CHAPTER 6

Potential benefits of integrated bioenergy and food production systems on degraded land in Wonogiri, Indonesia

Syed Ajijur Rahman, Himlal Baral, Roshan Sharma, Yusuf B Samsudin, Maximilian Meyer, Michaela Lo, Yustina Artati, Trifosa Iin Simamora, Sarah Andini, Budi Leksono, James M Roshetko, Soo Min Lee, Mihyun Seol and Terry Sunderland

Abstract: Cultivating suitable biofuel crops on degraded land by involving local communities can be a promising solution for energy and food security while restoring land. This chapter provides information on the socioeconomic and environmental benefits of *Calophyllum inophyllum* L., known locally as *nyamplung*, based on agroforestry systems practiced by local farmers in Wonogiri District, Central Java Province, Indonesia. Relevant information was gathered through field observations and a focus group discussion with 20 farmers practicing "*nyamplung*-based agroforestry systems" with rice, maize, peanuts and honey. The net present values (NPVs) of rice and peanuts indicated negative profitability when they were grown as monocultures, whereas maize generated only marginal profits. Amazingly, honey production utilizing *nyamplung* produced an NPV nearly 300 times higher than maize. However, combined with *nyamplung*, honey was also the commodity most sensitive to decreases in production, followed by *nyamplung*–peanut and *nyamplung*–rice combinations. While decreases in production had little effect on the NPVs of rice, peanuts and maize, these annual crops can only be cultivated for a maximum of six years within *nyamplung*'s 35-year production cycle, due to canopy closure after this time. In conclusion, *nyamplung*-based agroforestry systems can provide economic, social and environmental benefits on different scales. Additionally, considering the high profit potential of combining *nyamplung* with honey production, it is necessary to improve and develop bee husbandry practices to make doing so a viable option for local farmers.

Key words: Land restoration, *nyamplung*, local crops, benefits
Link: https://www.cifor.org/knowledge/publication/7164/
This is an edited version of an article previously published in *Food and Energy Security* (Rahman et al. 2019)

6.1 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 and Vandecar 2015). However, human land-use practices, particularly agriculture expansion, also lead to land degradation and a reduction of these valuable environmental services (Alcamo et al. 2005; Millennium Ecosystem Assessment 2005; Babigumira et al. 2014). This poses a serious challenge when aiming to end hunger and poverty, conserve biodiversity and adapt to climate change (Sunderland et al. 2007; Fleskens and Stringer 2014). Given the finite amount of productive land available, how to ensure the well-being of our expanding population – 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 target on Land Degradation Neutrality, have emerged and targeted global land restoration efforts (i.e., 2,500 million hectares) and intend to avoid targeted area overlap with good coordination (FAO 2015a, 2015b).

Land degradation is more acute in tropical countries like Indonesia. Faced with a growing population and rapid economic development, Indonesian landscapes are under considerable pressure. In recent years, the Government of Indonesia (GoI) has made significant progress in addressing deforestation and forest degradation issues (World Bank 2016). It has initiated a national programme to restore degraded land throughout the country (Budiman et al. 2020), and taken corrective action through policies on forest fire prevention and management; a moratorium on issuing new licences on primary forest and peatlands; and sustainable forest management certification and timber legality assurance systems.

Restoration of degraded land through afforestation, reforestation, agroforestation, natural regeneration and climate-smart agriculture provides an opportunity to reverse biodiversity loss and enhance the delivery of ecosystem services (Roshetko et al. 2007; Chazdon et al. 2016; Rahman et al. 2017). However, 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 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 (Lamb et al. 2005; Paudyal et al. 2017; Borchard et al. 2018; Maimunah et al. 2018). 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 on degraded or marginal lands that could otherwise be costly to restore (Tilman et al. 2006; Baral and Lee 2016). 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 in Indonesia – approximately USD 398 to USD 12,153 per hectare, depending on the condition of land and costs related to restoration methods (Table 1) – affects whether people managing agricultural and forest landscapes embrace such restoration efforts (Strassburg and Latawiec 2014; Brown 2017). With this in mind, bioenergy species like *nyamplung* (*Calophyllum inophyllum* L.) have potential for use as restoration crops in agroforestry systems, offering a climate-smart farming approach by producing bioenergy as well as playing a role in soil and biodiversity conservation (Prabakaran and Britto 2012; Baral and Lee 2016; Schweier et al. 2017; Borchard et al. 2018; Jaung et al. 2018; Maimunah et al. 2018). As such farming can bring environmental and socioeconomic benefits without sacrificing agricultural production, it might prove a viable way to shift toward sustainable production and scale back unsustainable agricultural practices that may lead to further degradation and deforestation (Boucher et al. 2011; Brown et al. 2013; Rahman 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 et al. 2017).

This research assesses the socioeconomic and environmental benefits of bioenergy within *nyamplung*-based agroforestry crop systems in Wonogiri District in Central Java Province, Indonesia. *Nyamplung*'s potential as a perennial crop for smallholder farmers has been recognized in Indonesia, the Philippines and India since more than twenty years ago (Roshetko and Evans 1999; Gunasena and Roshetko 2000; Uripno et al. 2014; Khamidah and Darmawan 2018), but limited research and few development activities have been conducted with the species.

