CHAPTER 3

Alternative forest plantation systems for the Southcentral Coast of Viet Nam: projections of growth and production using the WaNuLCAS model

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Summary

Short-rotation (3-4 years) and high density (4,500-10,000 trees per hectare) acacia for pulp and paper purpose is one of the most popular forest plantation systems in Viet Nam, including in the Southcentral Coast region. There is a need however to find alternative designs to further improve the economic return and environmental benefits such carbon storage that can be derived from the system, and to develop forest plantation systems for other purposes, such as timber production. We used the Water, Nutrient and Light Capture in Agroforestry Systems (WaNuLCAS) model to assess the performance of eight forest plantation systems for Quang Nam province that could be expected to provide higher and more stable income and higher levels of carbon storage, including timber production. The systems combined different spacings and rotations of acacia with cycles of cassava as intercrop.

Among the different systems, for farmers who largely rely on forest plantation as the source of income, the four-year rotation system with 3 x 3 m tree spacing for pulp and paper purpose and three seasons of cassava is the most feasible option as it leaves no income gap between investment and tree harvesting. In terms of carbon storage however, this system is inferior than the four-year rotation systems and the baseline. Among the systems for timber, the highest income per year, time-averaged carbon storage and timber production were obtained from 3.5 x 3.5 m and 4 x 4 m acacia spacing, in 12-year rotations. For these options, farmers need other sources to cover the income gap between investment and timber harvest and to the loan.

We conclude that the performance of current short-rotation forest plantation system can be improved by selecting appropriate tree spacing and include more cycles of intercrop. Systems with long rotations for timber, however, need to offer other income sources for farmers to maintain cash flow. Furthermore, since smallholder farmers with few resources generally are risk-averse, local authorities need to develop demonstration trials of selected alternative systems with the farmers, whilst improving micro-finance and loan system, and access to markets for other products than pulp and paper.

1. Introduction

In the last few decades, a similar pattern of forest policy has emerged in tropical countries, namely the decentralisation of forest management and afforestation programs with timber trees (Clement and Amezaga 2009, Pietrzak 2010, Sandewall et al 2010). In Viet Nam, a program to allocate forests to communities started in the 1990s, supported by a series of policies (Clement and Amezaga 2009, Sandewall et al 2010, To et al 2013).

One of the most popular forest-plantation systems in the country is short-rotation acacia for pulp and paper (Trieu et al 2016), usually densely planted in three to four year-rotations. The system dominates production forests in many regions in Viet Nam, including the Central Coast region (Tran et al 2014). The system rehabilitates soils (Tran et al 2014) since acacia is a nitrogen-fixing species and makes an important source of income for farmers (Pietrzak 2010, Nambiar et al 2015, Trieu et al 2016).

The short-rotation acacia system, especially in the Central Coast region, was developed primarily as monoculture with high density from 4,500 to 10,000 trees per hectare with inter crops such as cassava, only in the first year after planting before the closing of tree canopy. Like other monocultural practices however, this system can potentially harbour an economic risk for smallholder farmers without other income sources, and due to uncertainty in product price as well. For the latter, comparing the price of acacia in Thua Thien Hue province in 2015 and 2017, there was a drop of about 17% (Catacutan et al 2017). With increasing labour cost, the income benefits of short-rotation acacia will become questionable (Pistorius et al 2016).

There is a need for Viet Nam to move further along the forest-transition curve by introducing more permanent or longer-rotation forest plantation systems (Pistorius et al 2016). This is expected to enhance forest quality, economic performance and environmental services including carbon storage for climate change mitigation purpose. Meanwhile, Viet Nam imports 80% of its timber requirement as raw material for an export-oriented furniture industry (Pistorius et al 2016). The country is also committed to implement REDD+ and biodiversity conservation. Developing more permanent and longer-rotation forest-plantation systems could produce greater benefits for livelihoods and environment aligned with these commitments.

The sub-national, such as provincial authorities have targets for the area long-rotation timber plantations. Such plantations are expected to improve household incomes, contribute to climate change mitigation and reduce the intensity of shifting cultivation, especially in upland regions. For example, the National Forestry Program of the Forest Protection Department in collaboration with the Viet Nam Administration of Forestry plans to provide financial support for an initial 55 hectares of long-rotation timber plantations in Thus Thien Hue province.

In view of the above, we explored alternative forest plantation systems that were expected to generate higher and more stable income as well as greater environmental benefits such as greater carbon storage and control of soil erosion. The soil erosion hazard from short-rotation acacia systems was reported e.g. in Quang Nam and Thua Tien Hue province (Catacutan et al 2017) and took place especially during the replantation stage. The alternative systems combine different spacings and rotations of acacia with seasons of cassava as intercrop.

