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Integrating bioenergy and food production on degraded landscapes in Indonesia for improved socioeconomic and environmental outcomes

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Abstract
Growing bioenergy crops on degraded and underutilized land is a promising solution to meet the requirement for energy security, food security, and land restoration. This paper assesses the socioeconomic and environmental benefits of agroforestry systems based on nyamplung (tamanu) (*Calophyllum inophyllum* L.) in the Wonogiri district of Central Java, Indonesia. Data were collected through field observations and focus group discussions involving 20 farmers who intercrop nyamplung with maize, rice, and peanuts and utilize the species in honey production. Calculating each crop's net present value (NPV) demonstrates that when grown as monocultures, staple crops rice and peanuts lead to negative profitability, while maize generates only a marginal profit; yet honey production utilizing nyamplung produces a NPV nearly 300 times greater than maize. However, when utilizing nyamplung, honey is also the commodity most sensitive to decreases in production, followed by nyamplung–peanut and nyamplung–rice combinations. While decreases in production have little effect on the NPVs of rice, peanuts, and maize, these annual crops can only be cultivated for a maximum of 6 years within the nyamplung's 35-year cycle, due to canopy closure after this time. Nyamplung-based agroforestry systems can provide economic, social, and environmental gains on different scales. However, when considering the high profit potential of nyamplung combined with honey production, further research is needed to improve and develop bee husbandry practices so this becomes a viable option for local farmers.

KEYWORDS
agroforestry, degraded land, farmer, income, nyamplung (tamanu)

1 | INTRODUCTION

Landscapes provide valuable environmental goods and services to humankind, from income sources to goods for consumption, like food, fodder, fuelwood, timber, and water (Lawrence & Vandecar, 2015). However, human land use practices, particularly agriculture expansion, also lead to land degradation and a reduction of these valuable environmental services (Babigumira et al., 2014; Alcamo et al., 2005; Millennium Ecosystem Assessment, 2005); this poses a serious challenge when aiming to end hunger and poverty, conserve biodiversity, and adapt to climate changes (Fleskens & Stringer, 2014; Sunderland, Ehringhaus, & Campbell, 2007). Given the finite amount of productive land available, how to ensure the well-being of our expanding population,[1] projected to reach close to ten billion by 2050, without depleting the resource base and destroying ecosystems, is a pressing question (Sunderland, 2011; UN, 2017). In this context, restoration of degraded lands provides an opportunity to increase the global resource base for sustainable production of food and commodities, while addressing current and future global challenges. Several recent initiatives, such as the Bonn Challenge, the New York Declaration on Forests, and the SDG's target on Land Degradation Neutrality, have emerged targeted to global land restoration efforts (include Indonesia) and intended to avoid targeted area overlap with good coordination (Table 1).

Land degradation is more acute in tropical countries such as Indonesia. Faced with an increasing population and rapid economic development, Indonesian landscapes will remain under considerable pressure in coming decades. Around 28 million ha of Indonesian forest area were cleared and degraded due to poor management under other land uses between 1990 and 2015 (FAO, 2015a, 2015b; FAO, 2010). There are several intertwined drivers behind such deforestation and land degradation in Indonesia, including agricultural expansion, illegal logging, and forest fires (Koh, Miettinen, Liew, & Ghazoul, 2011; Sharma et al., 2018; Tosca et al., 2011). Comparing total land area, that is, 190.5 million ha, the total amount of degraded land across the Indonesian archipelago is 78 million ha (i.e., 40.98% of total land area) (Figure 1), which is huge and alarming (ICCC, 2014), and delivers limited benefits to human and environment. Restoration of these lands, through afforestation, reforestation, agroforestation, natural regeneration, and climate-smart agriculture, provides an opportunity to reverse the loss of biodiversity and enhance the delivery of ecosystem services (Chazdon & Guariguata, 2016; Rahman, Sunderland, et al., 2017; Roshetko, Lasco, & Delos Angeles, 2007).

At the same time, it is important to recognize that each landscape is unique, and restoration efforts should consider the underlying cause of degradation, as well as the socioeconomic and ecological demands on the landscape (Rahman, Sunderland, et al., 2017). Successful land restoration depends not only on the rehabilitation of biodiversity and the ecosystem, but also on the choice of appropriate species, and their suitability in the landscape, so that local people's needs can also be fulfilled (Borchard et al., 2018; Lamb, Erskine, & Parrotta, 2005; Maimunah et al., 2018; Paudyal et al., 2017). Equally, for a landscape to be sustainable, production of food and energy must coexist alongside biodiversity (Tilman et al., 2009). Research shows perennial bioenergy crops could be planted in degraded or marginal lands that could otherwise be costly to restore (Baral & Lee, 2016; Tilman, Hill, & Lehman, 2006). As governments and international organizations join the global effort to restore degraded lands, integrating bioenergy crops into such efforts provides opportunities to address both the social and economic challenges of restoration.

