land

MDPI

Article

Fruit Tree-Based Agroforestry Systems for Smallholder Farmers in Northwest Vietnam—A Quantitative and Qualitative Assessment

Van Hung Do [1,2,*], Nguyen La [1], Rachmat Mulia [1], Göran Bergkvist [2], A. Sigrun Dahlin [3], Van Thach Nguyen [1], Huu Thuong Pham [1] and Ingrid Öborn [2,4]

1 World Agroforestry (ICRAF) Vietnam, 249A Thuy Khue Street, Thuy Khue Ward, Tay Ho District, Hanoi, Vietnam; l.nguyen@cgiar.org (N.L.); r.mulia@cgiar.org (R.M.); n.thach@cgiar.org (V.T.N.); p.thuong@cgiar.org (H.T.P.)
2 Department of Crop Production Ecology, Swedish University of Agricultural Sciences (SLU), P.O. Box 7043, 750 07 Uppsala, Sweden; goran.bergkvist@slu.se (G.B.); ingrid.oborn@slu.se (I.Ö.)
3 Department of Soil and Environment, Swedish University of Agricultural Sciences (SLU), P.O. Box 7014, 750 07 Uppsala, Sweden; sigrun.dahlin@slu.se
4 World Agroforestry Centre (ICRAF) Headquarters, UN Avenue, P.O. Box 30677, Nairobi 00100, Kenya
* Correspondence: d.hung@cgiar.org

Received: 30 October 2020; Accepted: 13 November 2020; Published: 17 November 2020

Abstract: Rapid expansion of unsustainable farming practices in upland areas of Southeast Asia threatens food security and the environment. This study assessed alternative agroforestry systems for sustainable land management and livelihood improvement in northwest Vietnam. The performance of fruit tree-based agroforestry was compared with that of sole cropping, and farmers' perspectives on agroforestry were documented. After seven years, longan (*Dimocarpus longan* Lour.)-maize-forage grass and son tra (*Docynia indica* (Wall.) Decne)-forage grass systems had generated 2.4- and 3.5-fold higher average annual income than sole maize and sole son tra, respectively. Sole longan gave no net profit, due to high investment costs. After some years, competition developed between the crop, grass, and tree components, e.g., for nitrogen, and the farmers interviewed reported a need to adapt management practices to optimise spacing and pruning. They also reported that agroforestry enhanced ecosystem services by controlling surface runoff and erosion, increasing soil fertility and improving resilience to extreme weather. Thus, agroforestry practices with fruit trees can be more profitable than sole-crop cultivation within a few years. Integration of seasonal and fast-growing perennial plants (e.g., grass) is essential to ensure quick returns. Wider adoption needs initial incentives or loans, knowledge exchange, and market links.

Keywords: fruit tree-based agroforestry; economic benefits; ecosystem services; farmer perspectives; resource competition; systems improvement; uptake and expansion

1. Introduction

The United Nations sustainable development goals and Agenda 2030 include poverty eradication, ending hunger, and environmental restoration, among other objectives [1]. Related targets are to implement resilient agricultural practices that increase productivity and production, and to maintain ecosystems that strengthen the capacity for adaptation to climate change and risks and improve land health [2]. Agroforestry, a planned combination of trees and crops with or without livestock on the same land, is increasingly being recognised as a sustainable system to reconcile agricultural production and environmental protection [3,4]. When combined with contour planting on sloping uplands, agroforestry is an effective land-use system to reduce soil erosion and maintain soil fertility [5,6].

In addition, as an integrated and more permanent farming system, agroforestry can generate diverse economic, ecological, and social benefits [3,7] beyond those provided by sole-crop farming systems.

Mountainous areas in the lower Mekong region are experiencing severe forest and land degradation, driven by expansion of unsustainable farming practices [8]. For example, in northwest Vietnam, sole-maize cultivation is widespread over hills and fragile sloping land [9,10]. The northwest region is home to ethnic minorities with a poverty rate of about 14% in 2016, or 8% higher than the average poverty rate at the national level, according to the 2017 statistic book of Vietnam. Around 60% of land in the region has a slope of ≥ 30% [11]. Soil degradation in the region is acute, resulting in low crop productivity [12–16].