Table 1. Land restoration costs in Indonesia by degradation stage and restoration approach[1]

Degradation Stage	Restoration method	Estimated costs (USD ha^{-1})[2]
Stage 1 (least degraded)	Protection	398
Stage 2 (somewhat degraded)	Assisted natural regeneration	844
	Assisted natural regeneration (Castilo 1986)	3,489
Stage 3 (fairly degraded)	Framework Species Method	2,537
Stage 4 (most degraded)	Maximum diversity with mine site amelioration	10,890
	Miyawaki method	12,153

Notes:

1 Based on this table the average cost of land restoration in Indonesia is USD 5,000 per hectare (see Baral et al. 2019)

2 Based on 2018 prices

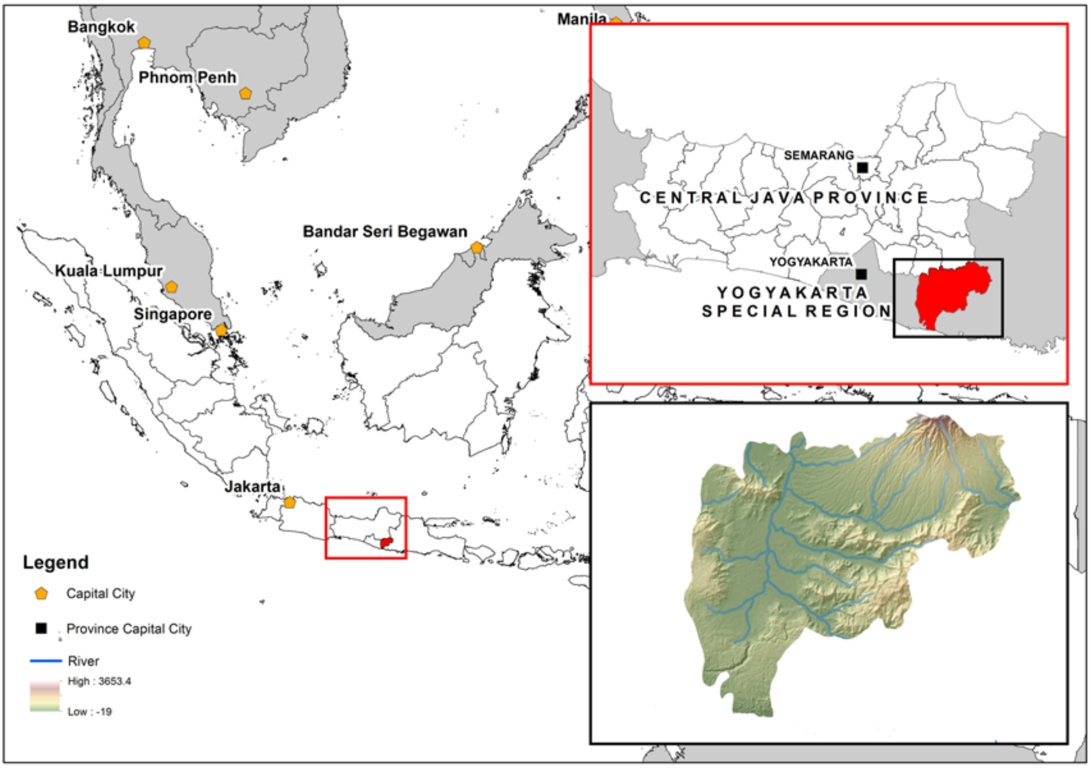
Source: Baral et al. 2019

6.2 Materials and methods

The study area is located in Wonogiri District in Central Java Province, Indonesia (Figure 1), which lies between 7°42'43.56"S and 8°12'42.79"S latitude. With its equatorial climate, it has average precipitation of 1,878 mm, and temperatures between 20°C and 38°C. The total area of Central Java is 3.25 million ha, of which 0.73 million ha (22.26%) is degraded (ICCC 2014; BPS 2018). The study area was previously managed by state-owned forestry company Perhutani, but is now considered an unproductive degraded area of state-owned land 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 per 100 g) (Hasnah and Windyarini 2015; Leksono et al. 2015).

During our focus group discussion (FGD), respondents said local household incomes were mainly being derived from crop production, cattle rearing and remittances from family members working in cities. Agriculture in the area mainly involved rainfed-based (November–March) subsistence practices adopted by small-scale farmers. Based on our FGD and field observations, two major land-use systems were being practiced 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 were practicing *nyamplung*-based agroforestry. Food crops were also planted on government managed land, using the government's 'forest estate lease' mechanism for farmers. Some farmers were also practicing beekeeping in *nyamplung* agroforestry areas for honey production.

The site was selected 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 areas to have farmers cultivating a variety of crops (e.g., monocultures of rice, maize and peanuts) alongside *nyamplung* for their livelihood necessities. This type of cultivation allowed their potential to be investigated with precision. The sustainability of livelihoods in the study area, like many other regions with degraded land in Indonesia, is threatened by poverty and low incomes (BPS 2013). Moreover, the legal restrictions on harvesting some products (e.g., timber) from natural forest provide an economic incentive for smallholders to integrate their farming systems. All of these characteristics in the study area are representative of a large proportion of Indonesian and tropical Asian agricultural landscapes.



a

b

c

Figure 1. Study site: (a) Wonogiri District, Central Java, Indonesia; (b) local *nyamplung*-based agroforestry system; and (c) peanut monoculture.