Being able to meet the high costs involved in land restoration (approximately from US$260 to US$2,880 per hectare, depending on the condition of land and costs related to restoration methods) affects whether people managing agricultural and forest landscapes embrace such restoration efforts (Brown, 2017; Strassburg & Latawiec, 2014). With this in mind, bioenergy species, for example, nyamplung, has potential to be used as a restoration crop in agroforestry systems, offering a climate-smart farming approach by producing bioenergy as well as the function for soil and biodiversity conservation (Baral & Lee, 2016; Borchard et al., 2018; Jaung et al., 2018; Maimunah et al., 2018; Prabakaran & Britto, 2012; Schweier et al., 2017). As such farming can bring environmental and socioeconomic benefits without sacrificing agricultural production, it proves a viable way

TABLE 1 Three leading global land restoration initiatives[a]

Initiative	Targeted land area to restore (million ha)	Time frame	Estimated total budget required (billion USD)
Bonn challenge	150	2011–2020	359
New York declaration on forests	350	2014–2030	837
Land degradation neutrality (SDG Target 15.3)	2,000	2015–2030	4,780

Notes. *Source*: FAO (Food and Agriculture Organization of the United Nations) (2015a,b).
[a]Based on an estimated cost of USD 2,390/ha (following TEEB, 2009).

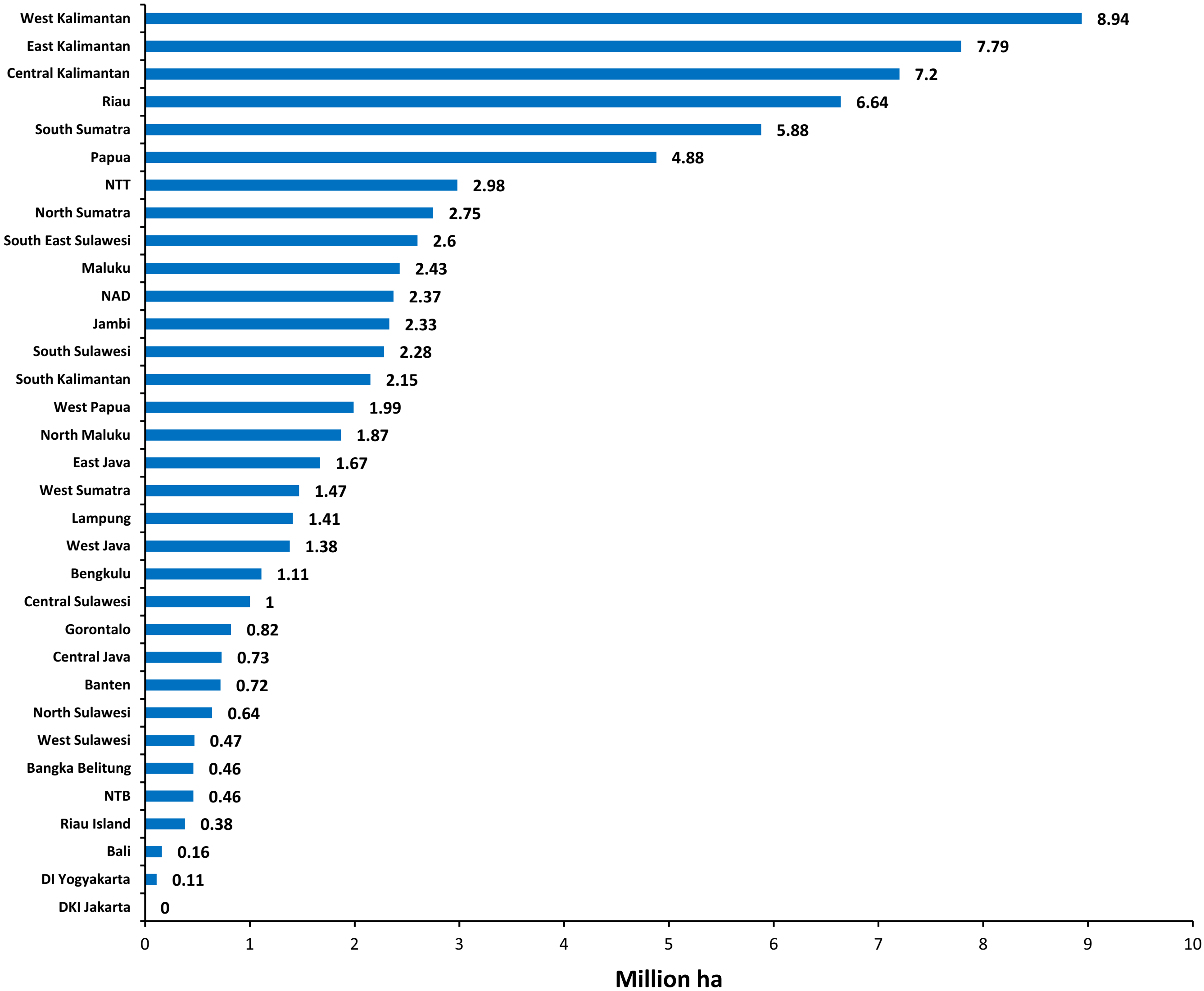

FIGURE 1 Area of degraded land in Indonesia by province (ICCC, 2014). *Note.* Degraded land is land that has declined productivity and hydrological functions, and low levels of biodiversity, vegetation cover, and carbon content. The soil of degraded land is also physically, chemically, and biologically infertile, due to loss of soil organic matter (Lal, 2015)

to shift toward sustainable production and scale back unsustainable agricultural practices that may lead to further degradation and deforestation (Boucher et al., 2011; Brown, Robinson, French, & Reed, 2013; Rahman, Sunderland, et al., 2017; Rahman, Jacobsen, et al., 2017). Improving access to affordable and reliable forms of energy, and enhanced and diverse food production, is essential to reduce poverty, eradicate hunger, and promote economic growth in the developing world (Malla, 2013; Rahman, 2017; Rahman, Jacobsen, et al., 2017).