Driven by high economic benefits, smallholder fruit-tree cultivation has recently expanded in several provinces in northwest Vietnam [17]. For example, the total area of fruit-tree plantations in Dien Bien, Yen Bai, and Son La provinces reached 58,464 ha in 2018, a 51.4% increase compared with 2015. The main fruit commodities are longan (*Dimocarpus longan* Lour.), mango (*Mangifera indica* L.) and plum (*Prunus domestica* L.). There is also some production of son tra (*Docynia indica* (Wall.) Decne), also called H'Mong apple, which is native to the region and one of 50 special fruits of Vietnam [18]. Son tra is a multipurpose tree, restoring natural forest cover and producing fruit [19].

Despite recent developments, farmers in the northwest region generally lack technical knowledge of agroforestry [9,20], including fruit tree-based agroforestry, in terms of adequate species composition, optimal plant arrangement and spacing, and management practices to optimise delivery of products and ecosystem services over time. Good management could better utilise potential economic, social, and environmental benefits of diversified tree-based farming systems. Farmers in the region usually develop "temporary" agroforestry by combining fruit trees and annual crops such as maize or cassava, and vegetables, in the early years of planting before tree canopy closure, most often in the first to third year after tree planting [21]. Reliable scientific-based information on permanent combinations of fruit trees and annual crops is necessary to promote agroforestry systems that can offer long-term and diverse income sources through product diversification to farmers in the region.

This study assessed the performance of two fruit-tree agroforestry systems in order to obtain knowledge on sustainable farming systems for the region. Quantitative and qualitative approaches were used to assess the agroforestry systems: longan–maize–forage grass and son tra–forage grass. Specific objectives were (i) to evaluate the productivity and profitability of agroforestry systems compared with sole-tree and annual crop systems over the seven years after establishment and (ii) to survey farmers on the performance of fruit tree-based systems to identify possibilities for improvement and wider-scale development.

2. Materials and Methods

2.1. Site Description

On-farm experiments with two agroforestry systems, longan (*Dimocarpus longan* Lour.)–maize (*Zea mays* L.)–forage grass and son tra (*Docynia indica* (Wall.) Decne.) –forage grass, were carried out on three farms each, using farms as replicates. The farms were situated in Van Chan district (21.56° N, 104.56° E; 374 m a.s.l.) in Yen Bai province and Tuan Giao district (21.56° N, 103.50° E; 1267 m a.s.l.) in Dien Bien province, northwest Vietnam (Figure 1). The climate at both sites is sub-humid tropical, with a rainy season from April to October and a dry season from November to March. Mean annual temperature is 18.6 °C and 21 °C; and annual rainfall is 1200–1600 mm and 1700–2000 mm in Tuan Giao and Van Chan, respectively. Mean slope of the experimental plots was 27% at both sites.