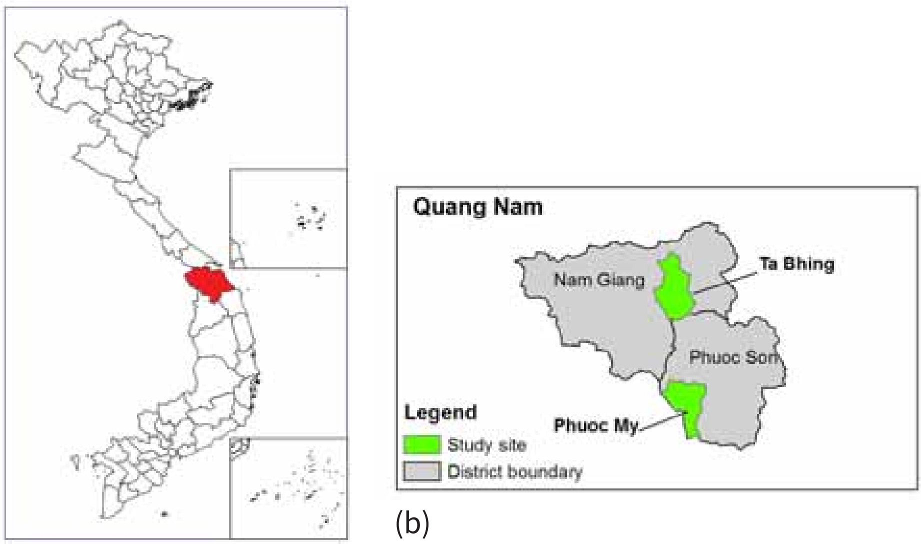
We assessed the growth, productivity and carbon storage of eight alternative acacia systems for Quang Nam province using the Water, Nutrient and Light Capture in Agroforestry Systems (WaNuLCAS), a tree–crop growth and interaction model (van Noordwijk et al 2011) as compared to the short-rotation and high density acacia system as baseline assumed to be of four-year rotation with a density of 10,000 trees per hectare and cassava in the first year after tree planting. The profitability and net present value (NPV) of all alternative systems were calculated to highlight the business cases of the alternative systems, compared to the baseline.

2. Materials and methods

Description of the study sites

The study was conducted in 2017 and the study sites were in Song Thanh Natural Reserve in Quang Nam Province, Southcentral coast of Viet Nam (Figure 12), within the Central Annamites, more specifically in the two buffer-zone communes—Ta Bhing and Phuoc My—of the Reserve. The communes were prioritized

(a)



(b)

Figure 12. Location of (a) Quang Nam province, Southcentral Coast of Viet Nam and (b) the two sampled communes, in Nam Giang and Phuoc Son district

by the provincial Department of Agriculture and Rural Development (DARD) and the forest management boards, for livelihood assessment and improvement.

Phuoc My commune has an elevation range of 223-446 masl. More than 70% of the commune lands are mountainous with narrow plain stretches between mountain ranges (People's Committee of Phuoc Son District 2015). Consequently, the commune is prone to flooding and landslides, which affect agricultural productivity.

Ta Bhing commune is located at a lower elevation, approximately 100 masl. The commune is also dominated by mountainous areas (People's Committee of Ta Bhing Commune 2015). The flat areas are concentrated at the feet of the mountains, along riverbanks and streams. The river system flows through steep terrain.

Based on commune statistics from 2014, Phuoc My had in total 1,590 people in 410 households belonging to various ethnic groups such as Gie Trieng (Bhnong), Kinh, Tay, Nung and Co Tu, with 95% from the

Bhnong group. There were 952 people of working age, of whom 820 or 86% worked in the agricultural sector. In terms of socio-economic status, 58% of all households were classified as poor.

Ta Bhing is larger than Phuoc My in terms of land area and population. In 2014, the commune had 2,500 people in 625 households (People's Committee of Ta Bhing Commune 2015). From the total population, 1,315 people (53%) were of working age, and in terms of socio-economic status, 58% of all households were, like Phuoc My, classified as poor.

In 2015, forest lands in Phuoc My covered 93% of the total area whereas in Ta Bhing it was 76% (Table 8). Among the forest lands, 1,706 ha or 15% of the total forest area in Phuoc My, were designated as production forest grown as plantations; in Ta Bhing, 227 ha or 3% of the total forest area was designated as production forest. The remaining forest areas were designated as protection or special-use forests. In both communes, the quality of natural forests was generally low after years of overexploitation. Timber for house construction was no longer available and non-timber forest products were limited. Agricultural land occupied 3% and 16% of the total area of Phuoc My and Ta Bhing, respectively.

Table 8. Land-use distribution and area in Phuoc My and Ta Bhing communes in 2015

Commune	Total land area (ha)	Agricultural land (ha)	Forestry land (ha)	Production forest (ha)
Phuoc My	12,281	351	11,407	1,706
Ta Bhing	15,886	2,567	7,151	227

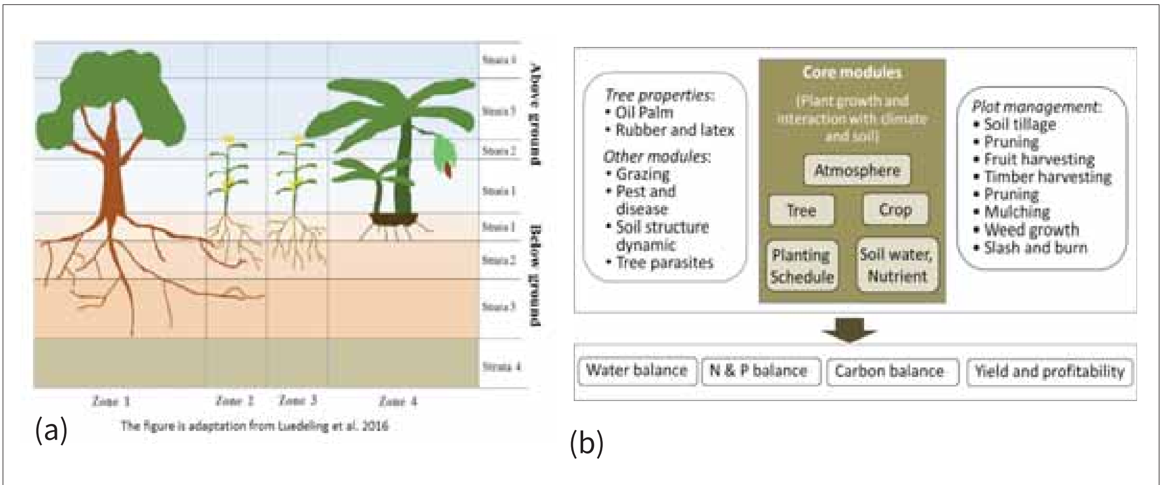
Source: People's committees of Phuoc My (2015) and Ta Bhing (2015) communes