This research assesses the socioeconomic and environmental benefits of bioenergy within nyamplung[2] based agroforestry crop systems[3] in the Wonogiri district of Central Java, Indonesia. Nyamplung's potential as a perennial crop for smallholder farmers has been recognized in Indonesia, the Philippines, and India (Gunasena & Roshetko, 2000; Khamidah & Darmawan, 2018; Roshetko & Evans, 1999; Uripno, Kolopaking, Slamet, & Amanah, 2014), but limited research and development activities have been conducted with the species.

2 | MATERIALS AND METHODS

2.1 | Study site

The study site is located in the Wonogiri district of Central Java, Indonesia (Figure 2), which lies between 7°42′43.56″S and 8°12′42.79″S latitude and between 110°45′15.20″E and 111°19′9.41″E longitude (BPS, 2018). At an average altitude of 141 m above sea level, the site's loam soil slopes

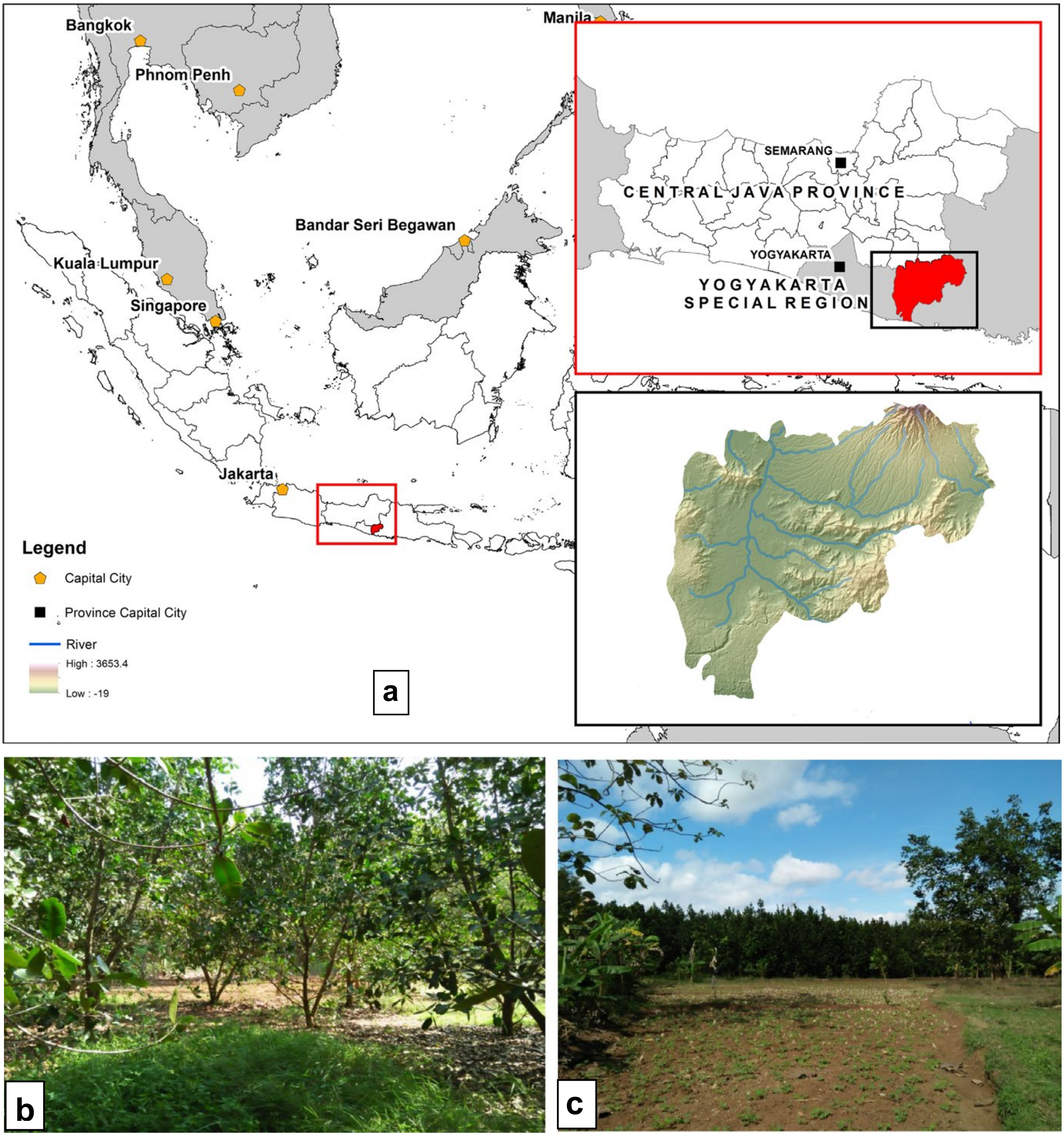

FIGURE 2 Study site: Wonogiri district, Central Java, Indonesia (a); local nyamplung-based agroforestry system (b); and monoculture of peanuts (c). Map and photographs © 2017 CIFOR

range from 0% to 10%. Its equatorial climate contributes an average precipitation of 1,878 mm, with temperatures between 20 and 38°C. The total area of Central Java is 3.25 million ha, in which 0.73 million ha (i.e., 22.26%) is degraded (BPS, 2018; ICCC, 2014). The study site was previously managed by Perhutani[4] and is now considered an unproductive degraded state-owned land area due to its lack of soil nutrition (N = 0.04%–0.07%, P = 1.80–4.07 ppm, and K = 0.11–0.13 me/100 g) (Hasnah & Windyarini, 2015; Leksono, Windyarini, & Hasnah, 2015).