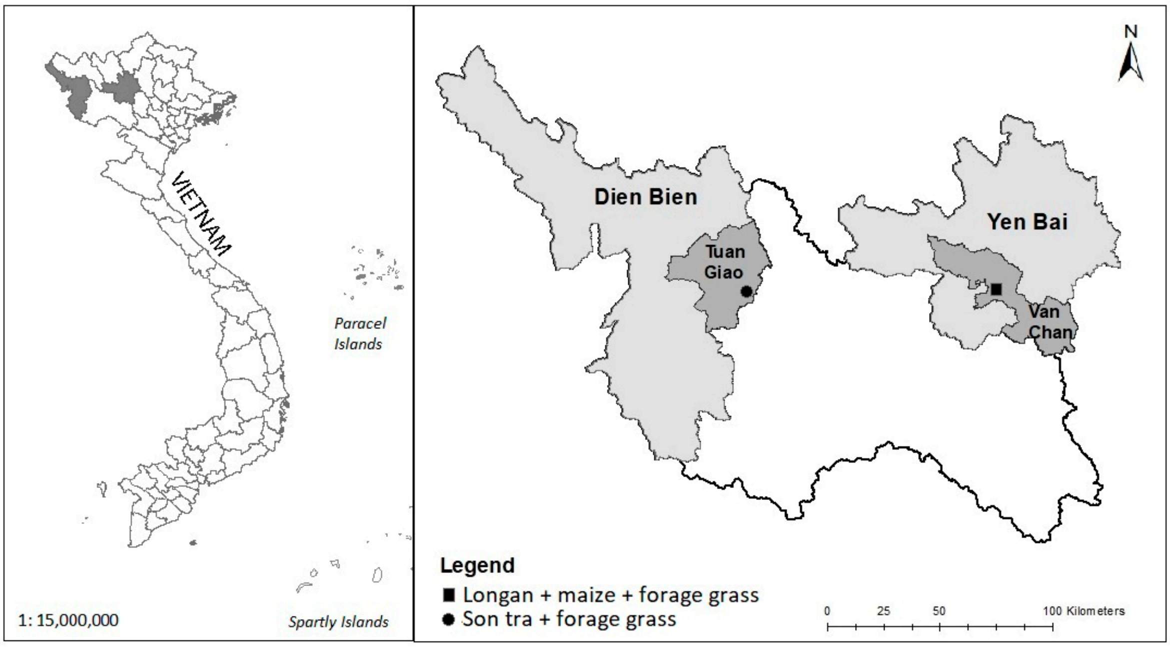

Figure 1. Location of the agroforestry experiments with longan-maize-forage grass in Van Chan District, Yen Bai province, and son tra-forage grass in Tuan Giao District, Dien Bien province, north-west Vietnam. Replicate trials were established on three farms in each district.

The soil profile at each site was characterised at the start of the experiments. The soils at Van Chan were silty clay loams, with, on average, pH 4.7, 1.7% soil organic matter (SOM), 0.12% total nitrogen (N), 0.02% total phosphorus (P), and 0.50% total potassium (K). The soil at Tuan Giao was silty clay, with, on average, pH 4.6, 3.8% SOM, and total N, P, and K of 0.24%, 0.02%, and 0.85%, respectively. SOM and total N, and P, and K were determined by the Walkley–Black method [22], Kjeldahl method [23], and digestion with mixed strong acids [24,25], respectively. Available soil P (Bray II) [26] was 5 mg kg^{-1} at Van Chan and 9.2 mg kg^{-1} at Tuan Giao.

2.2. Field Experiment Design

Both experiments were designed as randomised complete blocks with three replicates on three different farms. At Van Chan, the experiment lasted seven years (2012–2018). The agroforestry system consisted of longan, maize and guinea grass (*Panicum maximum* Jacq.) (LMG) and was compared with sole-crop maize (SM) and sole-crop longan (SL) (Figure 2a). The sole-crop longan was planted with 5 m row spacing and 5 m spacing between trees within rows (400 trees ha^{-1}). In the LMG system, longan was planted at 5 m spacing in double rows along contour lines, with 15 m between two double rows (240 trees ha^{-1}). Guinea grass was planted in double rows 0.5 m from the trees, and the distance between two rows was 0.5 m. The seed rate, row spacing, and distance between plants for sole-crop maize was 15 kg ha^{-1}, 0.65 m, and 0.3 m, respectively. The seed rate was 10–20% lower in the LMG system, since maize was not sown in the grass strips or within 0.5 m from the canopy of longan, so maize plants were sown with the same row spacing and plant distance in both systems. The longan variety used in the experiment was late maturing. The maize variety used in all cropping systems was the hybrid PAC 999.

