informants

The characteristics of the informants are presented in Figure 3 and Table A1 in the Appendix. The largest fraction (eight) of them had received education to levels ranging from primary to senior high school, two were illiterate, and the remaining three had proceeded to tertiary education. Four had attended vocational training courses (non-formal education) on the prevention and control of forest and land fires, provided by various government agencies including the BRG, but none of this training was related to agroforestry. Thus, a minority of the informants had received additional training. The ethnicity of most (six) of the informants was Dayak and Javanese and one belonged to the Lampung ethnic group.

The informants' ages ranged from 43 to 74 years and their average age was 57.5 years. The working age range in Indonesia is 15–64 years, so all informants were of working age except for the three aged 66, 68 and 74. Based on secondary data, 68 % of the population of Sabangau District (including Kalampangan Village) is of working age, while the corresponding figure for Jabiren Raya District (which includes Tumbang Nusa Village) is 67 %.

The main occupations of the informants varied. Ten were farmers, two were teachers and one farmer worked primarily as a fruit seller. On average, informants stated that they devoted considerable time and money to their agroforestry activities. For example, Informant 1 reported that, after retiring from teaching, he carried out plant cultivation activities within the agroforestry system every day. Farmers originating from Java (ex transmigrants) spent a large amount of time (around eight hours per day) on agricultural activities and so could manage agroforestry well or optimally, whereas farmers who came from local backgrounds generally had a variety of income sources including food stalls on the Palangka Raya – Banjarmasin road and additional agricultural activities.

The number of household members ranged from two to seven people (average 3.5). According to all informants, the number of family members affected not only the distribution of income in the family through expenditure, but also farming activities, because it reflected the workforce provided by the family. Informant farmers in Kalampangan even said that, for cultivating seasonal crops, they sometimes had to use paid labour. They also admitted that people engaged in agriculture on peatlands, which are marginal lands, tend to be lower-class with limited ability, knowledge and financial means so they are less able to manage farming well (cf. Malta 2011). A consequence of this condition can be that the application of technology is relatively limited and farmers tend to modify the technology according to their knowledge, experience and available capital, and thus adapt it to local farming habits.

Land ownership, tenure and trees

Table 2 shows the area of land farmed by each agroforestry farmer, along with its ownership status. In general, there are two types of ownership.

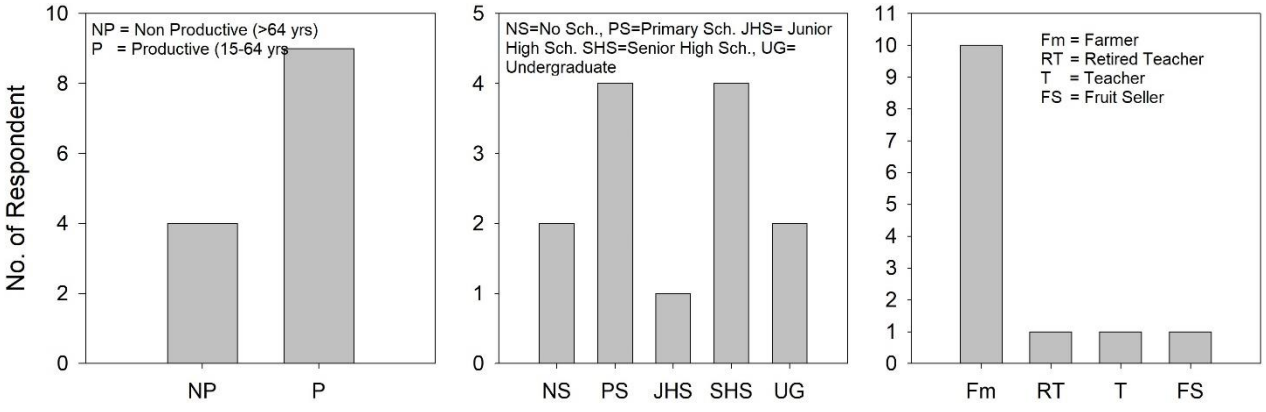

Figure 3. Characteristics of respondents based on age, education and main occupation.

Table 2. Area and ownership status of the land farmed by individual informants. The same Informant Numbers are used in all Tables.

Informant No.	Area (ha)	Ownership status	Current agricultural system practice	Type and age of planted trees
1	2	owned	monoculture, intercropping (chilli, cassava, corn)	*Dyera polyphylla*, 15 years
2	5	owned	monoculture, intercropping (pineapple)	*Dyera polyphylla*, 15 years
3	7	owned	intercropping (tomato, corn)	*Dyera polyphylla*, 15–17 years
4	1.75	owned	intercropping (corn, spinach, mustard, kangkung, spring onion)	*Dyera polyphylla*, 15 years
5	1.75	owned	intercropping (spinach, mustard, lettuce, corn)	*Dyera polyphylla*, 15 years
6	1.75	owned	intercropping (pineapple, kangkung, spinach, celery)	*Dyera polyphylla*, 15 years Agarwood
7	1.75	owned	monoculture, intercropping (leeks, spinach, mustard, vanilla)	*Dyera polyphylla*, 3 years
8	4	owned	monoculture, intercropping	*Shorea belangeran*, 5 years
9	8	owned	monoculture, intercropping (long bean, chilli)	*Shorea belangeran*, *Alstonia scholaris*, *Combretocarpus rotundatus*, *Alseodaphne* sp., mulberry (*Morus alba*), *Dyera polyphylla* (all aged approximately five months); previously planted sengon (*Falcataria moluccana*)
10	4	uses other people's land	monoculture (chilli)	*Dyera polyphylla*, 15 years
11	2	owned	monoculture	*Hevea brasiliensis*, 2 years *Nephelium lappaceum*
12	2	owned	monoculture (kangkung, spinach, bitter gourd)	*Dyera polyphylla*, 10 years
13	2	owned	intercropping (long bean, chilli, spinach, bitter gourd)	*Falcataria moluccana*, 2 years Fruits

Informants 1–6 (transmigrant farmers from Kalampangan) each had 2 ha of land allocated from the transmigration program, consisting of 0.25 ha of yard and 1.75 ha of farming area. The other seven informants (from Tumbang Nusa) farmed areas of 2–8 ha (average 3.42 ha). One of these respondents was farming someone else's land rent-free. The land owner, who was currently in Java because he had changed his employment situation, allowed the respondent to farm his land and thus maintain it. The remaining six respondents had purchased land, especially in the area adjacent to the road, then expanded their holdings behind the land they originally purchased. The two ex-transmigration farmers had land certificates, but land ownership was substantiated only by a Land Ownership Letter (SKT or *Surat Keterangan Tanah*) in all other cases (Table 2).

All except one of the tree species that are used for agroforestry in Central Kalimantan (Table A2) are species that grow naturally on local peatlands. The exception is the exotic multipurpose sengon tree *Falcataria moluccana* which was chosen by two farmers (15,000 seeds on 8 ha) because, at the time of planting, there was demand for sengon to supply a factory that was being built in Pulang Pisau, Central Kalimantan.

All of the respondent farmers planted intercrops in the agroforestry farming that they set up initially, but some farmers had now stopped intercropping due to the increasing size of the trees, arguing that this was dictated by tree shading and tree roots.