During our focus group discussion (FGD), the respondents informed that local household incomes are mainly derived from crop production, cattle rearing, and remittance from family members working in cities. Agriculture is mainly rainfed-based (November–March) subsistence practices adopted by small-scale farmers. Based on our FGD and field observations, two major land use systems are found in the study area: monocultures of rice, maize, and peanuts; and agroforestry (intercropping of rice, maize, and peanuts with nyamplung for seed production). In total, fifteen farmers are found practicing nyamplung-based agroforestry. Food crops are also planted on the government managed land, using the government's "borrowing forest areas" mechanism for farmers. Some farmers are also beekeeping in the nyamplung agroforestry area for honey production.

This site was selected as, in order to produce the required research data (i.e., socioeconomic and environmental benefits of nyamplung -based agroforestry systems), it was essential for the degraded area to have farmers cultivating a variety of crops (e.g., monocultures of rice, maize, and peanuts) alongside nyamplung for their livelihood necessities. Therefore, their potential can be investigated with precision. The sustainability of livelihoods in the study site, like many other parts (especially in the degraded land area) of Indonesia, is threatened by overall poverty with low income (BPS, 2013). Moreover, due to the legal restrictions on the harvest of some products (e.g., timber) from natural forest provide an economic incentive for smallholders to integrate their farming systems. All of these characteristics of the study area are representative of a similarly large proportion of Indonesian and tropical Asian agricultural landscapes.

2.2 | Data collection and analysis

A focus group discussion (FGD) session and field observations were used to collect primary data on the various local farming systems presented in this study. Twenty local farmers (i.e., 10 nyamplung-based agroforestry + 10 monocultures) attended the FGD session. Farmers in the FGD were purposively selected based on their good knowledge of local farming systems (i.e., the range of crops cultivated in the area, cultivation season, cultivation methods, production input and output costs, market value, socioeconomic and environmental potential of cultivation, farmer motivation), and the socioeconomic and geographic states of the village and its surroundings. A set of key FGD questions was prepared that guided the session. The FGD questions were clearly explained to the participants so that they could fully understand each issue covered. A report was prepared immediately after the session summarizing the answers and opinions given by the participants, and to check its validity, the summarized information was verified by the participants.

Field observations were conducted in two farming locations selected based on information gathered in the FGD. During observation, several pictures of local farming systems (i.e., nyamplung-based agroforestry and monoculture) were taken, and relevant farming information was noted. Secondary data were gathered from the Southeast Asian regional office of ICRAF and CIFOR's headquarters, both located in Bogor, West Java, to corroborate the primary data collected from the research site and to check their reliability, as well as for background information and qualitative inputs for the study.

Qualitative analysis was conducted using the narrative analysis technique, particularly the social and environmental potential of agroforestry systems based on the data collected from FGD and field observation. Quantitative analysis, that is, the net present value (NPV), was used to assess the overall economic performance of local farming systems over a 35-year and 6-year time period[5] using a 10% discount[6] rate. The NPV is calculated by the following formula:

$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1+r)^t}$$

where
B_t = the benefits of production by a cultivation practice,
C_t = the costs of production by a cultivation practice,
t = time, running until the end of the investment at T,
r = the discount rate.

Sensitivity analysis was also conducted on variation in understory crop yields when nyamplung is intercropped, as the combination of diverse species may affect understory crop production (see Elevitch & Wilkinson, 2000; Rahman, Sunderland, Roshetko, et al., 2016; Rahman, Jacobsen, et al., 2017).

The market for agricultural land is underdeveloped in the study area; therefore, the price of land is unstable and difficult to identify. However, as mentioned by Rahman, de Groot, and Snelder (2008), there is no need to value the land separately if farmers want to change their existing cultivation system to another. Thus, in our analysis, land value is omitted from the calculation. Farmers primarily use family labor for farmwork, but hired labor is also important in the study area. Family labor is not a cash expenditure from the farmer's perspective, and it is complicated to identify the amount of family labor contributing to the cultivation system, as farmers have different household size and labor availability. For this reason, the calculation was based on the total amount of labor/day required for each cultivation system. The costs of seeds, saplings, pesticides, and fertilizers are calculated based on actual costs for each cultivation system.

Details of the calculated yearly cash flow of the farming systems are presented in "Table A1" in Annex.

3 | RESULTS AND DISCUSSION

NPV is calculated for the monoculture of four popular agricultural crops: maize, rice, peanuts, and honey collection; and nyamplung (Figure 3). The monoculture of rice and