Source: Map and photographs ©2017 CIFOR

6.2.1 Data collection and analysis

A focus group discussion (FGD) and field observations were used to collect primary data on the various local farming systems presented in this study. Twenty local farmers (10 practicing *nyamplung*-based agroforestry and 10 practicing 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 seasons, cultivation methods, production input and output costs, market values, socioeconomic and environmental potential of cultivation, and farmer motivation), and the socioeconomic and geographic states of the village and its surroundings. A set of key FGD questions was prepared to guide the session. The FGD questions were clearly explained to the participants so they could fully understand each issue covered. A report was prepared immediately after the session to summarize the answers and opinions given by the participants as well as to check their validity. Lastly, 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 observations, several pictures of local farming systems (i.e., *nyamplung*-based agroforestry and monocultures) were taken, and relevant farming information was noted. Secondary data was 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 study area and check their reliability, and to provide background information and qualitative inputs for the study.

Using a narrative analysis technique, qualitative analysis of the social and environmental potential of agroforestry systems was conducted based on the data collected from the FGD and field observations. Quantitative analysis, that is, 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 with a 10% discount rate. A sensitivity analysis was also conducted on variation in understory crop yields where *nyamplung* was intercropped, as combinations of diverse species might affect understory crop production (Elevitch and Wilkinson 2000; Rahman et al. 2016; Rahman et al. 2017).

6.3 Results and discussion

NPV was calculated for monocultures of four popular farmed commodities: maize, rice, peanuts and honey, and for *nyamplung* (Figure 2). Rice and peanut monocultures led to negative profitability while maize only provided marginal profits (NPV of IDR 3 million) compared to those generated from *nyamplung* seed harvests (NPV of IDR 87.1 million) and from honey production (NPV of IDR 854.6 million) utilizing *nyamplung*. The commodity yielding the greatest profits was honey, with an NPV nearly ten times higher than that of *nyamplung* alone, and 300 times higher than maize grown as a monoculture.

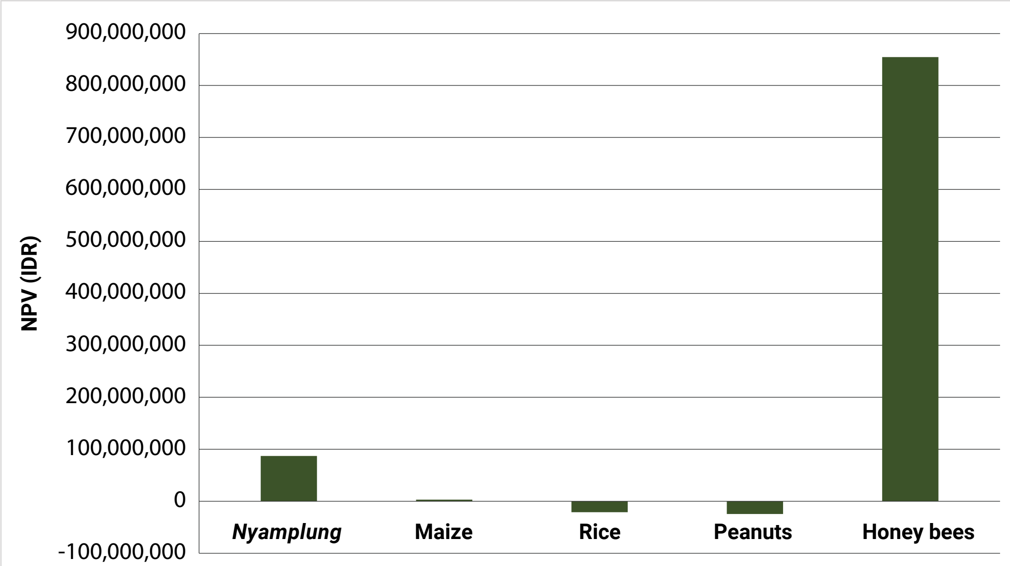


Figure 2. NPVs of five popular commodity monocultures in Wonogiri over a 35-year rotation period

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 as both a staple food and livestock feed. During the FGD, farmers stated that producing rice and peanuts was more affordable than purchasing those commodities in local markets.

As profits from *nyamplung* seeds could compensate for losses from rice and peanut cultivation, our analysis suggests that cultivating *nyamplung* with rice and peanuts might be financially preferable (i.e., NPVs of IDR 66.2 million and IDR 62.6 million, respectively), while intercropping with maize could generate extra profits (NPV of IDR 90.1 million) (Table 2).

Also, *Nyamplung* grown in combination with honey production could generate the highest profits (NPV of IDR 941.7 million). Even with losses of as much as 60% as a result of crop failure caused by pests and diseases, climate change etc., this agroforestry system could still generate a positive NPV, and therefore be financially viable. Similar cultivation modelling on combinations of tree crops and seasonal crops by Rahman et al. (2016) have also shown 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* would vary. Maize and rice could only be grown for the first six years of the 35-year cycle as *nyamplung* canopy closure thereafter would prevent such shade-intolerant crops from growing in the understory. Peanut production would follow a similar trend, and even in an optimistic scenario, its production could only continue until year eight of the cycle.