Motivation of agroforestry farmers

The reasons that individual informants gave for planting trees are summarised in Figure 4 and detailed data are presented in Table A3. Their primary motivations for planting agroforestry systems were the encouragement and support from government delivered via Banjar Baru Environmental and Forestry Research and Development Centre and BP DAS Kahayan, and the value of agroforestry as a long-term economic investment. For example, Informant 1 stated, "A guest from the Banjarbaru Forestry Research and Development Centre came to me and asked if he could plant trees on my land. I said it would be okay to plant trees with good and profitable prospects. Then he explained that, because the roots of the tree are pointing downwards, the sap will sell and the trees will produce income." Informant 7 said, "Within this village community, we usually plant rubber (*Hevea brasiliensis*) trees and rattan (*Calamus* sp.). When I asked the Head of the KHDTK (*Kawasan Hutan Dengan Tujuan Khusus* = Special Purpose Forest Area) he said it was advisable to plant jelutung (*Dyera* sp.). I was interested in planting jelutung because my parents planted it at a time in the past when only jelutung, hangkang (*Palaquium leiocarpum* Boerl) and nyatoh (*Palaquium obtusifolium* Burck.) were marketable." Informant 2 shared, "Having a tree is the same as having gold. My grandfather told me that selling just one teak tree could fetch Rp. 20,000,000 (USD 1380.08) to Rp. 25,000,000 (USD 1725.07). Instead,

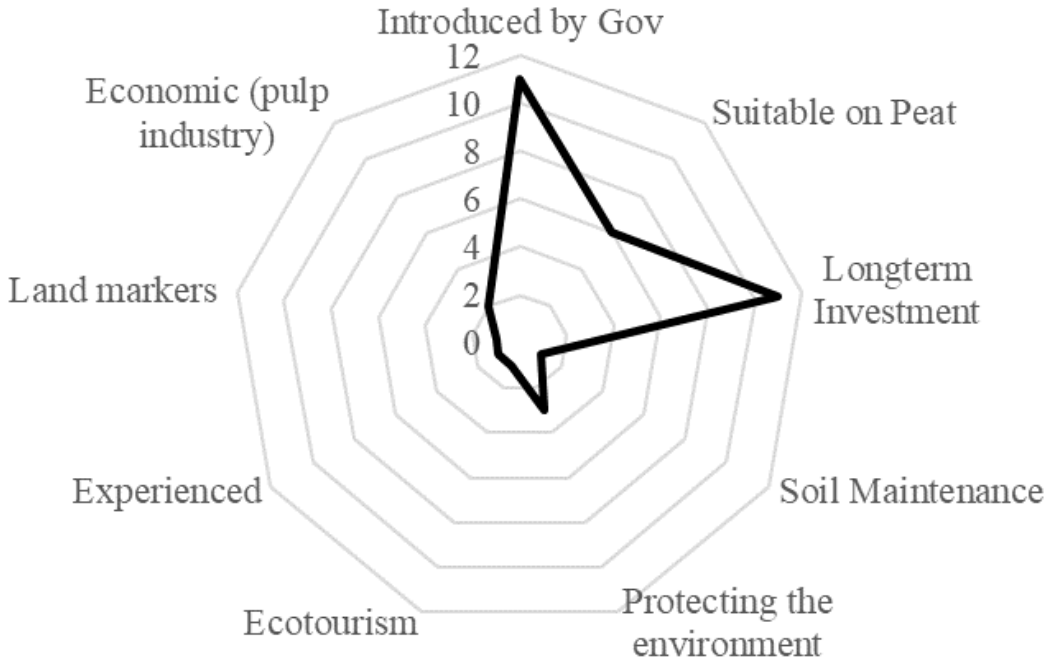

Figure 4. Radar graph summarising the farmers' motivations for engaging in agroforestry.

you could plant a jelutung. So planting jelutung is a natural choice for me." Informant 9 said, "I wanted to develop agroforestry because I saw other people have done it and, if other people can plant their land with agroforestry systems, I should be able to do it too. Planting trees is a step towards preserving the land. It is sad to see burn marks because the fire can burn down into the peat by 50 cm, creating a pool of water (where there used to be dry land)".

All informants believed that that the need for wood will increase in the future. Some farmers regard the timber of standing trees, including jelutung and rubber, as savings to be utilised when economic conditions become difficult. By tapping rubber alone, you can meet your daily food needs. More money can be earned by selling products from trees grown on actively cultivated land with secure tenure and well-fertilised soil. The farmers believed that this can be achieved by growing and fertilising annual crops in between rows of planted trees, because the fertiliser applied to these intercrops is also consumed by the trees. All respondent farmers reported that when they monocrop trees, fertilisation is usually done only at the start of planting.

All farmers in Kalampangan Village started agroforestry activities on peatlands following directions given by the Banjar Baru Environmental and Forestry Research and Development Centre, which explained the benefits of agroforestry activities. The head of the Forest Farmers group, who was also a respondent, explained that previously there had been as many as 15 farmers who carried out agroforestry through farmer groups following the government's directions, but only six of these farmers had continued and all of them had planted jelutung trees partially combined with agarwood.

The reasons given by the informants for planting trees can be grouped into the following categories:

(1) initiated or introduced by Forestry Research and Development (*Dyera* sp. seedlings from the forestry programme);
(2) long-term investment for posterity;
(3) suitable for development on peatland, with low plant mortality;
(4) land retention (mark of ownership); and
(5) the trees support family income even if the yield is small.

Reasons for the selections of intercrops planted between tree rows is presented in Figure 5. The most important reasons for the farmers' choices were: to adjust to market demand; the species were suitable for, and could grow well on, peatlands under shaded conditions; good income source in the short-term; and suitability as food reserves. In the context of food reserves, one respondent stated that cassava plants, for example, can be utilised in case of food shortages. Other reasons offered were following or imitating other farmers, as well as the availability of plant seeds in the form of assistance from the Banjar Baru Forestry Service.

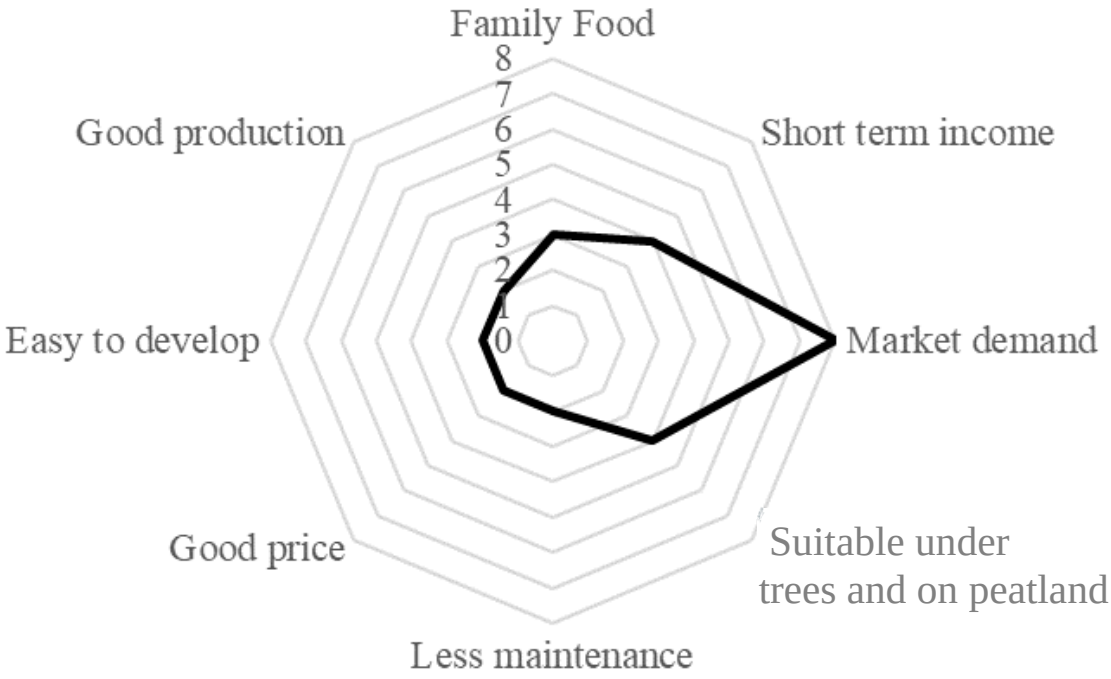

Figure 5. Radar graph summarising farmers' reasons for adopting intercropping.