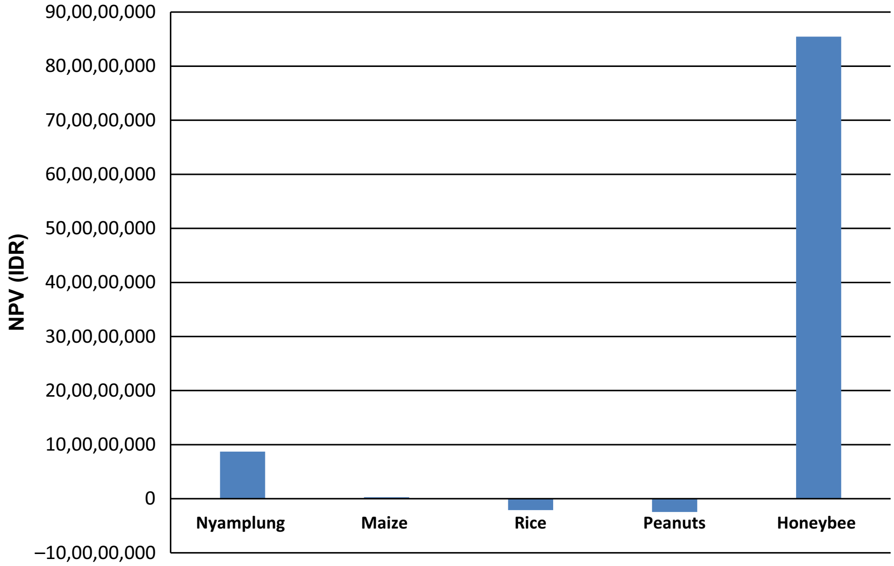

FIGURE 3 NPV of monoculture of five popular crops in Wonogiri over a 35-year rotation period

TABLE 2 Sensitivity of overall profitability (NPV in millions IDR ha^{-1}) to decreases in production of nyamplung and four understory crops counting 35-year time horizon

Decrease of production	Nyamplung	Nyamplung + integrated crop			
		Maize	Rice	Peanuts	Honey
0%	87.1	90.1	66.2	62.6	941.7
10%	74.8	89.8	64.1	60.1	856.2
20%	62.4	89.5	62.0	57.7	770.8
30%	50.1	89.2	60.0	55.2	685.3
40%	37.8	88.9	57. 8	52.8	599.9
50%	25.4	88.6	55.8	50.3	514.4
60%	13.1	88.3	53.7	47.8	428.9

peanuts leads to negative profitability; maize also provides only a marginal profit (IDR 3.0 million) when compared to nyamplung seed harvest profits (IDR 87.1 million) and profits generated from honey production (IDR 854.6 million) utilizing nyamplung. The crop yielding the largest economic profit is honey production, nearly ten times higher than the NPV of nyamplung alone, and 300 times higher than maize grown as a monoculture.

Despite negative profitability, farmers in Wonogiri cultivate peanuts and rice for their subsistence and food security value; rice is considered a staple food, with peanut leaves used as fodder for cattle production. Maize is used both as a staple food and for cattle consumption. During the FGD, farmers stated that production of rice and peanuts is profitable when compared to purchasing those commodities in local markets. As the profit of nyamplung seeds can compensate for losses from rice and peanut cultivation, our analysis suggests cultivating nyamplung with rice and peanuts is financially preferable (i.e., IDR 66.2 million and IDR 62.6 million, respectively), as well as to generate extra profit (IDR 90.1 million) by intercropping with maize (Table 2). Nyamplung grown for honey production add up highest profit (IDR 941.7 million). If intercropping with nyamplung can result in losses (e.g., crop failures due to pests and diseases, climate change) of as much as 60%, this agroforestry system still generates a positive NPV, and thus proves itself to be financially profitable. Similar cultivation modeling on the inclusion of tree crops with seasonal crops is used by Rahman, Sunderland, Roshetko et al. (2016) and showed improved economic performance (NPV) in their research sites in West Java and eastern Bangladesh.

However, over the full cycle, the economic return of each individual crop grown with nyamplung varies. Maize and rice can only be grown for the first six years of the 35-year cycle; nyamplung canopy closure thereafter prevents such shade-intolerant crops from growing in the understory. Peanut production follows a similar trend; even in an optimistic scenario, its production can only continue until year 8 of the cycle. More shade-tolerant crop alternatives, such as ginger and turmeric, are widely integrated into agroforestry

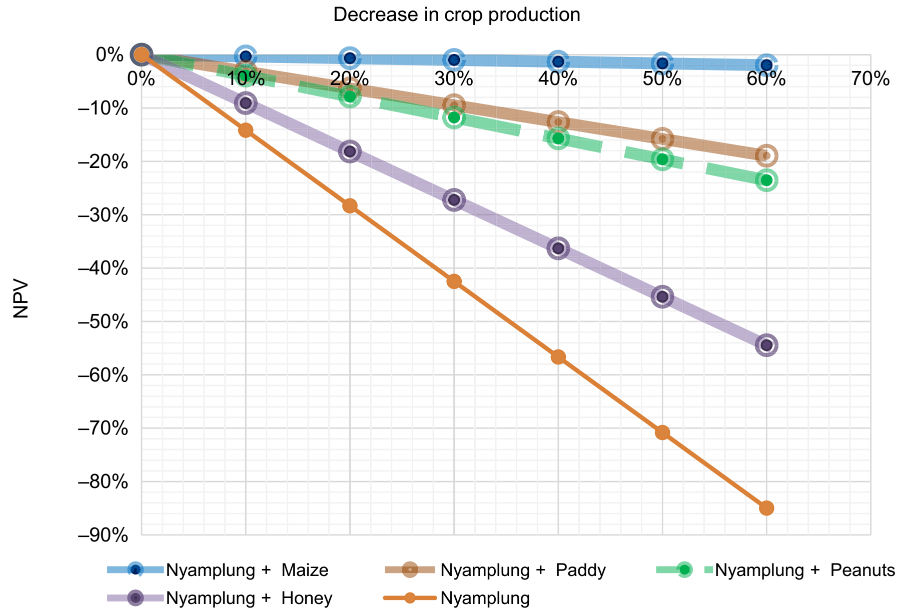

FIGURE 4 The proportional loss (%) of NPV with decreasing rates of crop production counting 35-year time horizon