Table 2. Sensitivity of overall profitability (NPV in millions IDR ha^{-1}) to decreases in production of *nyamplung* and four understory crops counted over a 35-year time horizon

Decrease in 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

More shade-tolerant crop alternatives, such as ginger and turmeric, have been widely integrated into agroforestry systems across Indonesia (Rahman et al. 2016; Riyandoko et al. 2016). However, due to poor soil conditions, these crops are not commonly cultivated in Wonogiri. Considering the decrease in yields when intercropped with *nyamplung*, maize resulted in the smallest loss (Figure 3; Table 2). Yet, even if maize production were decreased by half, its NPV would decrease by only 1.64% over the same time.

In comparison, *nyamplung* as a single crop and honey production with *nyamplung* (*nyamplung* + honey) were heavily sensitive to changes in yield. If the yields of *nyamplung* and *nyamplung* + honey were decreased by 60%, the resulting incomes (NPVs) would decrease by 85.0% and 54.5%, respectively. However, honey production would be possible from the sixth to the thirty-fifth year, unlike understory crops which could 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 matured and produced more nectar, this particular system of integration could be a highly desirable and beneficial investment option for Wonogiri's farmers.

As honey has a longer production life and higher income prospects than other commodities as described in the earlier section of this paper, any crop combination model with honey could have better income prospects. Therefore, even though our analysis of cultivation models was based on data collected from the study area, farmers could cultivate more complex systems, such as 'rice + maize + *nyamplung* + honey'; 'rice + peanuts + *nyamplung* + honey'; or 'maize + peanuts + *nyamplung* + honey', based on their livelihood objectives. Although honey production could provide higher income prospects in Wonogiri, very little literature mentions honeybee management in Central Java, particularly in relation to how bees interact 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), has not been identified clearly. Honey production has been practiced in Indonesia for years, but de Jong (2000) stated that the way in which bee collectors handle production differed greatly between regions. More research is needed for developing better bee husbandry

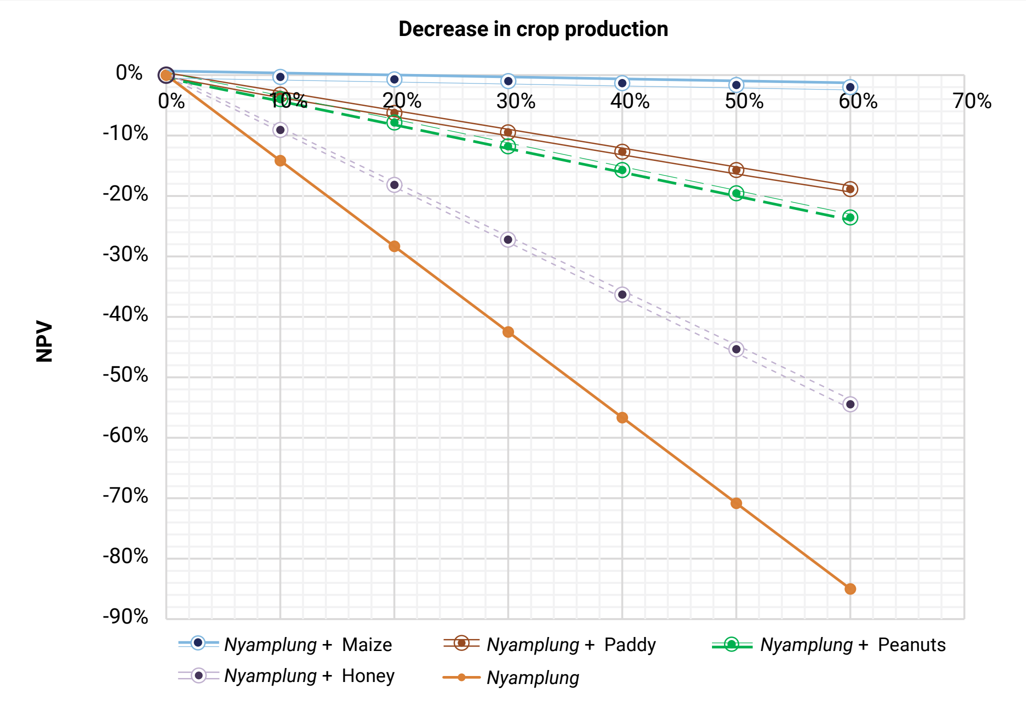


Figure 3. Proportional loss (%) of NPV with decreasing rates of production counted over a 35-year time horizon

practices, and so this could become a feasible option for local farmers. Regardless of honey production techniques and bee husbandry practices, a diversified agroforestry system would help to buffer against external shocks and pressures.

Nyamplung is already being cultivated by some farmers in the Wonogiri study area and shows viability for wider adoption. This is because, as our results demonstrate, there are good financial prospects for farmers to establish *nyamplung*-based cultivation systems on marginal lands, and help restore them (Artati et al. 2019).

As staple crops, rice, maize and peanuts have special livelihood and food security values for farmers, despite showing apparently negative (i.e., rice, peanuts) or marginally positive (i.e., maize) NPVs. Farmers might lack confidence and feel more exposed to higher market prices when buying rather than cultivating these commodities, and might be afraid of losing their cultural identity if they were to give up cultivating such specific traditional crops (Mwase et al. 2015; Rahman et al. 2016). They could bear such losses by gaining higher income from *nyamplung* and associated products (i.e., honey) which would enable them to purchase food and other necessities. Thus, in a wider sense, farmers' decisions to adopt *nyamplung*-based agroforestry systems could be based on considerations for tradition as well as the trade-offs 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* were valued in the community, as involvement in such combined cultivation was considered more prestigious than growing rice or maize monocultures.