Income from agroforestry

The range of informants' household incomes was USD 2277.00–9867.41 per year with an average of USD 5022.90 per year, or USD 189.75–822.28 per month with an average of USD 418.58 per month. Household income comes from various livelihood activities carried out by the informants, ranging from tree planting and agriculture to livestock husbandry and fisheries (tree nurseries, planting horticultural crops, secondary crops, raising goats, chickens and bees, and fishing), as well as other sources outside the agricultural sector (retirement, teaching, trading, guarding gardens). Table 3 provides information about incomes from agroforestry at the research sites.

All informants obtained income from agriculture, animal husbandry and fisheries although in widely differing proportions ranging from 3.7 % to 100 % of total income. Farmers in Kalampangan Village who apply intensive agriculture on the areas between trees earn 76.9 % of their total annual income from intercropping, while farmers in Tumbang Nusa Village earn less than this (47.3 %). Only five informants had earned income by selling jelutung seeds or seedlings (contributions of 4.1 %, 21.4 %, 31.0 %, 34.6 % and 42.0 %, respectively). However, all informants believed that planting trees was a form of saving or long-term investment that would provide economic benefits for their households in the long run. Comparing between the two research locations, Kalampangan Village - which practises intercropping more intensively and earns income by selling products from jelutung trees - had a higher average income (USD 5567.66 per year) than Tumbang Nusa Village (USD 4555.97 per year).

The financial analysis indicated that the cultivation practices making up this pattern of agroforestry do provide net benefits. The full range of results from the BCR calculation was 0.61–10.32, and only one farmer (Informant 3) had a BCR below unity (0.61).

Table 3. Annual income and sources of income of individual informants in each village. The conversion factor from USD to Indonesian rupiah (IDR) is 1USD = IDR 14,492.15.

	Informant No.	Agroforestry				BCR	Others		Total
		Trees		Agriculture, animal husbandry, fisheries					
		USD	%	USD	%		USD	%	USD
Kalampangan Village	1	1104.05	21.37	1992.46	38.56	7.03	2070.09	40.07	5166.38
	2	0	0	3622.65	100.00	1.65	0	0	3622.50
	3	4140.17	41.96	5727.24	58.04	0.61	0	0	9867.41
	4	1552.56	30.95	3464.50	69.05	3.51	0	0	5017.06
	5	0	0	3036.54	100.00	2.52	0	0	3036.54
	6	276.01	4.12	6420.03	95.88	10.32	0	0	6696.04
	Average	1178.80	16.40	4043.90	76.92		345.02	6.68	5567.66
Tumbang Nusa Village	7	2070.09	34.64	2663.51	44.57	2.65	1242.05	20.79	5975.40
	8	0	0	2760.11	100.00	2.05	0	0	2760.00
	9	0	0	2001.08	44.62	5.20	2484.10	55.38	4485.00
	10	0	0	1035.04	29.41	2.01	2484.10	70.59	3519.00
	11	0	0	662.43	9.09	3.53	6624.28	90.91	7286.40
	12	0	0	2277.09	100.00	2.06	0	0	2277.00
	13	0	0	207.01	3.70	2.67	5382.22	96.30	5589.00
	Average	295.73	4.95	1658.04	47.34		2602.39	47.71	4555.97
Grand Average		703.30	10.23	2759.21	60.99		1560.53	28.77	5022.90

Values of peatswamp forest ecosystems

Peatland ecosystems have important values for all informants, which indicates that the ecosystem is very important for livelihoods within the local community. In general, there is a difference between the values for Javanese and non-Javanese farmers. Javanese who work solely as agroforestry farmers on peatland can earn income from these activities. On the other hand, for non-Javanese and especially Dayak people who have a strong culture as hunter-gatherers, the peatland is a source of vegetables and fish protein. These people collect kelakai (the edible fern *Stenochlaena palustris*), young pineapple (*Ananas comosus*) and crinum lily (*Crinum asiaticum*) as vegetables and catch fish as a side-dish protein source. Thus, peat and its aquatic ecosystem are very important for all people living in peat areas and must be maintained. One of the informants also relies on the peatland to provide feed for domesticated goats, especially the uyah-uyah (*Stemonurus secundiflorus*) plant.

Revegetation with local trees has shown success. According to the seven informants from Tumbang Nusa Village, most of the community have planted rubber trees in their household environments. Rubber was also cultivated in the original village of Tumbang Nusa on the banks of the Kahayan River, where the alluvial soil meant that less intensive management was required. The main plant required for the Forest Research Agency's 'Repeat' rehabilitation area in Tumbang Nusa Village and Sebangau National Park is belangiran (*Shorea belangeran*). Informant 9 had established a local nursery for seedlings of *Shorea belangeran* as well as other trees such as *Alstonia pneumatophora* and meranti (*Shorea* spp.). Several agroforestry actors still have their own tree nurseries to this day. Apart from selling seedlings of these trees, they also planted seedlings to raise on their own farms.

There is a community tree nursery in Tumbang Nusa but not in Kalampangan. Nurseries are usually located near people's homes and are established for commercial purposes, usually in collaboration with the Provincial Forestry Agency or the Forestry Research and Development Centre in Banjarbaru who need tree seedlings for land rehabilitation activities. Nursery activities are carried out by the community, including respondents who are not agroforestry actors. Some of the stock is raised from seed collected in natural forests around the village at the end of the flowering period, while jelutung trees are purchased from farmers who have jelutung plantations.

All informants agreed that drainage was important for crop cultivation within agroforestry, and all of them made and used drainage channels. Only one was still experiencing a problem with crop output due to his relatively low-lying land being subject to periodic flooding, especially during the rainy season. However, these farmers used polybags for seasonal crop cultivation. For the people of Tumbang Nusa, an abandoned irrigation channel from the former Mega Rice Project provided an additional source of income in the form of purun (*Lepironia articulata*) plants which were used to manufacture 'green' drinking straws.

All informants appreciated the comfort provided by trees in the agroforestry system, in the form of beauty, shade and inner calm. Fresh air and comfortable temperatures improved the environment, and some farmers utilised this for *kelulut* (stingless bee) farming while others planned to exploit it for ecotourism. Table 4 shows the value of growing trees for all respondents.

Institutional support

Based on the interviews, one factor contributing to sub-optimal agroforestry management is the low income obtained from agroforestry farming activities and the absence of initial support from the government. Nonetheless, in the experience of four informants, the intended initial assistance (seeds and fertilisers) did turn out to support community participation in agroforestry.

Thus, supporting institutions are important for farming activities. The views of informants about the availability and role of institutions in supporting agroforestry management in the two study villages are summarised in Table 5. From this assessment it becomes clear that the rural supporting institutions are insufficient to support sustainable agroforestry management in the study area.

Points that emerged from an interview with a forestry sector stakeholder are summrised as follows:

(1) To increase success in the implementation of peatland revegetation, the government should carry out integrated peat restoration involving rewetting, revegetation and livelihood revitalisation in the same location, with support for upstream to downstream facilities and opening up of markets for the products produced to provide economic benefits for the community. The success of government intervention in the implementation of revegetation could be measured by four indicators, namely: governance, ecology, economy and social.

(2) In order to provide encouragement and motivation to the farmers involved, incentives should be given in the form of easy access to seeds, fertilisers and other agricultural materials.