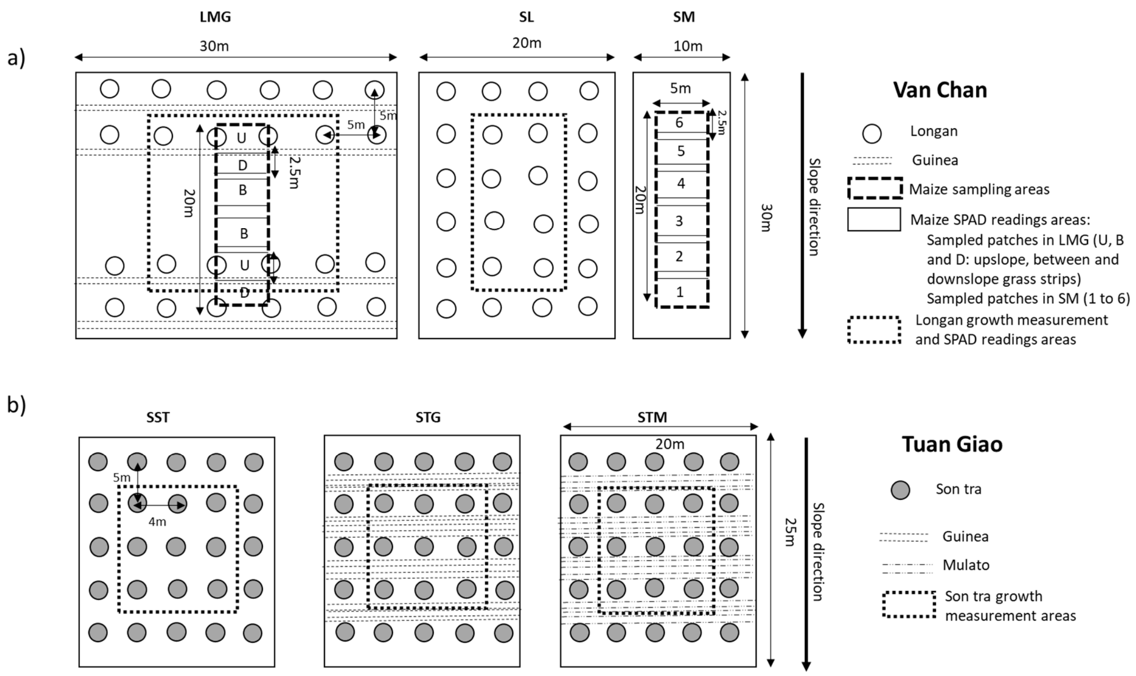

Figure 2. Design of field experiments: (**a**) Van Chan: sole-crop maize (SM), sole-crop longan (SL), and longan–maize–forage grass (LMG), U: upslope grass strips, D: downslope grass strips, B: between grass strips. The plot area was 300 m^2 for sole-crop maize, 600 m^2 for sole-crop longan, and 900 m^2 for the LMG agroforestry system; (**b**) Tuan Giao: sole-crop son tra (SST), son tra–guinea grass (STG), and son tra–mulato grass (STM). Plot area was 500 m^2.

The experiment at Tuan Giao lasted six years (2013–2018) and comprised three treatments: sole-crop son tra (SST), son tra–guinea grass (STG), and son tra–mulato grass (*Brachiaria* sp.) (STM). In all treatments, son tra was planted with 5 m row spacing and with 4 m spacing between trees within rows (500 trees ha^{-1}). Seven rows of guinea grass or mulato grass were planted between two rows of son tra in the STG and STM system, respectively (Figure 2b). The distance between the grass rows was 0.5 m and the strips were 1 m from the son tra rows. Grafted son tra seedlings were used, while guinea grass and mulato grass cuttings were obtained from a nursery.

Mineral NPK fertiliser was applied annually to maize in SM and LMG (NPK 5–10–3) as a basal application, with a topdressing with urea (46% N) and potassium chloride (48.6% K) at maize stage 6–7 fully expanded leaves (50%) and before silking (50%). In the SL and LMG treatments, 15 kg of composted animal manure and 1 kg of mineral fertiliser (NPK 5–10–3) were applied per longan tree in year 1. In years 2–7, 1 kg mineral fertiliser (NPK 5–10–3) was applied per tree, while in years 5–7, 20 kg of animal manure were applied per tree. In SST, STG, and STM, son tra received 15 kg composted animal manure and 1 kg mineral fertiliser (NPK 5–10–3) per tree in year 1 and an annual topdressing of 0.9 kg mineral fertiliser (NPK 5–10–3) per tree in years 2–6. In both experiments, the purpose of planting grass strips was to utilise nutrients in runoff, and therefore no nutrients were applied to the forage grasses. For more information about the experiments in Van Chan and Tuan Giao, see Table S1 in Supplementary Materials (SM).

2.3. Data Collection in the Field Trials

2.3.1. Tree Growth and Tree/Maize/Grass Yield Determination

Eight longan and nine son tra trees in each plot were measured every three months for the whole experimental period to determine base diameter (consistently measured at a height of 10 cm from soil surface because the trees were still small in the early years of experiments), canopy diameter, and plant height. Fresh weight biomass production of forage grasses was measured monthly by harvesting a

5 m forage grass strip per plot and weighing the biomass. Maize grain production was measured by harvesting a 5 × 20 m sub-area within each plot, air-drying the cobs outdoors before shelling and weighing. Fruit yield per plot was determined by collecting and weighing the fruit of all trees at harvest.