Nyamplung-based systems would also create employment opportunities for traders, and seasonal/regular-wage labourers, who could work harvesting, sorting and transporting farm products. Thus, such systems could support 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 et al. 2017).

Information from FGD participants and field observations demonstrated that *nyamplung* cultivation in our study area had already improved overall biodiversity and environmental quality, providing bird habitat and fresh air, as well as controlling soil erosion and protecting crops from wind damage, with the increased numbers of trees on degraded land.

Nyamplung production in our study area performed well even on low-fertility soils. This observation supports the perception that bioenergy crops might have low nutritional demands and maintenance requirements, and thus are suitable for marginal lands (Butterbach-Bahl and Kiese 2013; Dillen et al. 2013; Schweier et al. 2017). Baral and Lee (2016) argued that careful utilization of degraded lands to produce bioenergy crops, such as *nyamplung*, could avoid negative impacts on food production and associated land degradation. As fossil fuel-based energy is unsustainable and causes greenhouse gas (GHG) emissions, bioenergy could 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. This special species is also resistant to typhoons. The species is also useful in soil stabilization, as well as playing a role as a windbreak in coastal areas (Prabakaran and Britto 2012), which could help reduce erosion and protect crops. It could also support ecotourism as a landscape ornamental plant (Lim 2012; Atabani and Cesar 2014). Therefore, a properly designed bioenergy production system could contribute to the achievement of several objectives, such as increasing sustainable energy access, mitigating climate change and providing rural employment (Casillas and Kammen 2010).

Furthermore, as the Government of Indonesia set biodiesel blending rates of 20% in 2016 and 30% in 2020 for public and private use through Minister of Energy and Mineral Resources Regulation No. 12/2015[7] and Presidential Decree No. 61/2015 (Kharina et al. 2016), it has significantly increased the importance of domestic biofuel production. These policies have opened an opportunity to utilize and govern the use of degraded land for biofuel production without interfering with existing agriculture and forest land, and to save millions of square kilometres of such land from biofuel production and its possible associated threats (Mooney 2018). However, there might be a need for follow-up regulations on monitoring the long-term restoration of degraded and marginal lands for sustainable biodiesel production, and preventing the clearance of forested land for biodiesel crop plantations.

6.4 Conclusion

In agroforestry systems, intercropping *nyamplung* with various annual crops, or using it in association with honey production, provides farmers in Wonogiri with viable economic options at different scales. Most notably, this study shows that although monocultures of rice and peanut are not profitable (having negative NPVs), growing these commodities could become financially viable when combined with *nyamplung* production, due to the high value *nyamplung* holds as a bioenergy crop. Honey production is the most profitable practice in local agroforestry systems, and despite honey production with *nyamplung* having the highest percentage of NPV loss when production decreased, it would still generate the highest profits. In addition to their income prospects, as *nyamplung*-based agroforestry systems contribute to social solidarity and create employment, such cultivation is prestigious for local farmers, so they could contribute to making viable use of and restoring degraded lands in Central Java. As *nyamplung* is already being cultivated in the study region, there is a positive likelihood of farmers adopting these systems.

Nevertheless, effective implementation strategies must be adopted for such systems to become sustainable, possibly because farmers' financial resources and human capital may be restricted. For *nyamplung*-based agroforestry systems to have long-term environmental benefits, they must also remain socioeconomically favourable for local farmers in the long run. Further research is necessary for developing better bee husbandry, in order to ensure honey production with *nyamplung* can become a guaranteed viable option for local farmers. This challenge can be seen as a positive opportunity for improving local farmers' engagement, which could be achieved through supporting policies.

References

Alcamo J, van Vuuren D, Cramer W, Alder J, Bennett E, Carpenter S, et al. 2005. Changes in ecosystem services and their drivers across the scenarios. *Ecosystems and Human Well-being* 2: 297–373.

Artati Y, Jaung W, Juniwaty KS, Andini S, Lee SM, Segah H and Baral H. 2019. Bioenergy production on degraded land: Landowner perceptions in Central Kalimantan, Indonesia. *Forests* 10(2): 99.

Atabani AE and Cesar ADS. 2014. *Calophyllum inophyllum* L. – a prospective non-edible biodiesel feedstock: Study of biodiesel production, properties, fatty acid composition, blending and engine performance. *Renewable and Sustainable Energy Reviews* 37(2014): 644–655.

Azad AK, Rasul MG, Khan MMK, Sharma SC, Mofijur M and Bhuiya MMK. 2016. Prospects, feedstocks and challenges of biodiesel production from beauty leaf oil and castor oil: Nonedible oil sources in Australia. *Renewable and Sustainable Energy Reviews* 61(2016): 302–318.

Babigumira R, Angelsen A, Buis M, Bauch S, Sunderland T and Wunder S. 2014. Forest clearing in rural livelihoods: Household-level global-comparative evidence. *World Development* 64: 67–79.

Baral H and Lee SM. 2016. Sustainable Bioenergy Systems to Restore and Valorize Degraded Land. CIFOR Brief No. 37. Bogor, Indonesia: Center for International Forestry Research (CIFOR).