Table 4. Reasons for and benefits of planting trees, based on interview responses/

	Informant No.	Benefits of planting trees
Kalampangan Village	1	Whether or not direct benefits are realised from the trees, they produce oxygen and make the environment cool. I think plants and trees play an important role in life on Earth, making the planet habitable. Agroforestry is essential because disasters, floods and landslides are occurring everywhere due to disturbed ecology, and trees can be planted for mitigation. Planting trees alone is restoration, and the agroforestry system benefits me because it produces year-round returns, giving hope in every timeframe: short-term chilli and vegetables, medium-term cassava, and long-term *Dyera* sp. fruit. Below the ground is cassava, above the ground there are chillis and vegetables, and above those crops there is *Dyera* sp. fruit.
	2	Currently I benefit from the extraordinary results of selling jelutung fruit. I have bonded with the jelutung tree that I planted and will not cut it down, but only take the fruit to sell. The benefits of planting trees will be felt for a long time; the Dayak people who travel abroad will come back and remember this tree that was planted in the past as a marker and a link to family relationships.
	3	The trees keep the environment sustainable, and provide economic benefits in the medium term (jelutung latex) and in the long term (trees).
	4	In addition to advantages to the environment, planting trees is an investment that provides medium-term returns in the form of saleable seeds 2–3 times a year and long-term returns in the form of wood.
	5	Trees provide protection, and a long-term investment by producing wood; although you can't enjoy it now, it will be enjoyed later for posterity.
	6	Planting trees is good for preserving the environment. On the economic aspect, I am hoping to get benefits from jelutung in the form of seeds that can be sold, the sap can be sold easily (markets or buyers are available), the wood can be used for furniture, and I get agarwood from the agarwood trees.
Tumbang Nusa Village	7	The coolness of the trees provides a shady environment and comfortable atmosphere that will encourage people to visit for study, research and travel, and so ultimately provide economic benefits for us.
	8	Long-term investment because it has economic value; trees also protect the environment by preserving the soil and averting land and forest fires.
	9	Long term investment; protecting the environment / averting forest and land fires; there is a plan to make a tourist spot.
	10	Although planting trees has not provided economic returns, the trees provide comfort, coolness and fresh air.
	11	Planting trees has been done for a long time, especially by those who produce e.g. fruit and rubber trees for their own consumption or for sale; and planting trees make the environment fresh, shady and comfortable.
	12	Trees are a long-term asset which will be enjoyed by my children and grandchildren. They provide long-term investment (trees); and short-term income, e.g. from rambutan (*Nephelium lappaceum*).
	13	The trees are a long -term investment that will be realised in the form of wood products. Possibility of developing environment-based tourism in the area planted with trees.

Table 5. Perceptions of the quality of support in agroforestry management provided by various institutions. The number of respondents who chose each option is shown in brackets. The total number of respondents was 13 (6 from Kalampangan and 7 from Tumbang Nusa).

Institutional support	Kalampangan			Tumbang Nusa		
	Low	Moderate	Good	Low	Moderate	Good
Production (Farmers' Institutions)			X (6)	X (7)		
Production Facilities Provider (Kiosk, Co-operation-KUD)		X (5)	X (1)	X (5)	X (2)	
Extension Institution		X (4)	X (2)	X (6)	X (1)	
Capital Service Institutions (Farmers' cooperatives, savings and loan groups, joint business groups, small and medium enterprises)		X (4)	X (2)	X (7)		
Marketing (village market)		X (6)		X (2)	X (5)	
Agricultural Mechanisation Service (tractor, huller)	X (5)	X (1)		X (7)		

(3) In addition to facility support, farmers need to be given knowledge and assistance with selecting seeds and crop types to harvest and market.
(4) Extension agents are needed as the spearhead of programme implementation, for both knowledge transfer and mentoring. Field extension officers in the forestry sector come from the Forest Management Unit (Kesatuan Pemangku Hutan, KPH) but their number and distribution are limited. Therefore, it is necessary to cooperate with field extension workers at the Agricultural Mechanisation Service.

DISCUSSION

The practice of agroforestry on peatland

Agroforestry systems have long been employed in Indonesia, ever since the shift in human livelihood support from hunting and gathering to agriculture (Penot 2004, Penot *et al*. 2017). In Central Kalimantan, agroforestry was incorporated into shifting cultivation (swidden) systems, where people planted trees in fields that would be abandoned so that these areas continued to generate some benefit to communities and individuals. They used species such as rubber (*Hevea brasiliensis*), durian (*Durio zibethinus*), rambutan and langsat (*Lansium domesticum*). Communities have also traditionally planted trees as fences and to mark land boundaries in their yards.

Swidden agriculture was carried out primarily by Dayak people (Nopembereni *et al*. 2018, Silvianingsih *et al*. 2020) on shallow peat along riverbanks or in backswamps; this was the practice of the inhabitants of Tumbang Nusa village. With the construction of a state road connecting the cities of Palangka Raya in Central Kalimantan and Banjarmasin in South Kalimantan, people who initially lived in riverside villages and worked on river embankments gradually moved to the sides of the highway and commenced agricultural activities in the areas around the new settlements. In our study, seven farmers from the village of Tumbang Nusa were operating in this new agricultural setting. In contrast, the ex-transmigration community in Kalampangan Village, who originate from Java, are accustomed to intensive agricultural cultivation and have never carried out shifting cultivation activities.

In general, our informants cultivate areas with a peat layer > 3 metres deep which, in terms of soil fertility, is classified as marginal, requiring intensive fertiliser inputs to support development for agriculture. All respondents stated that when land clearing started, plant growth was not good without fertiliser applications, especially of manure and NPK fertiliser. Plant growth in peat soil certainly suffers from fertility problems. Alwi & Hairani (2007) and Harun *et al*. (2020) both state that peat soils have low fertility, including low pH and low nutrient levels, especially of the elements N, P and K. Also, the cation exchange capacity (CEC) is very high but base

saturation is very low (Salampak 1999, Harun *et al*. 2020). The fertility of peat soils depends on their maturity. The application of fertiliser has antagonistic effects; it may support plant growth, but also increases the rates of peat decomposition, peat subsidence and GHG emissions (Husnain *et al*. 2017, Khasanah & van Noordwijk 2019, Anshari *et al*. 2021). High inputs of fertiliser are required to improve the land sufficiently to achieve adequate plant growth and production, as practised by the informants with Javanese ethnic backgrounds. They report significant differences in success between agroforestry systems based on local native trees and those utilising other species deemed suitable for forestry, agroforestry and agro-food in the Indonesian climate and in Central Kalimantan (Table A3). In particular, Informant 9 initially planted sengon (*Falcataria moluccana*) trees which did not grow well.

The agroforestry practices developed by the informants vary, depending on their understanding and experience. Farmers in Kalampangan practice intercropping, combining trees with secondary crops. In these systems, the trees are arranged to admit sufficient sunlight to support vegetable crops planted between the trees. On the other hand, informants in Tumbang Nusa mix only woody plant species; they grow *Dyera* sp. or rubber (*Hevea braziliensis*) with rambutan, and alternating single-species rows of trees such as belangiran (*Shorea belangeran*), pulai (*Alstonia* spp.), tumih (*Combretocarpus rotundatus* (Miq.)), mulberry (*Morus alba*) , jelutung (*Dyera* sp.) and gemor (*Alseodaphne* sp.) on a different area of land. Vegetables are not intercropped with trees, but are planted separately using a monoculture cropping pattern. The main reason for not intercropping vegetables with trees is that the trees are planted more closely than in Kalampangan, to suit the land conditions and mimic the spacing of trees in the forest. According to Rotinsulu *et al*. (2022), farmers develop different types of agroforestry depending on peat depth. Most of them plant endemic trees including rubber (*Hevea braziliensis*), gelam (*Melaleuca leucadendra*) and gerunggang (*Cratoxylum arborescens*), intercropping with vegetables and fruits, on shallow peat; rubber, annual crops and fruits on medium-depth peat; and fruits and rubber on deep peat.

All informants know about and understand the use of both inorganic and organic fertilisers to increase peatland productivity. However, they agree that crop suitability is the main criterion for selection of trees, which should grow well without intensive maintenance and fertilisation. Although they applied limited amounts and types of fertiliser to their existing trees at the time of planting, in future they will adopt the principle that the trees will receive some of the fertilisers applied to intercrops, especially those grown seasonally in the spaces between trees.

Farmer institutions have a real influence on the success of agroforestry crop cultivation, especially seasonal crops such as vegetables and fruits, as shown by ex-transmigration farmers in the Kalampangan area. Farmer institutions play a role in providing cultivation facilities, including means for distributing subsidised fertilisers and sharing experience in plant cultivation practice. Based on information from the head of the Kalampangan forest farmer group, who is also a respondent, that group specifically initiates tree cultivation and honey bee husbandry. On the other hand, there are no active farmer groups in Tumbang Nusa where, especially in peat areas, the farmers adopt plant cultivation methods from Kalampangan, including the use of labour from Kalampangan. Firmansyah *et al*. (2017) suggest that farmer institutions have a role in solving farming problems, disseminating information and farming technology, and in providing a place for group members to collaborate both amongst themselves and with outside parties.