Based on a household survey that involved 103 households in Phuoc My and 153 households in Ta Bhing, Catacutan et al (2017) reported that acacia systems provided the main source of income to 26% of surveyed households in each Phuoc My and Ta Bhing. In other households, it was secondary to cash crops.

Tree–crop interaction model

WaNuLCAS is a generic tree–crop growth model that considers both aboveground (e.g. light availability) and belowground (e.g. soil water and nutrients) interaction as factors determining plant growth. It represents a system in four horizontal zones and four vertical soil layers (Figure 13a) and estimates the growth of plant components and plot productivity following the daily balance of above- and belowground resources. Figure 13b describes the main modules and outputs of the model.

In this study, the model was used to simulate the growth and interaction among acacia and cassava in the different systems under observed climatic and soil conditions in the study sites, to estimate plot productivity. We used the model outputs, namely growth and production of each plant component to estimate the economic return of the systems.



Source: the spatial arrangement figure was adapted from Luedeling et al 2016

Figure 13. (a) Spatial arrangement of a tree–crop system in WaNuLCAS into four lateral zones and four vertical soil layers; (b) The main modules and outputs

Soil and climate data

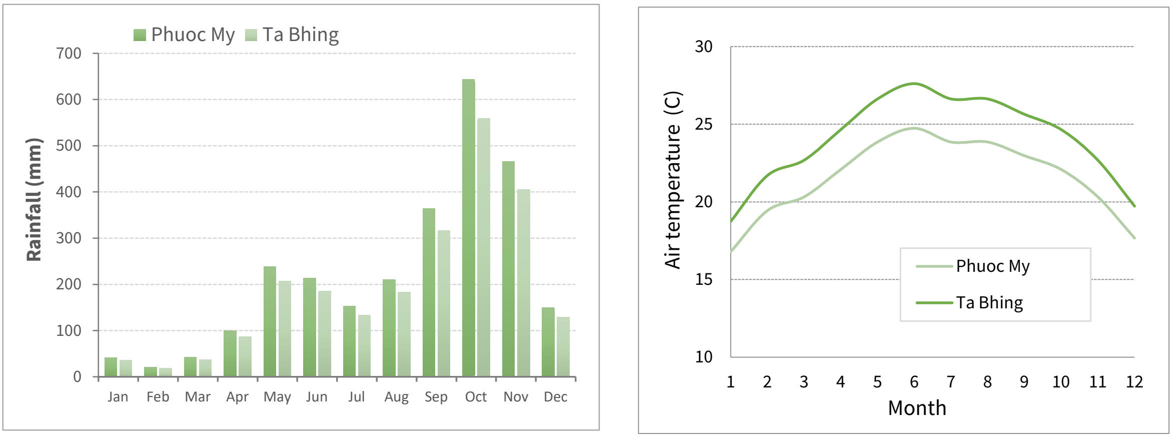
The model needs information on local soil and climatic conditions as well as plant characteristics to perform the simulations. Table 9 describes the soil chemical and physical characteristics in the two study communes based on soil sampling and analysis. In each commune, soil sampling consisted of eight replications conducted in four villages, down to 1 m soil depth. The samples were analysed by the Soils and Fertilizers Research Institute in Ha Noi city. A statistical test found that the two sampled communes had similar soil characteristics: sandy loam on top with sandy clay loam in the sub-soils. Hence, for the simulations, we used averaged soil data to represent both communes.

Table 9. Soil physical and chemical properties of the two study communes

Thickness of soil layer (cm)	Sand (%)	Silt (%)	Clay (%)	pH	C (%)	N	P-Bray (ppm)	CEC[1] (cmol kg^{-1})	Bulk density (g cm^{-3})	Texture[2]
0–10	66	19	14	4.2	2.3	0.15	40	8.7	1.256	Sl
10–30	60	18	20	3.9	1.3	0.10	31	8.2	1.280	SCL
30–60	57	16	26	3.9	0.7	0.06	26	8.6	1.346	SCL
60–100	57	14	28	3.9	0.5	0.04	28	9.3	1.365	SCL

[1] Cation exchange capacity; [2] SL = sandy loam, SCL = sandy clay loam

Figure 14a shows the monthly rainfall data in the two communes. As no weather station was available in either commune, the rainfall and temperature data were generated with WorldClim *(http://www.worldclim.org/)*. The annual rainfall was estimated to 2,650 mm in Phuoc My and 2,300 mm in Ta Bhing. In both communes, the rainy season usually occurs between September and November with flood risks and the dry season with drought risks in the first months of the year. The highest temperatures occur during May and July (Figure 14b).



a) b)

Figure 14. (a) Monthly average rainfall and (b) Air temperatures in the two study communes in Phuoc My, Quang Nam. Source: data generated from WorldClim.