2.3.2. Competition for Resources in the Longan–Maize–Forage Grass System

An in-depth study of the variation in plant N concentration, growth, and productivity was carried out in year 7 of the experiment at Van Chan. Maize stover (stems, leaves, cobs, and covers) and grain were harvested at physiological maturity and weighed to determine their fresh weight. Fresh sub-samples of these materials were weighed and dried to constant weight. The ratio between fresh and dry weight was calculated and used to calculate the total harvested dry weight of each material. Within the LMG plots, measurements and sampling were performed in duplicate patches at three positions on the plots; 2.5 m upslope of the grass strips, between grass strips (4 m distance), and 2.5 m downslope of the grass strips (marked U, B, and D, respectively, in Figure 2a). The sampled area of each patch was 2.5 × 5 m. Similar sampling of patches was carried out in SM.

Plant N status was monitored in LMG and SM using a soil plant analysis development (SPAD) 502 Plus chlorophyll meter to determine the amount of chlorophyll present in plant leaves [27], as a proxy for N concentration [28]. The SPAD readings and maize plant height measurements were carried out at four vegetative stages of the maize crop (3–4, 6–7, and 10–11 fully expanded leaves, and silking). In each sampled patch, five maize plants along a diagonal were used for measurements on each occasion. The third, sixth, ninth, and index leaves were used as standard leaves for the stages 3–4, 6–7, and 10–11 fully expanded leaves and silking, respectively. The SPAD readings were taken at two-thirds of the distance from the leaf tip towards the stem [29]. In grass, the SPAD readings were carried out on 10 new fully expanded leaves [30] and height measurements were made on 10 grass plants every month in a 5 m section of each grass strip before cutting during the maize season. For longan, the SPAD readings were taken on eight longan trees within LMG and SL (Figure 2a) at the beginning and end of the maize season. One fully expanded mature leaf on the east, west, south, and north side of each tree was selected. The third leaflet position from the terminal leaf of each fully expanded mature leaf was used as the standard leaf for SPAD readings [31].

2.3.3. Land Equivalent Ratio

A land equivalent ratio (LER) was used to compare yields in the different treatments, with LER greater than 1.0 indicating that the mixed system (intercrop) was more advantageous than the sole crop. LER was calculated as [32]:

$$\text{LER} = \text{Intercrop1/Sole crop1} + \text{Intercrop2/Sole crop2} + \ldots\ \ldots \tag{1}$$

The fresh yield of sole-crop guinea grass and sole-crop mulato grass was calculated from their average reported dry biomass yield, i.e., 30 ton ha^{-1} year^{-1} [33] and 18.5 ha^{-1} year^{-1} [34], respectively, assuming a dry matter content of 23% [35] and 21% [36], respectively. The LER of the LMG, STG, and STM systems was calculated annually.

2.3.4. Profitability

Cost-benefit analysis was performed for each agroforestry and sole-crop treatment, taking into account details of investment costs, maintenance costs, and revenue from products sold across monitoring years. Net profit was calculated by subtracting all input costs from gross income. Annual inputs included fertiliser, pesticide, labour, planting materials, etc. Total annual income was calculated based on yield and the price obtained for the different products at harvest. Data on the cost of inputs and market prices for products were obtained from the provincial extension departments covering the study sites (see Table S2 in Supplementary Materials). Net profits of each system were calculated as:

$$N = T - I \quad (2)$$

where N is net profit, T is total income, and I is total cost of all inputs, all in USD ha^{-1} year^{-1}.

2.4. Selection of Participants for Farmer Group Discussions

Farmers' perceptions and aspirations for the agroforestry systems involving longan–maize–forage grass (in Yen Bai) and son tra–forage grasses (in Dien Bien) were documented in group discussions carried out in January 2020. For each agroforestry system, two villages were selected: one village that hosted an experiment (experiment-hosting village) and a nearby village (non-hosting village) (Table S3 in Supplementary Materials). In each village, farmers who were familiar with or had observed the agroforestry system in the field experiment were selected and divided into three groups based on resources and gender (poor female, poor male, non-poor mixed female and male). Farmers hosting the experiments were interviewed individually, using the same open-ended questions as in the group discussions. In total, there were six different farmer groups at each study site, three in the experiment-hosting village and three in the non-hosting village, plus the three farmers hosting the experiments at each site (experiment-hosting famers). The Vietnamese government's poverty scale [37] was used to capture responses from farmers experiencing different levels of poverty. The questions (see Table S4 in Supplementary Materials) were posed by an interview team, including three researchers from World Agroforestry (ICRAF) in Vietnam who served as facilitators. All interviews were recorded and the responses were transcribed and translated into English by the researchers after each group discussion. The responses from farmers belonging to the different groups were then analysed to identify the consensus or most common responses to each question within each group. Thus, responses from individual farmers are not presented. The main ideas expressed in responses were identified and grouped into themes/categories reflecting farmers' perceptions of the two agroforestry systems tested in terms of tree, maize, and grass performance related to competition for resources, economic and ecological benefits, markets, constraints to adoption, and potential of agroforestry as a future option for the region.