Motivation of agroforestry farmers

Motivation is important in the adoption process. However, it is not easy to inspire motivation amongst small-scale farmers due to the limitations imposed by their land resources, knowledge and skills. We observed that the strength of motivation varies between individuals. The strongest (dominant) motive is the one that is the main cause of individual behaviour at any given moment. The relative strengths of the motives that are controlling a person in general can be gauged on the basis of: (1) strong will to do; (2) the amount of time invested; (3) willingness to prioritise over other obligations or duties; (4) willingness to pay for the sake of that action; and (5) persistence in doing the task. Farmers who want to increase their income will work hard, spending most of their time farming. The motivation of farmers may also be a factor in determining whether available technology will be accepted or rejected; farmers who are motivated by outside influences take the technology that is provided to them seriously (Soekartawi 1988).

In the case of agroforestry farmers on peatlands in the research location, they are more driven by economic motives. Thus, agroforestry farmers who are proven to persist in implementing agroforestry have a strong desire to maintain agroforestry activities and devote sufficient time, farming as they would in non-agroforestry agriculture. Farmers are

also diligent in learning from the initial guidance provided by the Banjar Baru Research and Development Agency and also from experience gained during agricultural activities using an agroforestry pattern. Some farmers even combine plant cultivation with other activities such as kelulut (honey bee) and livestock (goats, cows) husbandry. In the long term, farmers hope to earn income from wood, latex and even non-extractive sources such as tourism. Meanwhile, in the short term, income is obtained from intercropping, which is generally involves growing short-lived crops chosen according to market demand. Agroforestry farmers who aim to perpetuate maximum results from short-lived intercrops set the trees at wider spacings so that intercrops still get optimal sunlight for their growth.

Another study, by Sagastuy & Krause (2019), revealed that there are four main reasons why farmers implement agroforestry cultivation patterns, namely to increase income, diversify production systems, improve land quality and productivity, and increase self-sufficiency. Meanwhile the three most common reasons cited by conventional farmers for not switching to agroforestry were uncertainty over whether the system would be successful, declining yields of key agricultural crops, and lack of models and knowledge within the region.

Income from agroforestry

The development of *Dyera* sp. as part of an agroforestry system has better economic feasibility than planting the same tree in monoculture, because the benefits received from intercropping are quite large. In this study, the individual BCR values for twelve agroforestry actors were >1 and only one had a BCR of < 1. The BCR of the agroforestry system ranged from 0.61 to 10.32, which reflects the variation in benefits obtained from different intercropping combinations. The variations in BCR are influenced by intercropping business activities, which include the components of production inputs and commodity selling prices. Although the types of plants cultivated are the same, the use of different production inputs affects the BCR value, as does the selling price received by agroforestry farmers - which is largely determined by middlemen. The production inputs that are very influential are the use of fertilisers, herbicides and labour, and fertilisers account for the largest element of production expenditure. Intercropping conducted using in-family labour and optimal fertilisation gives a better BCR. The greatest benefit (BCR = 10.32) was obtained by combining tree components with pineapple, celery, spinach and kangkung (*Ipomoea aquatica*) intercrops. Pineapple planting provides great benefits for farmers because it requires no fertiliser and minimal maintenance, and it is adaptable and grows well on peatlands. The lowest benefit (BCR = 0.61) was attained from a combination of trees, tomato and corn crops, and livestock (cow) farming. The investment value of purchasing cattle exceeds the profit earned, which affects the overall BCR. Another component that influences the BCR is the selling price of the commodities produced. Agroforestry actors sell their agricultural products through traders who aim to make profits and largely determine the selling price. When a commodity is abundantly available in the market, the price received by agroforestry actors is very low because they share profits with the collecting traders. When compared with vegetable farming on peatlands, the BCR value in agroforestry patterns is greater than in monoculture with a BCR of 2.12–10.08 (results of reprocessing Sustainpeat Project data). This is possible because some agroforestry farmers still benefit from selling *Dyera* sp. fruit. Harun (2011) showed that *Dyera* sp. and the rubber agroforestry system has a Net Present Value (NPV) of USD 4816.36, Benefit-Cost Ratio (BCR) 8.68 and Internal Return Rate (IRR) 29. The calculations of Budiningsih & Effendi (2013) for agroforestry systems generally generate USD 638.10 for NPV, 5.35 for BCR and 24.1 for IRR.

The Biro Pusat Statistik (BPS 2020a, BPS 2020b) classifies the income of the Indonesian population into four categories based on the average monthly income, namely: very high (more than USD 241.51), high (USD 172.51–241.51), medium (USD 103.50–172.51) and low (less than USD 103.50). On this basis, eleven informants had very high incomes and the other two belonged to the high income category. In general, informants practising agroforestry on peatlands are included in the very high income category. Their average monthly income of USD 376.67 also exceeds the minimum wage for the districts of Palangka Raya and Pulang Pisau. This income is higher than the average monthly income of USD 308.26 achieved from the combination of land-based and non-land-based businesses on peatlands investigated by Surati *et al*. (2019), who also suggested the development of agroforestry systems adapted to the biophysical conditions of peatlands. Despite showing a very high level of income, only five informants obtained results from planting trees by selling *Dyera* sp. fruit/seeds, with a contribution to income of 10.2 %. The limited market for fruit/seeds and non-availability of the *Dyera* sp. latex market were concerns expressed by informants in relation to the development of agroforestry systems. Therefore, the selection of tree species for agroforestry developments should pay attention not

only to the biophysical suitability of the peatland environment, but also to the economic value and availability of markets.

Agroforestry in the context of peat conservation and peatland rehabilitation

The tendency of local communities to clear peatland for agriculture is certainly detrimental from the perspective of peat resource conservation. According to respondents, the Tumbang Nusa area experiences forest and land fires every dry season, with various negative consequences. Forest and peatland fires in Central Kalimantan, including the Tumbang Nusa Village area, have occurred since 1973 (Hoscilo *et al*. 2011) and even up to 2015 (Yulianti *et al*. 2020). On the other hand, the Kalampangan area never experienced forest and land fires, except in a new area called Jalan Misik, before it was opened for agricultural activities after the 2015 fires. The Kalampangan transmigrant farmer community, established in 1979–1980 (Jaya *et al*. 2002), took about ten years to adapt to the poor quality of peat soil and successfully cultivate crops using ash from weeds and peat as fertiliser; although nowadays the use of manure and artificial inorganic fertilisers is becoming more prominent. The newer part of Kalampangan village, known as Kalampangan Misik, has experienced substantial fires during most dry seasons. After the 2015 fires, the area was developed for cultivation of (mostly) vegetables and fruits.

Agroforestry farmers in Kalampangan Village who are ex transmigrants from Java generally use knowledge about plant cultivation based on their own previous experience of farming in peat areas before they converted to agroforestry activities and, in general, expect to use fertilisers. They learned quite inadvertently that peat soil can be improved by applications of ash so that various plants (as shown in Table 2) can be grown. When jelutung trees are planted for agroforestry purposes, 1–1.5 kg of manure is initially applied as a fertiliser (Jaya *et al*. 2021). On the other hand, the Dayak community and some local migrants have traditionally used deep peatlands for fisheries, especially capture fisheries (fish ponds). In the research area in Tumbang Nusa Village and other villages in Central Kalimantan, natural deep peat areas are used for capture fishery. Fish species found in the area include lele (Blackskin catfish, *Clarias meladerma*), Haruan (Striped snakehead, *Channa striata*), sepat (*Trichopodus pectoralis*), papuyu (Climbing perch, *Anabas testudineus*), kapar (*Belontia hasselti*), toman (Giant snakehead, *Channa micropeltes*) and karandang (*Channa pleurophthalma*) (Nurseptiani *et al*. 2021), which are either acquired and sold for income or consumed. Amongst the respondents, one farmer cultivates swamp fish using a karamba (cage) system which is placed in canals on his own land. Yuptriani *et al*. (2020) stated that peat areas were a source of livelihood for the community because they provided income from fishing. However, the views of Dayak people have been affected by their perceptions of the success of farmers cultivating peatland (Fransiska *et al*. 2020).