Alternative acacia-based systems

The short-rotation and high density acacia system with four-year rotation and a density of 10,000 trees per hectare with cassava in the first year after tree planting was assumed as the baseline system. Compared to the baseline, the eight alternative systems were designed as alley cropping with wider tree spacing wherein cassava is intercropped between acacia trees for up to five years. The systems with rotation more than eight years are intended for timber. For the assessments with the WaNuLCAS model, we assumed that the systems are free of weeds, fully controlled in terms of pest and disease, and with no synthetic fertilizer application. Parameter values representing plant and growth characteristic of acacia and cassava are available in the tree and crop library of the WaNuLCAS model. The parameters include those representing the ability of acacia trees as nitrogen-fixer. Table 10 describes the characteristics of the eight alternative systems.

Table 10. Alternative acacia-based systems for Quang Nam province

System	Tree spacing (m)	Tree density (trees ha^{-1})	Rotation (years)	Purpose	No. of cassava seasons
1	2 x 2	2,500	4	pulp & paper	2
2	3 x 3	1,111	4	pulp & paper	3
3	3 x 3	1,111	8	timber	3
4	4 x 4	625	8	timber	4
5	3.5 × 3.5	816	12	timber	3
6	4 x 4	625	12	timber	4
7	5 x 5	450	14	timber	5
8	6 x 6	278	14	timber	5

Comparison with the baseline

The alternative systems were compared with the baseline in terms of timber production, time-averaged carbon storage, income per year and Net Present Value (NPV). Based on the interview with farmers and local authorities in both communes, the total production and maintenance costs of the baseline practice range from USD 200 to USD 1,000 per hectare and the average gross income range from USD 1,000 to USD 2,000 per hectare. The wide range in production costs could be owing to the presence or absence of tree seedling subsidy from the Government. The variance in gross income could be attributed to variation in transport costs determined by the location of the plantation, usually relative to main roads. Furthermore, based on a direct measurement of 75 acacia trees of different ages in Phuoc My commune, the average stem diameter of 3.5 year-old acacia trees in the baseline system was 8 cm (±0.5 cm). We assumed comparable acacia growth in Ta Bhing due to relatively similar soil and rainfall condition.

Profitability analysis

Net income per year and NPV were used as two indicators of economic benefits. The NPV (USD per hectare) was calculated as follows:

$$NPV = \sum_{t=0}^{t=n} \frac{R_t - C_t}{(1+i)^t}$$

Where R_t is revenue at year *t* (USD per hectare), C_t production cost at year *t* (USD per hectare), and *i* is the annual discount rate set as 6.5% (Viet Nam Agribank 2017 interest rate). Both net income per year and NPV were considered costs for land preparation and plot management to include seedling costs and labour costs for weeding. The cost for transporting timber can vary depending on plot location. In this study, we used USD 20 per ton or cubic metre (the former for pulp and paper, the latter for timber) for average transportation cost, as informed by local authorities. For the profitability analysis, we used VND 1,450 (≈ USD 0.06) kg^{-1} as the price of fresh cassava and VND 200,000 (≈ USD 9) m^{-3} for the acacia logs as farm gate price. For acacia timber, according to local authorities, the price of 8, 12 or 14-year acacia timber was VND 2 million (≈ USD 90) m^{-3}. The detail of cost components is given in Table 13 below.

3. Results

Growth and production of acacia

The stem diameter at breast height of four-year old acacia trees in the baseline system according to the WaNuLCAS model was 9 cm (Table 11), which is comparable to the observed value. The wider tree spacings produced larger stem diameter under the same rotation length. The stem diameter in the systems for timber purpose ranged between 27-31 cm for those with 8-year rotation, 35-37 cm with 12-year rotation, and 44-47 cm with 14-year rotation (Table 11).

The timber production per tree was higher with wider tree spacing and longer rotation, but this is not the case in terms of timber production and time-averaged carbon storage per hectare. For example, System 5 (3.5 x 3.5 m) and System 6 (4 x 4 m) with 12-year rotation provided higher timber production and time-averaged C stock per hectare than System 7 (5 x 5 m) and 8 (6 x 6 m) with 14-year rotation.

Table 11. Production and economic return of different acacia-cassava systems

System	Tree spacing (m)	Initial density (trees ha^{-1} year^{-1})	Rotation (years)	Stem diameter (cm)*	Timber production (m^3 tree^{-1})*	Total timber production (m^3 ha^{-1})*	C stock** (ton ha^{-1})*	Income of the system# (USD ha^{-1} year^{-1})	NPV (USD ha^{-1})
4-year rotation									
Baseline	1 × 1	10,000	4	9	0.03	287	37	175	221
1	2 × 2	2,500	4	15	0.07	187	23	311	824
2	3 × 3	1,111	4	19	0.12	136	16	364	972
8-year rotation									
3	3 × 3	1,111	8	27	0.24	271	39	1,028	4,689
4	4 x 4	625	8	31	0.33	208	30	875	4,900
More than 8-year rotation									
5	3.5 × 3.5	816	12	35	0.42	346	53	1,188	6,489
6	4 × 4	625	12	37	0.49	304	46	1,077	5,824
7	5 × 5	400	14	44	0.68	273	42	889	4,833
8	6 × 6	278	14	47	0.77	213	33	774	4,107