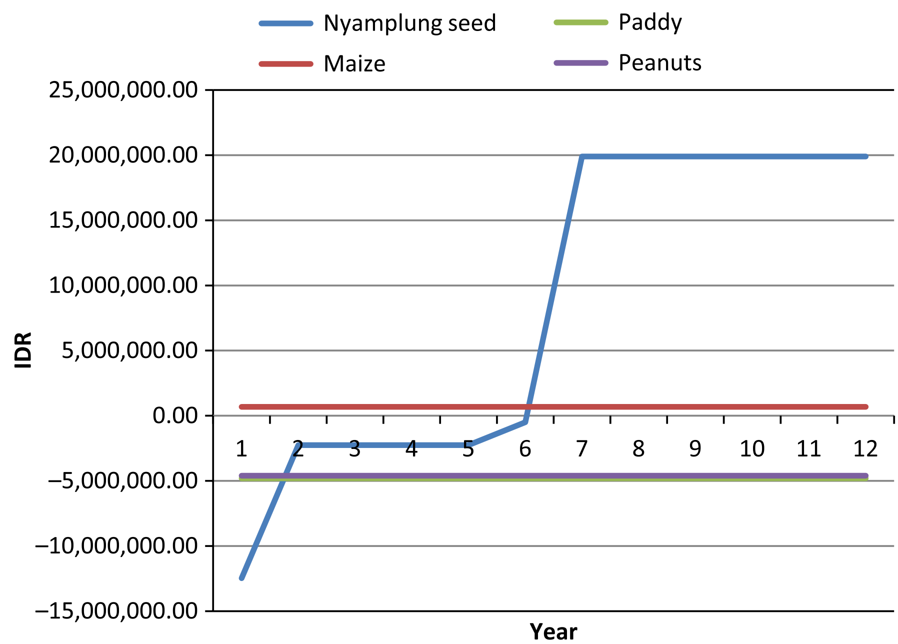

FIGURE 5 Annual cash flow (IDR) of different cultivation systems (excluding honey) in a 12-year time horizon

systems across Indonesia (Rahman, Sunderland, Roshetko, Basuki, & Healey, 2016; Riyandoko Martini, Perdana, Yumn, & Roshetko, 2016); however, due to the poor soil condition, these crops are not commonly cultivated in Wonogiri. When considering the decrease in yields seen while intercropping with nyamplung, maize results in the smallest loss (Figure 4; Table 2), yet even if maize production decreases by half, its NPV decreases by only 1.64%. In comparison, nyamplung as a single crop and honey production with nyamplung (nyamplung + honey) are heavily sensitive to changes in yield. If the yields of nyamplung and nyamplung + honey are decreased by 60%, the income (NPV) would decrease 85.0% and 54.5%, respectively. However, honey production is possible from the 6th year to 35th year, unlike understory crops which can only be cultivated at the starting phase of the system when nyamplung trees are young. As the NPV of honey production would likely increase as nyamplung trees mature and produce more nectar, this particular system of integration could prove itself a highly desirable investment option for Wonogiri's farmers.

The yearly cash flow of nyamplung and three popular understory agricultural crops (i.e., maize, rice, and peanuts) of our research site is also provided in Figure 5, by counting a much shorter project life, that is, 12 years, which allows the project performance to be seen during the early years, in particular the profits/losses associated with four selected crops other than honey.

Nonetheless, as the honey production has a longer production life and higher income prospect than other crops as described in the earlier section of this paper, any crop combination model with honey can have better income prospect. Therefore, although our analysis of the presented cultivation model is based on available data collected from the research site, farmers may cultivate more complex systems, for example, rice +maize +nyamplung +honey, rice +peanuts +nyamplung +honey, and maize +peanuts +nyamplung +honey, based on their livelihood objectives.

Although honey production has a higher income prospect in Wonogiri, very little literature exists on honeybee management in Central Java, especially with regard to its interactions with nyamplung trees. Additionally, the extent to which honeybees are sensitive to external pressures and shocks, such as climate change, which has already adversely impacted insect pollinators in Europe and the Middle East (Carreck, 2016), is unclear. Even though honey procurement in Indonesia has been practiced for years, de Jong (2000) states that the way in which bee collectors handle production differs greatly between regions. More research is needed to develop better bee husbandry practices so this becomes a viable option for local farmers. Regardless, a diversified agroforestry system will help to buffer against external shocks and pressures.

Nyamplung is already cultivated by some farmers in Wonogiri research site and shows viability for wider adoption. This is because, as our results demonstrate, there is a good financial prospect for farmers to establish nyamplung-based cultivation systems, particularly on marginal land, helping to restore it (see also Artati et al., 2019).

However, as a staple crop, rice, maize, and peanuts have special livelihood and food security value for farmers, and even they have apparently negative (i.e., rice, peanuts) or little positive (i.e., maize) NPV. Farmers may lack confidence and feel more exposed to higher market price of these crops than that of cultivation, and may regret the loss of cultural identity by giving up the cultivation of such specific traditional crops (see also Mwase et al., 2015; Rahman, Sunderland, Roshetko, et al., 2016). Nonetheless, farmers are also concerned to bear such losses by gaining higher income from nyamplung and associated products (i.e., honey) that enable them to purchase food and other necessities. Thus, in a wider sense farmers' decisions to adopt in nyamplung-based agroforestry system are based on traditional consideration as well as the trade-off between lower and higher income prospects.