An important component of many of the farmers' agroforestry systems is jelutung rawa (*Dyera polyphylla* (Miq.) Steenis). Because this plant grows naturally on inundated land and is adapted to grow in tropical peat swamps, it is compatible with land management that benefits the environment and is thus very well suited for peat rehabilitation agroforestry systems (Harun 2016). The wood can be processed into blocks or boards, plywood and wood pulp; the sap can be tapped and sold in blocks or sheets that can be used as an insulator for electrical cables, as well as in tyres and gum; while the resin can be used in cosmetics, varnishes and essential oils (Tata *et al*. 2015).

The decline or loss of the original peatland forest cover is linked with lowering of the water table (Wösten *et al*. 2006, Sumarga *et al*. 2016, Uda *et al*. 2017, Cooper *et al*. 2019), which affects characteristics of the peat soil including the decomposition process and compaction. The result is land subsidence (Sherwood *et al*. 2013, Evans *et al*. 2019) associated with an increase in bulk density (Sinclair *et al*. 2020). In general, farmers do not realise that trees are an important factor for peat conservation. This emerged when they were asked if they knew that the surface of peatland subsides due to decomposition following opening of the peat swamp forest. All agroforestry actors stated that they were not aware of this consequence.

In the future, additional activities that utilise the value of environmental services provided by forest areas for tourism should be considered.

RECOMMENDATIONS

1. The main motivation in starting agroforestry activities is a farmer’s understanding that in the future there will be limited trees and that planting trees with a combination of intercrops can provide an adequate income. Thus, actors who devote considerable time to agroforestry can meet the economic needs of the family. Government support, especially in initiating peatland rehabilitation using agroforestry, is important, but the government and its agencies

should study the performance of each crop under local conditions before recommending widespread use by smallholders. Government support can be provided in the form of seeds and other supporting facilities such as fertilisers and agroforestry cultivation guidance as well as creating a market for products such as jelutung latex. To promote successful tree planting for agroforestry, it is important to understand the characteristics of trees in terms of how they adapt to peatland conditions, as well as to test or improve trees locally (Tata & Susmianto 2016).

2. Restoring degraded peatland requires the re-establishment of vegetation cover which increases humidity, lowers temperatures and reduces fire risk. The appropriate approach to revegetation depends on the level of peat degradation that has occurred. Where peat swamp forest vegetation is still present, hydrological rehabilitation alone may be sufficient to allow natural regeneration of the forest, as long as the area is protected from tree cutting and fires. However, if only a few trees remain, enrichment planting is necessary. If fire has occurred in most of the area, then ecological rehabilitation involving both hydrological rehabilitation and replanting will be required. Species found adjacent to and within protected or conserved areas of ecological importance should be included in the species mix. Revegetation programmes located near settlements should utilise peat swamp species that can provide economic benefits such as sago (*Metroxylon sago*), jelutung (*Dyera* sp.), gelam (*Melaleuca leucadendra*) and *Alseodaphne* sp. However, trees planted for revegetation purposes take a long time to reach their productive stage (Giesen & Sari 2018). From this research, the trees of *Dyera polyphylla*, *Shorea belangeran*, *Alstonia scholaris*, *Combretocarpus rotundatus* and *Alseodaphne* sp., grew well and could be managed by agroforestry farmers. Uda *et al*. (2020) found that the best choices of crop plants were sago (*Metroxylon sago*), banana (*Musa paradisiaca*) and pineapple (*Ananas comosus*), followed by water spinach or kangkung, macaque or edible fern (*Stenochlaena palustris*), ilip nuts or tengkawang (*Shorea* spp.), dragon fruit (*Hylocereus undatus*), mangosteen (*Garcinia mangostana*) and sweet melon (*Cucumis melo*). Sago and ilip nuts have market sustainability and scalability, while bananas, pineapples and sweet melons have market scalability and farmer acceptability.

3. The role of farmer institutions in supporting and encouraging more sustainable land use is not functioning optimally. Also, relevant economic institutions have not provided optimal support for marketing. Indeed, there is no evidence that any support institutions function effectively in the research area; such as the information technology and extension services, the providers of production facilities (Kiosk, KUD = Village Unit Cooperatives), and the financial, marketing and agricultural labour institutions. Thus, the benefits received by farmers are relatively low, although institutional support in Kalampangan is generally better than in Tumbang Nusa (Table 5). The results of our study indicate that all of the supporting infrastructure needs to be improved, including farmers' access to funding and production facilities.

4. The success rate of peatland revegetation programmes carried out by Indonesian communities is rather low (Nurohman *et al*. 2019) with a low tree survival rate. The main cause is associated with the marginal agronomic characteristics of peatlands. Our study has shown that government intervention through tree planting programmes stimulates agroforestry activities and these can yield good income for farmers. However, many farmers and communities are still not adopting the agroforestry principle of combining the cultivation of profitable trees and intercrops in peatland areas. Agroforestry will have a better chance of adoption if farmers can demonstrate that it can produce crops with high economic value. To further support uptake, the agriculture and forestry agencies should compile a comprehensive rationale for agroforestry as a solution to the conservation and rehabilitation problems in tropical peatlands.

5. The way that degraded land is used is important and requires attention. For peat conservation and fire prevention, the government can direct the use of degraded land so that it becomes productive land, although it cannot be managed too intensively. Agroforestry and agricultural activities still cause peat subsidence of 0.41–3.21 cm yr^{-1} (Evans *et al*. 2021), which may increase flood risk. Peatland can otherwise be used for animal-based enterprises such as bee husbandry, fish and goat farming. Intercropping can be adapted for areas with shallow water table by applying the principles and techniques of paludiculture (Tan *et al*. 2020).

6. In agroforestry practices, land management is still carried out with the main objective of peatland drainage so that the oxygen needs of plants can be met (Dariah & Nurzakiah 2014). Drainage can also improve the physical properties of the peat and remove some phytotoxic organic acids. On the other hand, drainage is antagonistic to conservation of the peat deposit because it promotes decomposition and greenhouse gas emissions. It also makes peatlands vulnerable to fire. Therefore, peatlands under agroforestry should generally be managed to minimise the need of drainage.

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AUTHOR CONTRIBUTIONS

The joint first authors AJ and AE led the study, and drafted the manuscript with EUA; AJ, EUA and MO undertook data collection and analysis. SD directed the data analysis and GII and YS provided input on peatland fertility and the final improvement of the manuscript. All authors were involved in the study and read, commented on and contributed to the final manuscript.

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Editor: Olivia Bragg

Author for correspondence: Dr Adi Jaya, Faculty of Agriculture, University of Palangka Raya, Jalan Yos Soedarso, Kompleks UPR Tunjung Nyaho, Palangka Raya 73112, Indonesia. Email : adijaya@agr.upr.ac.id

Appendix

Questionnaire for study of agroforestry farming for tropical peatland conservation and rehabilitation in Central Kalimantan, Indonesia

Introduction

Hello, my name is _____. I am speaking to you as part of Agroforestry Research. This research is being carried out by a research team from the University of Palangka Raya so that we can learn more about the environment, agroforestry farming practices and the income from these activities. We invite you to participate in this research as respondents who are expected to provide a brief explanation by answering questions about your identity, family, work and agriculture in your area. Your involvement in this survey is completely voluntary, and you have the right to stop the interview at any time. You also have the right not to answer the questions we ask. Your identity will not be known from the information provided, and the information we receive will be treated strictly confidentially. Such information will only be used as part of this research study and will be stored securely. It is hoped that the results of this research will be used to identify methods of agroforestry cultivation as a way to conserve and rehabilitate peatlands.