**Projected by WaNuLCAS. The figures for stem diameter and timber production are the model's projection at the end of rotation year. ** Time-averaged carbon stock in the system. #Total income divided by rotation year and includes income from cassava.*

Net income

Although System 1 and 2 generated lower timber production per hectare, the annual incomes that could be derived from these systems were higher compared to the baseline because of reduced costs for labour. The baseline incurs higher labour cost because of the high tree density (10,000 trees per hectare). However, if labour cost was borne by the household in all systems, then System 1 would have lower profitability compared to the baseline while the income of System 2 would be comparable to the baseline. Among the eight alternative systems, System 3, 5 and 6 returned higher incomes per year, NPV, time-averaged C stocks and timber production per hectare compared to other systems (Table 11).

Income share from cassava

Income per year from cassava was low in the baseline system because of stronger interaction in above and belowground resources with adjacent acacia trees (Table 12). The wider tree spacing in System 1 and 2 that have similar rotation year with the baseline system induced a higher cassava growth resulting in higher annual income. However, a wider tree spacing in systems with longer rotation than four years not necessary led to higher cassava production and income per year. For example, in System 5 wherein acacia trees are planted 3.5 m apart for 12-year rotation, the income per year from cassava was low due to a strong competition in resources with mature acacia trees. This resulted in the lowest income share from cassava in System 5, compared to the other systems. The highest income share from cassava was found in System 2, wherein the acacia trees are planted 3 m apart with four-year rotation and three seasons of cassava.

Table 12. Income share from acacia and cassava

System	Tree spacing (m x m)	Rotation (years)	No. of cassava seasons	Total income (USD ha^{-1} year^{-1})	From acacia (USD ha^{-1} year^{-1})	Cassava (USD ha^{-1} year^{-1})	% Income Acacia	% Income Cassava
Baseline	1 x 1	4	1	175	138	37	79	21
1	2 × 2	4	2	311	206	105	66	34
2	3 × 3	4	3	364	137	227	38	62
3	3 × 3	8	3	1,028	915	113	89	11
4	4 × 4	8	4	875	689	186	79	21
5	3.5 × 3.5	12	3	1,188	1,090	99	92	8
6	4 × 4	12	4	1,077	953	124	88	12
7	5 × 5	14	5	889	731	158	82	18
8	6 × 6	14	5	774	561	214	72	28

Investment cost

Among the alternative systems, the lowest investment cost (the total of establishment and maintenance cost) belongs to System 2 and 3, namely when the acacia trees are planted 3 m apart with three seasons of cassava (Table 13). The other systems have higher investment cost than USD 1,000 ha^{-1}. The highest investment cost belongs to System 7, especially due to the establishment cost for five seasons of cassava. According to farmers, the maintenance cost for weeding and forest protection are only necessary in the first three years of short- or longer-rotation acacia systems.

Table 13. Investment cost of the alternative acacia-cassava systems

Cost component	Systems 1	2	3	4	5	6	7	8
Establishment cost								
I. *Labour cost*								
Land preparation (USD ha^{-1})	139	139	139	139	139	139	139	139
Digging the pit for acacia (USD ha^{-1})	132	59	59	33	43	33	21	15
Filling the pit for acacia (USD ha^{-1})	66	29	29	16	21	16	11	7
II. *Seedling cost*								
Seedling cost (USD ha^{-1})	125	56	56	31	41	31	20	14
Transportion for acacia seedlings (USD)	78	35	35	19	25	19	12	9
Maintenance cost								
I. *First year*								
Labour for replanting dying acacia (USD)	11	5	5	3	4	3	2	1
New acacia seedling (USD)	13	6	6	3	4	3	2	1
1st weeding (USD ha^{-1})	89	89	89	89	89	89	89	89
2nd weeding (USD ha^{-1})	62	62	62	62	62	62	62	62
Forest protection (USD ha^{-1})	10	10	10	10	10	10	10	10

II. *Second year*	62	62	62	62	62	62	62	62
1st weeding (USD ha^{-1})	89	89	89	89	89	89	89	89
2nd weeding (USD ha^{-1})	62	62	62	62	62	62	62	62
Forest protection (USD ha^{-1})	10	10	10	10	10	10	10	10
II. *Third year**	62	62	62	62	62	62	62	62
1st weeding (USD ha^{-1})	89	89	89	89	89	89	89	89
2nd weeding (USD ha^{-1})	62	62	62	62	62	62	62	62
Forest protection (USD ha^{-1})	10	10	10	10	10	10	10	10
Cost for cassava as intercrops								
Number of season	2	3	3	4	3	4	5	5
Total cost (USD ha^{-1})	75	162	162	338	253	338	542	542
Total establishment cost of trees (USD ha^{-1})	539	317	317	239	270	239	203	183
Total maintenance cost (1st year) (USD ha^{-1})	185	172	172	167	169	167	165	164
Total maintenance cost (2nd year) (USD ha^{-1})	161	161	161	161	161	161	161	161
Total maintenance cost (3rd year) (USD ha^{-1})	161	161	161	161	161	161	161	161
Total investment cost for the system (USD ha^{-1})	1,121	973	973	1,066	1,014	1,066	1,232	1,211