Our research not only identified nyamplung-based systems as being economically viable, but also demonstrated that nyamplung cultivation strengthens social solidarity, with farmers sharing tree-planting knowledge. Farmers cultivating nyamplung are valued in the community, as involvement in such cultivation is more prestigious than rice and maize monocultures. Nyamplung-based systems also create employment opportunities (traders, and seasonal/regular wage-laborers for harvesting, sorting, and transporting of farm products), thus supporting the emergence of farm-related rural employment and expertise. From a social and institutional perspective, as well as creating jobs and being a symbol of prestige and cultural identity, agroforestry in Indonesia can be critically important in strengthening social cohesion (Michon, 2005; Rahman, Jacobsen, et al., 2017).

Information from FGD participants and field observation demonstrated that nyamplung cultivation in our study site improved overall biodiversity and environmental quality, that is, bird habitat, fresh air, soil erosion control, and protecting crops from wind damage, by increasing number of trees in the degraded land. Nyamplung production in our study area performs well even in low-fertility soils. This supports the perception that bioenergy crops have low nutritional demands and maintenance requirements, and thus are suitable for marginal lands (Butterbach-Bahl & Kiese, 2013; Dillen, Djomo, al Afas, Vanbeveren, & Ceulemans, 2013; Schweier et al., 2017). Baral and Lee (2016) argued that careful utilization of degraded lands to produce bioenergy, such as nyamplung, could avoid negative impacts on food production and associated land degradation. As fossil fuel-based energy is unsustainable and contributes to greenhouse gas (GHG) emissions, bioenergy can be a viable alternative to address future societies' green and sustainable energy needs. Nyamplung is also useful as a firebreak as it shades out fire-prone grasses, and is moderately tolerant to fire. It is also resistant to typhoons. The species is also useful in soil stabilization, as well as serving as a windbreak in coastal areas (Prabakaran & Britto, 2012), which helps reduce erosion and protect crops. It also supports ecotourism as a landscape ornamental plant (Atabani & Cesar, 2014; Lim, 2012). Therefore, a properly designed bioenergy production system can contribute to achievement of several objectives, such as increasing sustainable energy access, mitigating climate change, and providing rural employment (Casillas & Kammen, 2010).

Furthermore, as the government of Indonesia through Ministry of Energy and Mineral Resources (Regulation No. 12, 2015[7]) and revision toward Presidential Decree No. 61, 2015, has set biodiesel blending rate to 20% in 2016 and 30% in 2020 for public and private use (Kharina, Malins, & Searle, 2016), it has significantly increased the importance of domestic biofuel production. The policies have opened an opportunity to utilize, and govern use of degraded land for biofuel production without interfering existing agriculture and forest land, and to save millions of square miles of agricultural and forest land from such biofuel production and their possible extension threat (Mooney, 2018). However, there will be a need for follow-up regulations that could sustainably contribute to and monitor restoration of degraded and marginal land for biodiesel production for a longer term, and to avoid forest land clearance for biodiesel crop plantations.

4 | CONCLUSION

In agroforestry systems, intercropping nyamplung with various annual crops, or using it in association with honey production, provides farmers with viable economic options at different scales. Most notably, this study shows that although monocultures of rice and peanut are not financially profitable (having negative NPV), they become so when coupled with nyamplung production, due to the high value nyamplung seeds hold as a bioenergy crop. Honey production is the most profitable practice in this system. Although honey production from nyamplung has highest percentage of NPV loss if production decreases, still it provides largest profit. Besides high income prospect, as nyamplung-based systems contribute to social solidarity and create employment, and such cultivation is prestigious for the farmers, they can contribute to making viable use of Central Java's degraded lands and help to restore them. However, for these systems to become sustainable, an effective implementation strategy must be adopted, as farmers' resources such as financial and human capital may be restricted. If a nyamplung-based system is to have long-term environmental benefits, it should also remain socioeconomically favorable for local farmers in the long run.

As nyamplung is already being cultivated in the study region, there is a positive likelihood of farmers adopting these systems; however, further research is needed to develop better bee husbandry to ensure honey production with nyamplung becomes a viable option for local farmers. This challenge can be seen as a positive opportunity to increase local farmers' engagement, which can be achieved through policy support.

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ENDNOTES

[1] Due to this population growth, the expansion of agriculture has quickened the pace of land transformation and degradation of ecosystem (Hooke & Martín-Duque, 2012). This problem is compounded by the agricultural intensification currently being practiced in some areas in order to increase crop production and provide food security being accompanied by serious forms of land degradation (Brookfield, 1972, 1984; Snelder & Lasco, 2008). Nearly 20 million km^2 of land, or ~40% of the global agricultural land area, has already been degraded. Of this, over half is so degraded that farmers lack the means to restore it (Hooke & Martín-Duque, 2012; Rahman, 2017). Farmland is affected by soil nutrient depletion and soil physical degradation due to repeated cultivation without periodic application of fertilizers, plant organic matter, and manure (Rahman, Jacobsen, Healey, Roshetko, & Sunderland, 2017; Rahman, Sunderland, Roshetko, & Healey, 2017; Snelder & Lasco, 2008).