Date:

Time:

Village:

LIST OF QUESTIONS: AGROFORESTRY PRACTICES IN CENTRAL KALIMANTAN

I. Identity of respondent

1. Name : _____
2. Age : _____ years
3. Education : _____
4. Ethnicity : _____
5. Address : _____
6. How long have you lived in this village : _____ years
7. Livelihood :
   a. Main job : _____
   b. Other job : _____
8. Estimated income per month : Rp. _____
9. Number of family members : _____ person

II. Agricultural practices

10. How long have you been a farmer? _____ years
11. What is the ownership status of the land that you use for farming?
    a. Owned
    b. Rented
    c. Borrowed
    d. Other _____
12. How much land is cultivated for agriculture? ____hectare
13. Please describe the agricultural system used, including the agroforestry pattern
    a. _____
    b. _____
    c. _____
    d. _____

14. What is the most frequently/dominantly planted type of intercrop and why? Give an estimate of the profit earned.

No.	Crops	Reason for choice	Estimate of the profit (Rp)
1.			
2.			
3.			
4.			
5.			

15. Please describe the costs and income of each type of plant.

Crops	Planting frequency/year	Cost (Rp)										Production (kg)	Price (Rp)
		Seeds	Lime	Fertiliser			Pesticide			Manpower	Irrigation		
				1	2	3	1	2	3				
1.													
2.													
3.													
4.													
5.													
6.													

16. What is the pattern of farming system/model that you have developed?
    _____
    _____
17. Does the developed pattern provide an advantage?
    a. YES, because of the advantages: _____
    _____
    b. NO, because of the disadvantages: _____
    _____
18. Is the system/model used in accordance with the soil conditions?
    a. YES
    b. NO
19. Do you know the type of land being cultivated (Peatland/wetland/swampland, dry land, etc.)? If yes, please state type: _____
20. In your opinion, is peatland development fertile or not? What are the obstacles to farming on peatlands? _____
    _____
21. In your opinion, what is the use of the peat swamp forest around this village?
    _____
    _____

III. Understanding of agroforestry

22. What do you know about the agroforestry model as a form of forest management or timber trees with short-term commodity crops?
    _____
    _____
23. When did you start your agroforestry activities and from whom did you learn about agroforestry? What tree did you plant?
    _____
    _____
24. What motivates you to cultivate with this agroforestry pattern, especially planting trees?
    _____
    _____
25. In your opinion, can agroforestry be applied as the pattern or system of farming in the area currently being worked on?_____
    _____
26. Do you want to expand the agroforestry pattern/system?
27. a. YES, because: _____
    _____
28. b. NO, because:_____
    _____
29. Can you name the institutions that support agricultural activities in this village and what do you think about the quality of their support?
    _____
    _____
30. What is the role of these institutions or institutions in supporting the implementation of agroforestry development? The institution concerns a. Production, b. Production Facilities provider (Kiosk, Co-operation-KUD), c. Extension Institution, d. Capital Service Institutions, e. Village Market and f. Agricultural Mechanization Service (Tractor, huller).
    _____
    _____
31. Do you know other farmers who carry out agroforestry as you do, in this village?
    _____
    _____

Table A1. Characteristics of informants.

	Informant No.	Age of informant (years)	Highest level of formal education	Additional training	No. years resident in the village	Ethnic group	Main job	Other job	Number of family members
Kalampangan Village	1	68	Diploma 2	none	40	Javanese	retired teacher	farmer	4
	2	58	no school	none	40	Javanese	farmer	none	4
	3	64	Senior High School	none	40	Javanese	farmer	none	7
	4	74	no school	none	40	Javanese	farmer	none	2
	5	66	Primary School	none	40	Javanese	farmer	none	4
	6	53	Senior High School	none	32	Javanese	farmer	District Social Team	3
Tumbang Nusa Village	7	64	did not graduate from Junior High School	Land and Forest Fire Control	64	Dayak	farmer	none	3
	8	59	Senior High School	Land and Forest Fire Control	59	Lampung	farmer	Village Land and Forest Fire Control Team	2
	9	49	did not graduate from Junior High School	Land and Forest Fire Control		Dayak	farmer	trade / shop	2
	10	60	Primary School	none	60	Dayak	fruit seller	farmer	3
	11	47	undergraduate	none	47	Dayak	teacher	farmer, trade / shop	3
	12	43	Secondary Engineering School	none	53	Dayak	farmer	trade / shop	4
	13	43	Junior High School	Land and Forest Fire Control	53	Dayak	farmer	trade / shop, motorcycle workshop	5

Table A2. Trees planted as part of agroforestry in Central Kalimantan. Sources: Indartik (2009), Nugroho (2012), Nugraha *et al*. (2013), Febrian (2014), Tata & Susmianto (2016).

Tree	Uses	Advantages and disadvantages
jelutung (*Dyera polyphylla*)	Produces latex; source of raw materials for chewing gum and handicrafts; raw materials for pencils and furniture.	Grows naturally in (and well adapted to) flooded swamps; the main obstacle is limited availability of markets for latex products.
belangiran (*Shorea belangeran*)	Strong wood for building materials.	Grows well under conditions of moderate inundation; is relatively fire resistant and readily produces new shoots after a fire; has high tolerance for various conditions of degraded peat forest; propagates by seed, natural shoots, and vegetatively from shoot cuttings. The growth rate is quite slow.
gemor (*Alseodaphne* spp.)	Basic ingredients for mosquito repellent, incense and adhesives.	Adaptive to inundated peat swamps and has economic value.
pulai (*Alstonia pneumatophora*)	The wood can be used as a raw material for handicrafts, pencils, blackboards and cabinets; the bark, leaves and flowers can be used as medicine.	Scattered distribution throughout Indonesia, adaptive and grows naturally in swamps.
tumih (*Combretocarpus rotundatus*)	The wood is used for frames, door panels, windows, furniture, parquet flooring and stairs.	Grows naturally in, adaptive and suitable for peat swamp areas; relatively resistant to fire.
rubber (*Hevea braziliensis*)	Besides latex, rubber products include wood (timber), charcoal and particleboard, gypsum and parquet boards (flooring), furniture, plywood and reconstructed wood.	Rubber is commonly cultivated by the community although it needs development to get good production.
sengon (*Falcataria moluccana*)	Insulation board, cement casting, match industry, pencil manufacture, particle board, and paper pulp industry raw materials.	Less adaptive and less suitable for peat swamp areas; improvement in land quality still in the marginal category.

Table A3. Motives of the 13 informants for conducting agroforestry on peatlands at Tumbang Nusa and Kalampangan Villages. No. = Informant No.

No.	Reason for planting trees	Types of agroforestry	Reasons for planting intercrops	Advantages of the agroforestry system	Disadvantages/weaknesses of the agroforestry system
1	1. Introduced by Forestry Research and Development (R&D). 2. Suitable for development on peatlands. 3. Long-term investment for seeds, latex and trunk/wood.	1. Chilli. 2. Cassava. 3. Corn.	1. Food supply for family. 2. Source of short-term income that can be adjusted to fit market demand and thus secure good selling prices.	1. Provides food for family. 2. Provides short, medium and long term income. 3. Provides shade, comfort and fresh air for planting trees.	1. Jelutung root system can interfere with the growth of intercrops, but this has been anticipated by making a trench beside the jelutung plant to force downward rather than spreading root growth. 2. The spacing and direction of planting influences sunlight.
2	1. Planting trees as a long-term investment in a culture that has been taught since living in Java. 2. Jelutung was chosen because it adapts to the natural conditions that will be developed.	1. Leeks. 2. Spinach. 3. Mustard. 4. Vanilla.	1. The types of vegetables grown can be adjusted to fit current demand, so they are easy to market at a good price.	1. Provides short-term (vegetables and crops), medium-term (vanilla) and long-term (tree crops) benefits. 2. Protects environment, provides fresh air.	1. On the first land plot (0.25 ha) jelutung was planted with a spacing of 1.5 × 4 m so that intercrops could not be cultivated after three years (jelutung age is currently 15 years). Now vanilla plants (which require shade) will be planted as an alternative, for medium-term income. 2. The second land plot (1.5 ha) was planted with jelutung at wider (3 × 6 m) spacing so that several types of vegetable can still be planted as intercrops (*Dyera polyphylla*, age is currently three years).