**no maintenance cost for the system after the third year*

Feasible alternative systems for farmers and tradeoff with carbon storage

Comparing the baseline with the other four-year rotation acacia systems (i.e. System 1 and 2), the alternative systems provided higher income if the labor cost was borne by households, and thanks to income from cassava in the second or third year after tree planting. If the priority is to provide higher and more stable income in terms of longer cash flow, then System 2 is a feasible option. Between System 1 and 2, the latter has no income gap between investment and timber harvest, and much smaller gap between investment cost and total income from cassava before timber harvest (Table 14). Both in System 1 and 2, however, the loan return period should not be shorter than four years. In terms of time-averaged carbon storage, System 2 has lower carbon storage compared to the baseline and System 1, resulting in a tradeoff between economic and mitigation objectives.

Among the systems with eight-year rotation, the income from System 3 is higher than System 4, but the latter provided longer cash flow due to more cassava seasons. The longer cash flow resulted in a smaller gap between investment cost and total income from cassava before timber harvest (Table 14). In case the priority is to reduce the income gap between years, System 4 is a more feasible option for farmers. Similar to the 4-year rotation systems, System 4 is preferable in terms of income stability, but inferior in terms of time-averaged carbon storage compared to System 3.

Among the systems with longer than 8-year rotations, the systems with more cassava seasons are preferred options if farmers are short of cash flow, for example System 7 and 8, although the total income from these two systems was lower than from System 5 and 6, which have shorter rotations and fewer cassava seasons. A tradeoff between economic and mitigation occurred as System 7 and 8 were more feasible options for farmers than System 5 and 6.

Table 14. Gap between investment cost and total income from cassava in the alternative systems

System	Tree spacing (m x m)	Rotation (years)	No. of cassava seasons	Investment cost (USD ha^{-1})	Total income from cassava (USD ha^{-1})	Gap between investment and income* (USD ha^{-1})
1	2 × 2	4	2	1,121	210	911
2	3 × 3	4	3	973	681	292
3	3 × 3	8	3	973	339	634
4	4 × 4	8	4	1,066	744	322
5	3.5 × 3.5	12	3	1,014	297	717
6	4 × 4	12	4	1,066	496	570
7	5 × 5	14	5	1,170	790	380
8	6 × 6	14	5	1,211	1,070	141

** Gap between investment cost and total income from cassava before timber harvest*

4. Discussion

Informal interviews with farmers in the two study communes they preferred short-rotation acacia systems to longer rotations, because the current acacia seedlings were only suitable to harvest within four years after plantation. They claimed that exceeding this period the wood quality declined and the logs could not be sold. Furthermore, they reported that the communes generally experienced a four-to-five-year cycle of extreme weather events, particularly heavy storms, that damaged longer rotation acacia systems.

The common acacia variety in the two study communes was the hybrid *Acacia mangium x auriculiformis*. Sein and Mitlohner (2011) highlighted the superior quality of this hybrid variety compared to its 'parents' *Acacia mangium* and *Acacia auriculiformis*, indicating that the hybrid could be cultivated in longer rotations. The qualities included a slightly higher wood density (Kha 2000) compared to its parents; deeper root system than either of the parents and therefore more resistant to strong winds (IUFRO 2000) and suitability to stabilize sloping land and reduce the risk of soil erosion (Sein and Mitlohner 2011).

Furthermore, the wood of the hybrid could produce higher paper quality, and the hybrid has two-to-four times more rhizobium nodules (in weight and number) compared to its parent species which increased its capability for soil improvement (Kha 2000). Such documented benefits call for further discussion with farmers and local authorities to understand their perspective on why they consider variety in suitable for longer-rotation forest plantation.

Another constraint in introducing the alternative systems that smallholder farmers are generally risk-averse, and reluctant to test alternative forest-plantation systems without successful demonstration trials. This response was understandable since many of the farmers in the two study communes were living below the poverty lines and forest plantations generated substantial income especially for those with small landholdings and without income from other sources (Catacutan et al 2017). Therefore, trying new, unproven systems carried a high economic risk. The initiative to establish demonstration trials should come from local government by allocating suitable lands, to show the benefits of timber-based systems.

Pistorius et al (2016) mentioned that the income gap between investment and timber harvest is the main challenge in encouraging smallholder farmers to adopt longer-rotation forest plantation systems. In the systems evaluated in this study, the income gap was reduced by enabling more seasons of cassava. Furthermore, the longer and accumulated cash flow from cassava still could not fully cover the investment cost until the timber harvesting time. Therefore, it will be difficult to adopt forest plantation systems with longer rotation than four years, let alone if they had to engage in loan systems with short payback period to cover the investment. Among the eight alternative systems, only System 3 provided no income gap due to cash flow from cassava, followed by income acacia logs in the fourth year.

Considering inputs from local authorities in Quang Nam and Thua Thien Hue province, Catacutan et al. (2017) designed five complex alternative acacia-based systems integrating acacia, native tree species, cassava as annual crop, and understorey. Examples of native tree species considered for the systems were *Melia azedarach* and *Litsea glutinosa*, with purple amomum (*Amomum longiligulare*) as understorey. Both tree species were chosen based on farmers and local authorities' knowledge that melia could grow well in Ta Bhing and litsea in Phuoc My. Farmers also considered these two species as native to the communes. A tree-suitability analysis confirmed that both species had high to moderate suitability in Ta Bhing and Phuoc My (Catacutan et al 2017).