[2] Nyamplung (*Calophyllum inophyllum* L.) is a tropical tree species common in East Africa, India, Southeast Asia, Australia, and the South Pacific. In Indonesia, it grows on almost all islands, including Sumatra, Java, Kalimantan, Sulawesi, Maluku, East Nusa Tenggara, and Papua (Bustomi Rostiwati et al., 2008). This tree grows at elevations of 0–500 m which have mean annual temperatures of 7–48°C and mean annual rainfall of 750–5,000 mm. It grows well on deep soil near the coast and thrives on pure sand and at pH 4–7.4. It flowers twice a year and produces fruit yields up to 46,600 kg ha^{-1} year^{-1} (Atabani & Cesar, 2014; Bustomi Rostiwati et al., 2008). The tree has a lifetime of more than 200 years (Cole, 2012). Its seeds have high potential as a biofuel source (Atabani & Cesar, 2014; Azad et al., 2016). Seeds have a higher oil content than other biofuel species like jatropha and Circassian bean (Leksono, Hendrati, Windyarini, & Hasnah, 2014). The species also has other economic uses, which includes using the pressed seeds (oil cake) for manure and other products (e.g., briquettes, wood reservation, medicine, soap, oil for skin care and textile coloring) (Leksono et al., 2014; Orwa, Mutua, Kindt, Jamnadass, & Simons, 2009). It has also been highly valued for its timber, and more recently, its anticancer and anti-HIV compounds it possesses (Hathurusingha, Ashwath, & Midmore, 2011; Itoigawa et al., 2001). The plant also provides ecosystem services acting as windbreaker for coastal areas, reducing wind and salt spray damage, protecting crops, mitigating temperatures, and conserving coastal areas (Rodrigues, Mascarenhas, & Jagtap, 2011).

[3] It can also be one of the potential alternatives of oil palm. Oil palm has high economic value and carbon sequestration potential (Goodrick, Nelson, Banabas, Wurster, & Bird, 2015; Syahrinudin, 2005) and has been the main source of biofuel in Indonesia, and it has raised concerns about widespread community conflict, compromising food consumption and destroying forests and consequent biodiversity (Abram et al., 2017; Gaveau et al., 2016; Vijay, Pimm, Jenkins, & Smith, 2016).

[4] Perhutani is a state-run forestry company working in Java.

[5] Even nyamplung has a long life, and a 35-year time period was considered appropriate as local farmers are unlikely to be interested in pursuing very long-term projects. Likewise, biofuel may no longer compete with other increasing energy sources, like solar energy. A 12-year period was further considered if some farmers want to pursue relatively much short-term project.

[6] This was considered an appropriate rate to match the banking system of the research site.

[7] This regulation also increased mandatory biodiesel blending rate to 30% in 2016 for electricity generation.

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ANNEX

TABLE A1 Yearly total cash flow of the selected crops (i.e., maize, rice, peanuts, honey) when used as intercropping with nyamplung

Year	Nyamplung	Maize	Rice	Peanuts	Honey
1	−12477000.00	680000.00	−4800000.00	−4600000.00	0.00
2	−2260000.00	680000.00	−4800000.00	−4600000.00	0.00
3	−2260000.00	680000.00	−4800000.00	−4600000.00	0.00
4	−2260000.00	680000.00	−4800000.00	−4600000.00	0.00
5	−2260000.00	680000.00	−4800000.00	−4600000.00	0.00
6	−500000.00	680000.00	−4800000.00	−4600000.00	146000000.00
7	19900000.00	0.00	0.00	−4600000.00	146000000.00
8	19900000.00	0.00	0.00	−4600000.00	146000000.00
9	19900000.00	0.00	0.00	0.00	146000000.00
10	19900000.00	0.00	0.00	0.00	146000000.00
11	19900000.00	0.00	0.00	0.00	146000000.00
12	19900000.00	0.00	0.00	0.00	146000000.00
13	19900000.00	0.00	0.00	0.00	146000000.00
14	19900000.00	0.00	0.00	0.00	146000000.00
15	19900000.00	0.00	0.00	0.00	146000000.00
16	19900000.00	0.00	0.00	0.00	146000000.00
17	19900000.00	0.00	0.00	0.00	146000000.00
18	19900000.00	0.00	0.00	0.00	146000000.00
19	19900000.00	0.00	0.00	0.00	146000000.00
20	19900000.00	0.00	0.00	0.00	146000000.00
21	19900000.00	0.00	0.00	0.00	146000000.00
22	19900000.00	0.00	0.00	0.00	146000000.00
23	19900000.00	0.00	0.00	0.00	146000000.00
24	19900000.00	0.00	0.00	0.00	146000000.00
25	19900000.00	0.00	0.00	0.00	146000000.00
26	19900000.00	0.00	0.00	0.00	146000000.00
27	19900000.00	0.00	0.00	0.00	146000000.00
28	19900000.00	0.00	0.00	0.00	146000000.00
29	19900000.00	0.00	0.00	0.00	146000000.00
30	19900000.00	0.00	0.00	0.00	146000000.00
31	19900000.00	0.00	0.00	0.00	146000000.00
32	19900000.00	0.00	0.00	0.00	146000000.00
33	19900000.00	0.00	0.00	0.00	146000000.00
34	19900000.00	0.00	0.00	0.00	146000000.00
35	19900000.00	0.00	0.00	0.00	146000000.00

Note. As understory, maize and rice can only be cultivated for first six years and peanuts for eight years considering nyamplung tree growth and canopy closer. From year 6, nyamplung trees can start producing seeds (low), but from year 7, it can be with full production. Honey can be produced from year 6 when nyamplung trees start flowering.