2.5. Statistical Analysis

The software R (version 3.6.1) was used for all statistical analyses. Repeated measures ANOVA with the mixed model was used to assess the effects of the different treatments on maize, grass, and tree performance; yield; and profitability over the years. Log-transformation was used to normalise the data where necessary. When a significant difference was indicated in F-tests, lsmeans was used to identify significant ($p < 0.05$) differences between means. Repeated measures ANOVA was also applied to compare SPAD values and growth of maize in LMG and SM plots in year 7 of the experiment at Van Chan. ANOVA was used to compare the yield of maize at different positions relative to the grass strips within LMG in the last year, and then Tukey's HSD test was used to identify positions that were significantly different from other positions.

3. Results

3.1. Tree Growth

There was a significant effect by cropping systems on growth of longan trees. Base diameter, canopy diameter, and height in the sole-crop (SL) system were significantly greater ($p < 0.05$) than in the LGM system (Figure 3a). By the end of year 7, the base diameter of longan in SL and LMG had increased by 9 and 7 cm, respectively, since planting, and the height of longan trees was about 148 cm in SL and 121 cm in LGM, i.e., a height increase of 36 and 32 cm year^{-1} in SL and LGM, respectively.

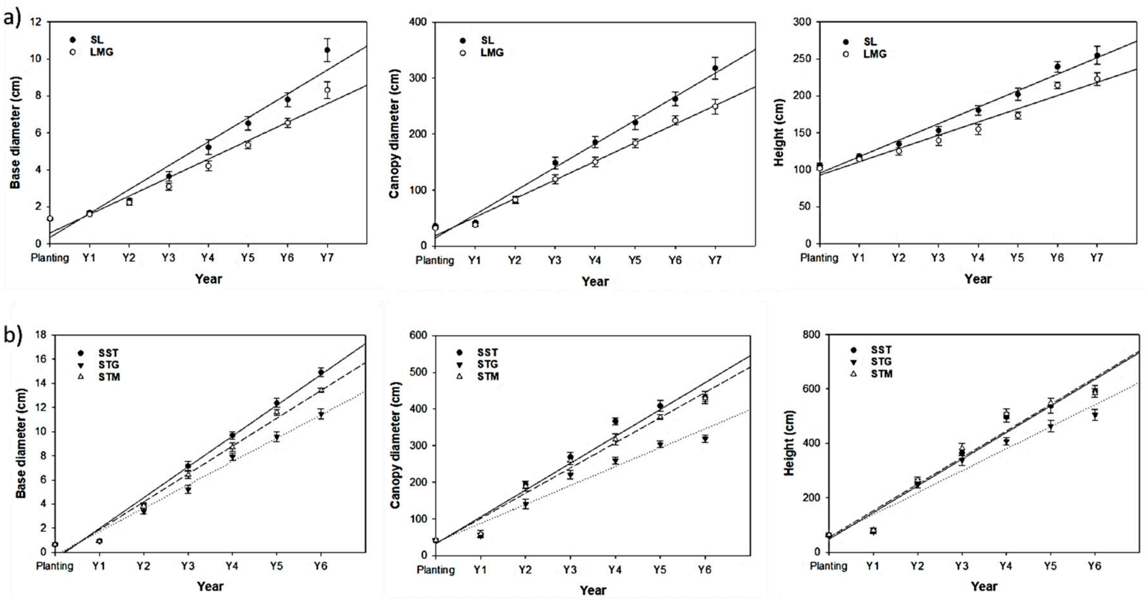

Figure 3. Regression lines describing tree growth (mean and standard error): (**a**) Growth of longan in the sole-tree system (SL) and longan–maize–forage grass (LMG) system; (**b**) growth of son tra in the sole-tree system (SST), son tra–guinea grass (STG) system, and son tra–mulato grass (STM) system.