The complex alternative systems consisted of three designs namely double-row, block-design, and two systems with gradual transition from short- to long-rotation timber plantation. The first two have a design with melia and with litsea as the tree species, whereas the third was only with acacia. The spatial and temporal cover of annual crop and understorey in the systems are dynamic adapting to tree canopy's development. For example, Figure 15 describes a partial layout of the double-row design that alternates two rows of acacia with two rows of litsea, with 3 m apart. The spacing for acacia trees is 4 x 4 m and 2 x 2 m for litsea. Acacia is planted for 12 years for timber and litsea for bark production. Cassava is planted with 0.5 x 0.5 m spacing and amomum with 1 x 1 m between trees and between the double rows. Over time, along with an increase in tree canopy's cover, the cassava density is reduced and eventually replaced by amomum as understorey. Another double-row design is with melia, where the trees are planted with 2 x 3 m spacing.

In the block design, acacia is also planted with 4 x 4 m and litsea with 2 x 2 m spacing. In one hectare, there are 12 rows of acacia within its block and 24 rows of litsea or melia within respective block. The distance between blocks of acacia and litsea or melia is 3 m. The alley between trees is planted with cassava for four years and then replaced by amomum in the fifth year. Similar to the double-row design, cassava density is reduced as the canopy closes and ultimately replaced by amomum in the fifth year. The spatial arrangement from year 2 to 12 in this design is similar to the pattern in the double-row design.

In the gradual transition system, 2,500 acacia trees are initially planted 2 x 2 m. In year four, 50% thinning is reducing the density to 1,250 trees per hectare. In the eighth year, a subsequent 50% thinning is applied, further reducing tree density from 1,250 to 625 trees per hectare. The remaining trees are harvested for timber in the twelfth year. The harvested acacia trees in the fourth and eighth years are marketed for pulp and paper.

Due to their complexity, especially the dynamic cover of annual crop and understorey over time, these alternative systems could not be properly simulated by the WaNuLCAS model. By relying on secondary data, without assessing