No.	Reason for planting trees	Types of agroforestry	Reasons for planting intercrops	Advantages of the agroforestry system	Disadvantages/weaknesses of the agroforestry system
3	1. As a medium-term investment (jelutung latex), and long-term (trees). 2. Tried various types of trees including: gaharu and fruit (mango, orange, avocado, durian) but they didn't survive because the area was submerged, only jelutung was suitable). 3. Seeds received as assistance from Balai Pengelolaan DAS (BP DAS), Ministry of Forestry.	1. Cow. 2. Tomato. 3. Corn.	1. In accordance with market demand and suitable for cultivation under a jelutung tree.	Provide short, medium and long term income.	There is no loss from applying agroforestry.
4	1. Through farmer groups, received seed as assistance from BPDAS. 2. Long term investment.	1. Corn. 2. Spinach. 3. Mustard. 4. Kangkung. 5. Spring onion.	1. Market demand. 2. Can be planted beneath a jelutung tree.	Provide short, medium and long term income.	There are no disadvantages from the agroforestry system, because the spacing is set quite wide (10m × 5m), so that the intercropping plants still get enough sunlight.
5	1. Long term investment. 2. Received seed as assistance from BPDAS.	1. Spinach. 2. Mustard. 3. Lettuce. 4. Corn.	Market demand.	Provide short-term income (from intercropping), medium-term (Jelutung seeds) and long-term (latex and wood).	Intercrop production is less than optimal due to lack of sunlight due to the tight spacing of jelutung (5m × 3m).
6	1. Got seed as assistance from Banjar Baru Environmental and Forestry Research and Development Centre. 2. Hoping to benefit from jelutung in the form of seeds that could be sold, sap that could be sold easily (available in the market), and wood that could be used for furniture; from agarwood tree (*Lignum aquila*) to get gaharu.	1. Pineapple. 2. Kangkung. 3. Spinach. 4. Celery.	Market demand.	The harvest obtained from intercrops.	The selection of jelutung trees has not yet delivered results as latex and wood; because there is no demand or market for jelutung latex now, and the wood has a slow growth rate compared to other timber trees such as *Acacia*.

No.	Reason for planting trees	Types of agroforestry	Reasons for planting intercrops	Advantages of the agroforestry system	Disadvantages/weaknesses of the agroforestry system
7	1. Introduced by Forestry R&D. 2. Jelutung is suitable for development on peatland and an endemic tree; jelutung, hangkang and nyatu trees are plants that provide economic value to the Dayak community. 3. Planting trees as a long-term asset which will be enjoyed by my children and grandchildren, especially to source jelutung seeds.	1. Pineapple. 2. Goats. 3. Kelulut honey bees (*Meliponini*).	1. Pineapple does not require intensive maintenance and gives good results, but will not get enough sunlight after the jelutung plants reach an age of five years. 2. Goats are easy to maintain because they can find their own abundant supply of food. 3. The kelulut honey bee is easy to care for and has available food, the price is favourable, and marketing is easy.	1. Provides short, medium and long term income. 2. Provides shade, comfort and fresh air for planting trees.	1. *Dyera polyphylla* is grown at tight spacing with the intention that the root systems of different trees unite to prevent the trees from falling over. This means that tumpeng sari and other intercrops can no longer be planted after the tree canopy expands.
8	1. Long-term investment, because it has economic value. 2. Maintenance of the soil. 3. *Shorea belangiran* selected because it is suitable for planting on peatlands and has a low mortality rate. 4. Protecting the environment / avoiding land and forest fires.	1. Tree nursery for *Dyera polyphylla*, *Shorea belangiran*, *Falcataria moluccana*, *Shorea leprosula*, *Gonystylus bancanus*. 2. Chickens.	1. Market demand and good selling price. 2. Can be developed in the village.	1. Planting trees reduces land clearing, clean land reduces the potential for forest and land fires. 2. Provides fresh air.	1. The agroforestry system has no disadvantages / weaknesses, even though other plants are not grown between the trees.

No.	Reason for planting trees	Types of agroforestry	Reasons for planting intercrops	Advantages of the agroforestry system	Disadvantages/weaknesses of the agroforestry system
9	1. *Falcataria moluccana* was planted initially because the farmer was tempted to produce this species for the pulp factory that was being built in Pulang Pisau, but it did not provide good growth in two years. 2. Local tree species are appropriate; also support from Forestry R&D. 3. Long term investment. 4. Protecting the environment / avoiding forest and land fires. 5. There is a plan to make a tourist spot.	1. Pineapple. 2. Tree nurseries for *Dyera polyphylla, Shorea belangiran, Falcataria moluccana, Shorea leprosula, Areca catechu.* 3. Vegetables (long bean, chilli). 4. Fish cage (karamba) of local fish such as *Channa striata, Clariidae, Anabas testudineus, Belontia hasselti*.	1. Pineapple was planted because it is suitable for peatlands and not difficult to manage. 2. Tree nurseries because there is demand for seedlings every year. 2. Vegetables and fish cages are currently being developed and these trials will continue.	1. Agroforestry systems provide both short-term and long-term benefits.	1. Selection of plant types is important; selection of *Falcataria moluccana* trees because this resulted in very large investment losses (seeds, fertilisers and labour).
10	1. *Dyera polyphylla* seed programme from forestry R&D. 2. Trees provides comfort, coolness.	1. Chilli.	1. Suitable for the soil type. 2. Chilli has good market prices.	1. Planted trees provide comfort and coolness.	1. Other crops cannot be planted because they do not get sunlight.
11	1. Supporting the family economy; even though yield is small because it is influenced by price, the trees can provide a long-term income for children and grandchildren. 2. The farmer has experience in producing this commodity, developed from a young age. 3. Rubber offers a long-term income to meet the needs of daily life because it (and fruit trees such as rambutan) can give repeated harvests. Not planting new timber producing trees but maintaining existing ones.	1. Kelulut (stingless) honey bees.	1. Ten boxes of Kelulut house provided by Forestry R&D are currently being augmented because this species gives good results. 2. Will grow vegetable crops, both for own consumption and for sale.	1. A short term and long term investment.	1. No weaknesses or disadvantages have been identified.

No.	Reason for planting trees	Types of agroforestry	Reasons for planting intercrops	Advantages of the agroforestry system	Disadvantages/weaknesses of the agroforestry system
12	1. Suitable for growing on peatlands. 2. Trees are a long-term asset which will be enjoyed by children and grandchildren. 3. Directions from forestry R&D. 4. Long-term investment (trees); and short-term income (rambutan) although rambutan has not produced for the last two years. 5. Free land markers (alternative to trenches).	1. Tree nursery for *Dyera polyphylla, Shorea belangiran, Falcataria moluccana*. 2. Vegetables (kangkung, spinach, bitter gourd).	1. Intercrops meet daily / short term needs.	1. Provides family food (vegetables) as well as investment / savings in the form of trees.	1. Not yet providing results / income because latex has not been produced.
13	1. Planted *Falcataria moluccana* because the pulp factory in Pulang Pisau District provides a market. 2. Various kinds of fruit such as mango, rambutan and pineapple are grown because of government support. 3. Long-term investment and possible development of tourism.	1. Tree nursery for *Dyera polyphylla, Shorea belangiran, Falcataria moluccana*. 2. Vegetables (long bean, chilli, spinach, bitter gourd).	1. Easy to implement and can give good results.	1. Provides short, medium and long term income. 2. Planted trees provide shade, comfort and freshness. 3. Preferable to leaving the land to scrub because fire risk is reduced.	1. The agroforestry system has no disadvantages / weaknesses.