Baral P, Larsen M and Archer M. 2019. Does Money Grow on Trees? Restoration Financing in Southeast Asia. Washington, DC: Atlantic Council.

Borchard N, Bulusu M, Hartwig A, Ulrich M, Lee SM and Baral H. 2018. Screening potential bioenergy production of tree species in degraded and marginal land in the tropics. *Forests* 9: 594.

Boucher D, Elias P, Lininger K, May-Tobin C, Roquemore S and Saxon E. 2011. The root of the problem: What's driving tropical deforestation today? Cambridge, MA: Union of Concerned Scientists.

BPS (Badan Pusat Statistik). 2013. *Statistik Daerah Kabupaten Wonogiri 2013*. Wonogiri, Indonesia: BPS.

BPS (Badan Pusat Statistik). 2018. *Luas Daerah dan Jumlah Pulau Menurut Provinsi, 2002-2016*, Retrieved from https://www.bps.go.id/statictable/2014/09/05/1366/luas-daerah-dan-jumlah-pulaumenurut-provinsi-2002-2016.html.

Brookfield HC. 1972. Intensification and disintensification in Pacific agriculture: A theoretical approach. *Pacific Viewpoint* 13(1): 30–48.

Brookfield HC. 1984. Intensification revisited. *Pacific Viewpoint* 25(1): 15–44.

Brown LR. 2017. Restoring the earth: the earth restoration budget. Earth Policy Institute, Retrieved from http://www.earth-policy.org/mobile/books/pb4/PB4ch8_ss7?phpMyAdmin = 1d6bec-1fea35111307d869d19bcd2ce7

Brown DG, Robinson DT, French NHF and Reed BC. eds. 2013. Land use and the carbon cycle: Advances in integrated science, management, and policy (pp. 505–522). Cambridge, MA: Cambridge University Press.

Budiman I, Bastoni, Sari EN, Hadi EE, Asmaliyah, Siahaan H, Januar R and Hapsari RD. 2020. Progress of paludiculture projects in supporting peatland ecosystem restoration in Indonesia. *Global Ecology and Conservation* 23: e01084.

Bustomi RSR, Sudrajat LB, Kosasih S, Anggraini I, Syamsuwida D, Lisnawat Y, et al. 2008. *Nyamplung (Calophyllum inophyllum L.) Sumber Energi Biofuel yang Potensial*. Jakarta, Indonesia: Badan Litbang Kehutanan.

Butterbach-Bahl K and Kiese R. 2013. Bioenergy: Biofuel production on the margins. *Nature* 493: 483–485.

Carreck N. 2016. Decline of bees and other pollinators. *In* Sivanpillai R and Shroder JF. eds. *Biological and environmental hazards, risks, and disasters*. pp. 109–118. Waltham, MA: Elsevier.

Casillas CE and Kammen DM. 2010. The energy-poverty-climate nexus. *Science* 330: 1181–1182.

Castilo A. 1986. An Analysis of Selected Restoration Projects in the Philippines. Ph.D. thesis, University of Philippines.

Chazdon RL and Guariguata MR. 2016. Natural regeneration as a tool for large-scale forest restoration in the tropics: Prospects and challenges. *Biotropica* 48: 716–730.

Cole RV. 2012. The artistic anatomy of trees. New York, NY: Dover Publications.

de Jong W. 2000. Micro-differences in local resource management: The case of honey in West Kalimantan, Indonesia. *Human Ecology* 28: 631–639.

Dillen S, Djomo SN, al Afas N, Vanbeveren S and Ceulemans R. 2013. Biomass yield and energy balance of a short-rotation poplar coppice with multiple clones on degraded land during 16 years. *Biomass and Bioenergy* 56: 157–165.

Elevitch CR and Wilkinson KM. 2000. Economics of farm forestry: Financial evaluation for landowners. *In* Elevitch CR and Wilkinson KM. eds. Agroforestry guides for Pacific Islands # 7. Holualoa, Hawaii: Permanent Agricultural Resources (PAR).

FAO (Food and Agriculture Organization of the United Nations). 2015a. Sustainable financing for forest and landscape restoration: Opportunities, challenges and the way forward. Discussion paper. Rome, Italy: FAO.

FAO (Food and Agriculture Organization of the United Nations). 2015b. Global Forest Resources Assessment 2015: How are the world's forests changing? Rome, Italy: FAO.

Fleskens L and Stringer LC. 2014. Land management and policy responses to mitigate desertification and land degradation. *Land Degradation and Development* 25: 1–4.

Gaveau DLA, Sheil D, Husnayaen SMA, Arjasakusuma S, Ancrenaz M, Pacheco P and Meijaard E. 2016. Rapid conversions and avoided deforestation: Examining four decades of industrial plantation expansion in Borneo. *Scientific Reports* 6: 32017.

Goodrick I, Nelson PN, Banabas M, Wurster CM and Bird MI. 2015. Soil carbon balance following conversion of grassland to palm oil. *GCB Bioenergy* 7(2): 263–272.

Gunasena HPM and Roshetko JM. 2000. Tree domestication in Southeast Asia: Results of a regional study on institutional capacity. Bogor, Indonesia: International Centre for Research in Agroforestry (ICRAF).