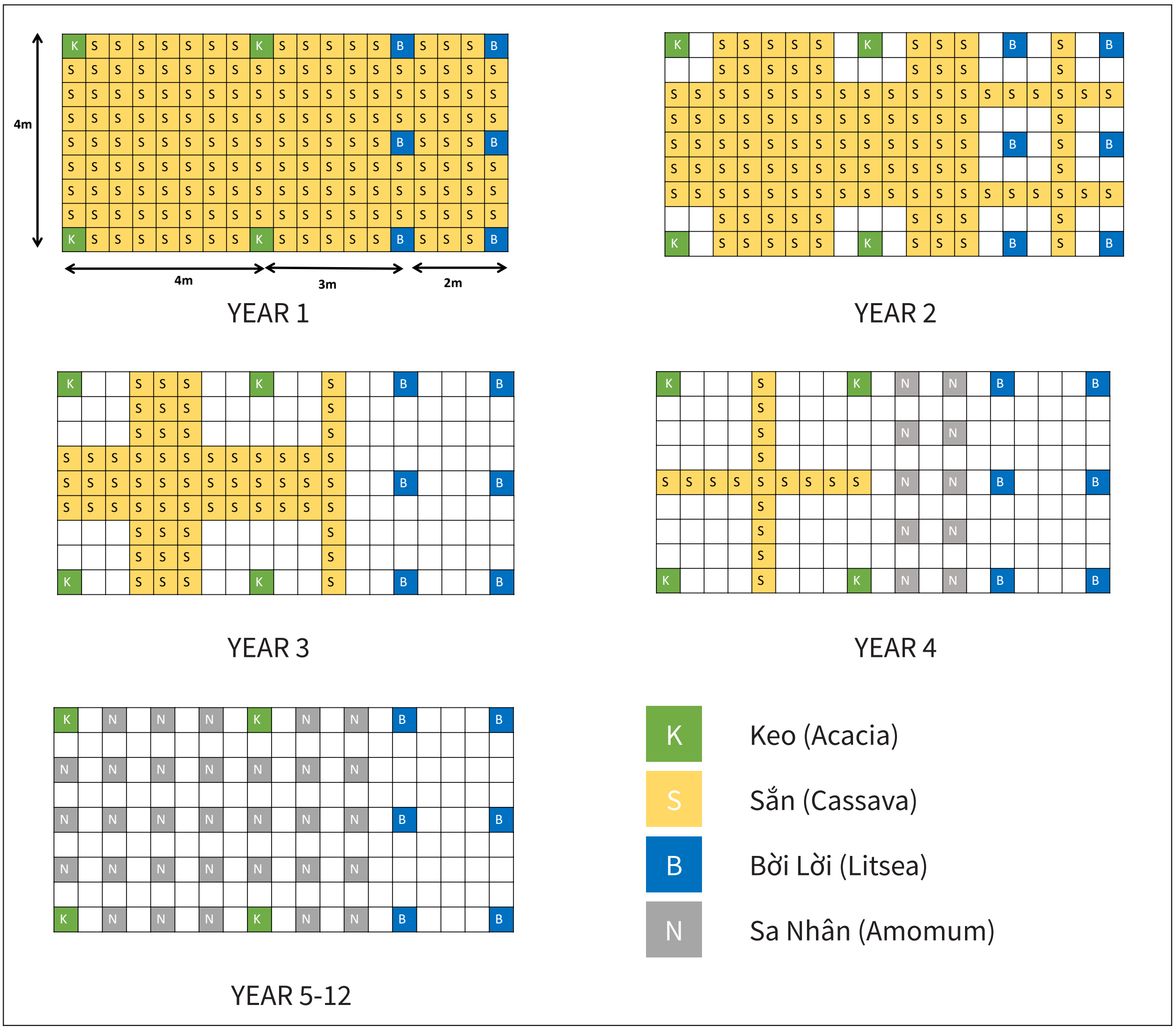


Figure 15. Partial layout of 1 ha double-row acacia-litsea-cassava-amomum system with 12-years rotation cycle for acacia trees.

interaction among plant components with the model, the authors provided the first estimation of potential economic return and carbon storage of the systems. Comparisons among the systems informed that owing to early bark harvesting of the litsea, the double-row and block design of the acacia-litsea-cassava-amomum system could potentially reduce the income gap and return the investment six years after planting. Systems with melia provided investment return after within eight years, whereas a gradual timber-transition system after seven years. The authors concluded that optimizing the space in the system with dynamic spatial and temporal distribution of annual crop and understorey, and the integration of tree species, such as litsea for bark production, that can provide earlier income to farmers is worth to explore further by establishing demonstration trials. Improving micro-finance and loan systems that can provide more flexibility in terms of payback, and providing opportunities and access to farmers to engage in other sources of income, are still deemed as very necessary.

Related to alternative designs of forest plantation systems with native tree species, a project by UNIQUE forestry and land use GmbH, Climate Focus and the Institute of Resources and Environment of Hue University, developed silvicultural models for Thua Thien Hue and Quang Nam provinces with three native-tree species—*Tarrietia javanica*, *Dipterocarpus alatus* and *Hopea odorata*—to provide options the short-rotation acacia monocultural system (Pistorius et al 2016). They proposed three systems, with six-year acacia plantations for wood chips as the baseline. The first system was an acacia sawlog production system extending to a 12-year rotation. The second was a rapid transition from acacia monoculture into a silvicultural model with native-tree species replacing acacia in the fourth and sixth years after planting. The third was a slow transition to native-tree species' plantations that could be harvested within 16 years. The Biodiversity Conservation Corridor (BCC) project in Quang Nam and Thua Thien Hue provinces had similar programs for forest-plantation improvement, testing some 'pure' forestry models with acacia, *Machilus odoratissima* Nees and *Mangletia glauca*. All these long-rotation plantation systems however shared similar concern the need to cover farmer's income gap between investment and timber harvesting, either by integrating profitable short-term crops into the systems or by enhancing access to other income sources, either farm or non-farm, and loan system with more flexible date of payback.

Finally, the trade-off between economic and mitigation purpose can be potentially reconciled if a scheme that provides rewards to higher carbon storage in forest plantation systems exists. The rewards can provide a solution to overcome the income gap in case they are relatively substantial in terms of financial value, and farmers can receive on e.g. annual or shorter-term basis. In Viet Nam, there is a scheme for indirect payment for forest ecosystem service (PFES) promulgated as a national Decree (namely Decree 99/147), with fixed reward/payment rate to ecosystem service provided by forests. At the moment, however, the Decree only regulates payment for forest water service, not other services, such as carbon storage for mitigation. Efforts to amend the regulations provided in the Decree, or through REDD+ schemes for C-reward are therefore necessary for combining afforestation programs with mitigation interventions more effectively, especially in the regions with production forest areas in Viet Nam. The reward and more permanent forest plantation systems, through better control of soil erosion and sedimentation, higher sub-surface and ground flow, as well as enrichment of on-farm biodiversity, above and belowground, will contribute to the maintaining or restoring the multiple functions of the National Reserve.

5. Conclusion and Recommendation

The forest plantation systems discussed in this chapter represent alternative designs to short-rotation acacia-cassava systems for pulp and paper, the most popular forest plantation system in Viet Nam.

If farmers largely depend on acacia system as source of income, the four-year rotation for pulp and paper purpose with 3 x 3 m tree spacing that allows three seasons of cassava is the most feasible option. This is due to longer cash flow until the third year after tree planting, followed by income from acacia logs in the fouth year. In this case, there is no income gap between investment and tree harvesting, and the loan payback can be set at the fourth year. In terms of time-averaged carbon storage, however, this system is inferior compared to other four-year rotation system including the baseline.

Forest plantation systems for timber with rotation longer than four years, can be introduced to farmers with opportunities and access to other sources of income, either farm or non-farm, that can be used to cover the income gap between investment, timber harvesting and loan payback. Under this condition, the forest plantation system with 3.5 x 3.5 m or 4 x 4 m acacia spacing, both with 12-year rotations, provide the highest income per year, time-averaged carbon storage and timber production.

Since farmers are risk averse, encouraging them to adopt selected alternative forest plantation systems will need the local authorities to establish demonstration trials to provide on-ground examples. In the same time, improvement in micro-finance and loan system for farmers to meet the loan payback and developing market links for products other than acacia for pulp and paper are necessary. Combined efforts will encourage the adoption of better-performance forest plantation systems in Viet Nam in general.

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