The base diameter of son tra trees was significantly greater ($p < 0.05$) in the sole-tree system than in the systems with forage grass (STM and STG) (Figure 3b). Both tree height and canopy diameter were affected by the cropping system, with an interaction between cropping system and year ($p < 0.05$). Three years after planting, the canopy diameter and height of son tra trees were similar in the agroforestry and sole-tree systems. However, from year 4 to 6, canopy diameter and tree height were significantly higher ($p < 0.05$) in the sole-tree and STM systems than in the STG system (Figure 3b).

3.2. Yield and Land Equivalent Ratio

During the first three years, the products in LMG were primarily maize cobs and forage-grass biomass (Table 1). The grass started yielding from year 2. The products became more diversified from year 4, when longan started to bear fruit, and yield increased during subsequent years. There was no significant effect from the cropping system, or interaction between treatments and year, on maize yield. However, the yield of longan was significantly higher in the sole-tree system than in LMG, and there was a significant interaction between treatment and year ($p < 0.05$). From year 2 to 7, LER of the LMG system ranged from 1.1 to 1.9 (Figure 4a).

In the STG and STM agroforestry systems, the guinea grass and mulato grass were harvested from year 2 (2014), with high yield (Table 1). The agroforestry practices had more products from year 3, when son tra started to bear fruit. However, there was a significant effect from the cropping system on the productivity of son tra ($p < 0.05$), with fruit yield being significantly lower in agroforestry than in the sole-crop system. LER of the agroforestry practices from year 2 to 6 ranged from 0.5 to 1.1 for STG and 0.6 to 1.8 for STM (Figure 4b).

Table 1. Yield of maize (dry grain), longan, and son tra (fresh fruit) in sole-crop/tree systems (SM, SL, SST) and of these crops and forage grasses (fresh matter) in agroforestry systems (LMG, STG, STM) in the seven years of the field experiments.

		Yield (Ton ha^{-1})							
Crop/Trees	**Cropping System**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**Mean**
Maize	SM	5.9 (±0.1)	4.7 (±0.4)	4.1 (±0.3)	4.2 (±0.3)	4.3 (±0.1)	4.2 (±0.2)	4.6 (±0.5)	4.6 (±0.2)
	LMG	5.5 (±0.3)	5.3 (±0.1)	3.9 (±0.2)	4.1 (±0.2)	4.1 (±0.1)	4.0 (±0.2)	4.2 (±0.4)	4.5 (±0.3)
By cropping system					*p*-value = 0.33				
Cropping system x year					*p*-value = 0.35				
Longan	SL				0.35 (±0.2)	0.32 (±0.3)	0.47 (±0.1)	3.04 (±1.1)a	1.04 (±0.7)a
	LMG				0.06 (±0.03)	0.18 (±0.2)	0.38 (±0.2)	0.90 (±0.3)b	0.30 (±0.1)b
By cropping system					*p*-value = 0.02				
Cropping system x year					*p*-value = 0.03				
Guinea grass	LMG		4.4 (±4.4)	19.5 (±2.3)	15.9 (±1.2)	18.2 (±1.1)	18 (±1.5)	14.6 (±4.1)	15 (±2.3)
Son tra	SST	na			0.6 (±0.4)	5.6 (±4.1)	2.1 (±1.6)	8.7 (±7.6)	4.2 (±1.8)a
	STG	na			0.2 (±0.1)	1.8 (±0.8)	0.2 (±0.2)	1.8 (±1.3)	1.0 (±0.5)b
	STM	na			0.2 (±0.1)	0.9 (±0.4)	0.5 (±0.4)	4.7 (±3.4)	1.6 (±1)ab
By cropping system					*p*-value = 0.03				
Cropping system x year					*p*-value = 0.75				
Guinea grass	STG	na		67 (±26.3)	61 (±11)	55 (±6.3)	56 (±2.9)	67 (±5.9)	61 (±2.6)
Mulato grass	STM	na		58 (±29)	65 (±4)	74 (±7.6)	64 (±4.7)	66 (±4)	65 (±2.5)
By cropping system					*p*-value = 0.62				
Cropping system x year					*p*-value = 0.85				

SM: sole-crop maize, SL: sole-crop longan, LMG: longan–maize–forage grass, SST: sole-crop son tra, STG: son tra–guinea grass, STM: son tra–mulato grass; na: not applicable since the experiment was established in 2013. Values are mean ± standard error; different letters indicate significant differences ($p < 0.05$).