Hasnah TM and Windyarini E. 2015. *Teknik budidaya & pertumbuhan tanaman nyamplung pada tiga kondisi lahan di Jawa. Peranan dan Strategi Kebijakan Pemanfaatan Hasil Hutan Bukan Kayu (HHBK) dalam Meningkatkan Daya Guna Kawasan (Hutan).* Seminar presentation. pp. 265–272. Gadjah Mada University, 6–7 November 2014. Yogyakarta, Indonesia: Forestry Faculty, Gadjah Mada University.

Hathurusingha S, Ashwath N and Midmore D. 2011. Provenance variations in seed-related characters and oil content of *Calophyllum inophyllum* L. in northern Australia and Sri Lanka. *New Forests* 41(1): 89–94.

Hooke RL and Martín-Duque JF. 2012. Land transformation by humans: A review. *GSA Today* 22(12): 4–10.

ICCC (Indonesia Climate Change Center). 2014. Critical areas map of forestry planning agency. Jakarta, Indonesia: ICCC.

Itoigawa M, Ito C, Tan HTW, Kuchide M, Tokuda H, Nishino H and Furukawa H. 2001. Cancer chemopreventive agents, 4-phenylcoumarins from *Calophyllum inophyllum*. *Cancer Letters* 169(1): 15–19.

Jaung W, Wiraguna E, Okarda B, Artati Y, Goh CS, Syahru R, et al. 2018. Spatial assessment of degraded lands for biofuel 3 production in Indonesia. *Sustainability* 10(12): 4595.

Khamidah N and Darmawan ARB. 2018. Viabilitas benih nyamplung (*Calophyllum inophyllum* L.) dari biji yang telah di skarifikasi terhadap media tanam yang berbeda. *Ziraa'ah* 43(1): 104–110.

Kharina A, Malins C and Searle S. 2016. Biofuels policy in Indonesia: Overview and status report. Washington, DC: International Council on Clean Transportation.

Lal R. 2015. Restoring soil quality to mitigate soil degradation. *Sustainability* 2015(7): 5875–5895.

Lamb D, Erskine PD and Parrotta JA. 2005. Restoration of degraded tropical forest landscapes. *Science* 310: 1628–1632.

Lawrence D and Vandecar K. 2015. Effects of tropical deforestation on climate and agriculture. *Nature Climate Change* 5: 27–36.

Leksono BE, Hendrati RL, Windyarini E and Hasnah T. 2014. Variation in biofuel potential of twelve *Calophyllum inophyllum* populations in Indonesia. *Indonesian Journal of Forestry Research* 1(2): 127–138.

Leksono BE, Windyarini E and Hasnah T. 2015. Growth, flowering, fruiting and biofuel content of *Calophyllum inophyllum* in provenance seed stand. Conference paper. Proceedings of International Conference of Indonesia Forestry Researchers III- 2015: Forestry research to support sustainable timber production and self-sufficiency in food, energy, and water. pp. 171–180. 10–12 October 2015. Bogor, Indonesia: Forestry Research, Development and Innovation Agency.

Lim TK. 2012. Edible medicinal and non-medicinal plants. Dordrecht, the Netherlands: Springer Science+Business Media.

Maimunah S, Rahman SA, Samsudin YB, Artati Y, Simamora TI, Andini S, et al. 2018. Assessment of suitability of tree species for bioenergy production on burned and degraded peatlands in Central Kalimantan, Indonesia. *Land* 7(4): 115.

Malla S. 2013. Household energy consumption patterns and its environmental implications: Assessment of energy access and poverty in Nepal. *Energy Policy* 61: 990–1002.

Michon G. ed. 2005. Domesticating forests: How farmers manage forest resources. Bogor, Indonesia: IRD, CIFOR and ICRAF.

Millennium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Synthesis. Washington, DC: Island Press.

Mooney C. 2018. It's the big new idea for stopping climate change, but it has huge environmental problems of its own. Retrieved from https://www.washingtonpost.com/news/energy-environment/wp/2018/01/22/a-technology-many-hoped-would-fight-climatechange-would-cause-even-bigger-environmental-problems-scientists-say/?noredirect=on&utm_term=.0defcd729713

Mwase W, Sefasi A, Njoloma J, Nyoka BI, Manduwa D and Nyaika J. 2015. Factors affecting adoption of agroforestry and evergreen agriculture in southern Africa. *Environment and Natural Resources Research* 5: 148–157.

Orwa C, Mutua A, Kindt R, Jamnadass R and Simons A. 2009. Agroforestree Database: A Tree Reference and Selection Guide (version 4.0). Retrieved from http://www.worldagroforestry.org/af/treedb/

Paudyal K, Putzel L, Baral H, Chaudhary S, Sharma R, Bhandari S, et al. 2017. From denuded to green mountains: Process and motivating factors of forest landscape restoration in Phewa Lake watershed, Nepal. *International Forestry Review* 19(4): 75–87.

Prabakaran K and Britto SJ. 2012. Biology, agroforestry and medicinal value of *Calophyllum inophyllum L.* (clusiacea): A review. *International Journal of Natural Products Research* 1(2): 24–33.

Rahman SA. 2017. Incorporation of Trees in Smallholder Land Use Systems: Farm Characteristics, Rates of Return and Policy Issues Influencing Farmer Adoption. PhD Thesis, University of Copenhagen, Denmark and Bangor University, UK.

Rahman SA, de Groot W and Snelder DJ. 2008. Exploring the agroforestry adoption gap: Financial and socioeconomics of litchi-based agroforestry by smallholders in Rajshahi (Bangladesh). *In* Snelder DJ and Lasco RD. eds. Smallholder tree growing for rural development and environmental services: Lessons from Asia. *Advances in Agroforestry Series* (Vol. 5: pp. 227–244). Dordrecht, the Netherlands: Springer Netherlands.

Rahman SA, Jacobsen JB, Healey JR, Roshetko JM and Sunderland T. 2017. Finding alternatives to swidden agriculture: Does agroforestry improve livelihood options and reduce pressure on existing forest? *Agroforestry Systems* 91: 185–199.

Rahman SA, Sunderland T, Kshatriya M, Roshetko JM, Pagella T and Healey JR. 2016. Towards productive landscapes: Trade-offs in tree-cover and income across a matrix of smallholder agricultural land-use systems. *Land Use Policy* 58(2016): 152–164.

Rahman, SA, Sunderland T, Roshetko JM, Basuki I and Healey JR. 2016. Tree culture of smallholder farmers practicing agroforestry in Gunung Salak Valley, West Java, Indonesia. *Small-scale Forestry* 15(4): 433–442.

Rahman SA, Sunderland T, Roshetko JM and Healey JR. 2017. Facilitating smallholder tree farming in fragmented tropical landscapes: Challenges and potentials for sustainable land management. *Journal of Environmental Management* 198(2017): 110–121.

Riyandoko ME, Perdana A, Yumn A and Roshetko JM. 2016. Existing conditions, challenges and needs in the implementation of forestry and agroforestry extension in Indonesia. Working paper No. 238. ICRAF, Bogor, Indonesia.

Rodrigues RS, Mascarenhas A and Jagtap TG. 2011. An evaluation of flora from coastal sand dunes of India: Rationale for conservation and management. *Ocean and Coastal Management* 54(2): 181–188.

Roshetko JM and Evans DO. eds. 1999. Domestication of agroforestry trees in Southeast Asia. Forest, farm, and community tree research reports, special issue. 242 p.

Roshetko JM, Lasco RD and Delos AMD. 2007. Smallholder agroforestry systems for carbon storage. *Mitigation and Adaptation Strategies for Global Change* 12: 219–242.

Schweier J, Molina-Herrera S, Ghirardo A, Grote R, Díaz-Pinés E, et al. 2017. Environmental impacts of bioenergy wood production from poplar short-rotation coppice grown at a marginal agricultural site in Germany. *Global Change Biology: Bioenergy* 9(7): 1207–1221.

Sharma R, Nehren U, Rahman SA, Meyer M, Rimal B, Seta GA and Baral H. 2018. Modeling land use and land cover changes and their effects on biodiversity in Central Kalimantan, Indonesia. *Land* 7(2): 1–14.

Snelder DJ and Lasco RD. 2008. Smallholder tree growing in South and Southeast Asia. *In* Snelder DJ and Lasco RD. eds. *Smallholder tree growing for rural development and environmental services: Lessons from Asia. Advances in agroforestry series* (Vol. 5: pp. 3–33). Dordrecht, the Netherlands: Springer.

Strassburg BBN and Latawiec AE. 2014. The economics of restoration: costs, benefits, scale and spatial aspects. Retrieved from https://www.cbd.int/doc/meetings/ecr/cbwecr-sa-01/other/cbwecrsa-01-iis-en.pdf

Sunderland TCH. 2011. Food security: Why is biodiversity important? *International Forestry Review* 13(3): 265–274.

Sunderland TCH, Ehringhaus C and Campbell BM. 2007. Conservation and development in tropical forest landscapes: A time to face the trade-offs? *Environmental Conservation* 34(4): 276–279.

Syahrinudin SL. 2005. The potential of oil palm and forest plantations for carbon sequestration on degraded land in Indonesia. *Ecology and Development Series* 28: ZEF Bonn, Germany. 120 p.

TEEB (The Economics of Ecosystems and Biodiversity). 2009. TEEB climate issues update. Retrieved from http://www.teebweb.org/media/2009/09/TEEB-Climate-Issues-Update.pdf

Tilman D, Hill J and Lehman C. 2006. Carbon-negative biofuels from low-input high-diversity grassland biomass. *Science* 314(5805): 1598–1600.

Tilman D, Socolow R, Foley JA, Hill J, Larson E et al. 2009. Beneficial biofuels: The food, energy, and environment trilemma. *Science* 325: 270–271.

UN (United Nations). 2017. World population prospects 2017. Retrieved from https://esa.un.org/unpd/wpp/Graphs/Probabilistic/POP/TOT/

Uripno B, Kolopaking LM, Slamet RM and Amanah S. 2014. Implementation of demonstration plots energy self-sufficient village *nyamplung* (*Calophyllum inophyllum* L.) in Buluagung and Patutrejo villages. *International Journal of Science and Engineering* 7(1): 81–90.

Vijay V, Pimm SL, Jenkins CN and Smith SJ. 2016. The Impacts of oil palm on recent deforestation and biodiversity loss. *PLOS ONE* 11(7): e0159668.

World Bank. 2016. The cost of fire: An economic analysis of Indonesia's 2015 fire crisis (No. 103668). The World Bank, Jakarta, Indonesia.