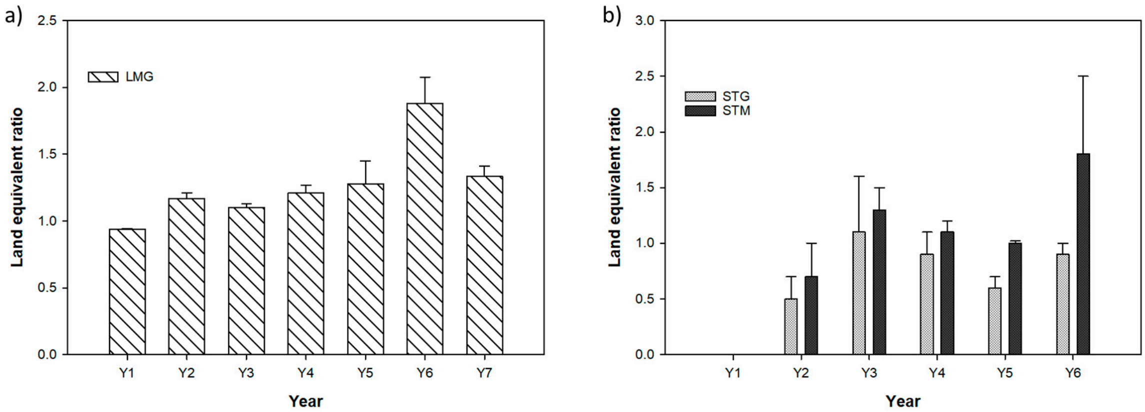

Figure 4. Land equivalent ratio (LER) of the agroforestry practices in each year of the experiment, expressed as mean and standard error (bars): (**a**) Longan–maize–forage grass (LGM); (**b**) son tra–guinea grass (STG) and son tra–mulato grass (STM).

3.3. Leaf Nitrogen Content and Competition in LMG

The SPAD value was significantly higher in sole-crop maize than in the LMG system ($p < 0.05$) from maize development stages 6–7 to silking, while maize plant height was significantly higher from 10–11 fully expanded leaves to silking (Table 2). However, the biomass of maize, including grain and stover, was not significantly different between the sole-crop and agroforestry systems.

Table 2. Dry yield, height, and SPAD readings of maize in the longan–maize–forage grass system (LMG) and the sole-crop system (SM) in year 7 of the experiment.

	Maize Growth Stage					At Maturity		
	Cropping System	**3–4 Leaves**	**6–7 Leaves**	**10–11 Leaves**	**Silking**		**Cropping System**	**Dry Yield (Ton Ha^{-1})**
SPAD	SM	38.0	44.6a	52.1a	57.7a	Grain	SM	4.6
	LMG	38.5	41.3b	47.8b	54.3b		LMG	4.2
p-value			<0.001			*p*-value		0.25
Height (cm)	SM	28.4	65.2	112.1a	230.4a	Stover	SM	5.6
	LMG	26.9	61.4	96.3b	218b		LMG	4.9
p-value			<0.001			*p*-value		0.09

Different letters indicate significant differences ($p < 0.05$).

The height of maize upslope, downslope, and between grass strips in LMG during year 7 was not significantly different from the height of maize in SM at the stages of 3–4 and 6–7 fully expanded leaves (Figure 5a). However, in later development stages, maize growth was significantly higher ($p < 0.05$) between two grass strips than immediately upslope or downslope of the grass. In stages 6–7 and 10–11 fully expanded leaves and silking, the SPAD readings of maize between grass strips were also significantly ($p < 0.05$) higher than those upslope and downslope of grass strips. The average SPAD readings for longan trees were not significantly different between LMG and SL (Figure 5a). Meanwhile, the average SPAD readings of guinea grass recorded 43.4 within LMG. This indicates that competition for N took place at positions where trees, crops, and grass were close to each other within the LMG system.

In LMG, the yield of maize grain between grass strips was 24% higher ($p < 0.05$) than in SM and about 62% higher than in upslope and downslope maize in LMG (Figure 5b). Yield of stover was also significantly higher (53–59%) between grass strips than for maize upslope and downslope of grass strips. Overall, the results clearly showed competition between grass, longan, and maize upslope and downslope of the grass strips within the LMG system in year 7.

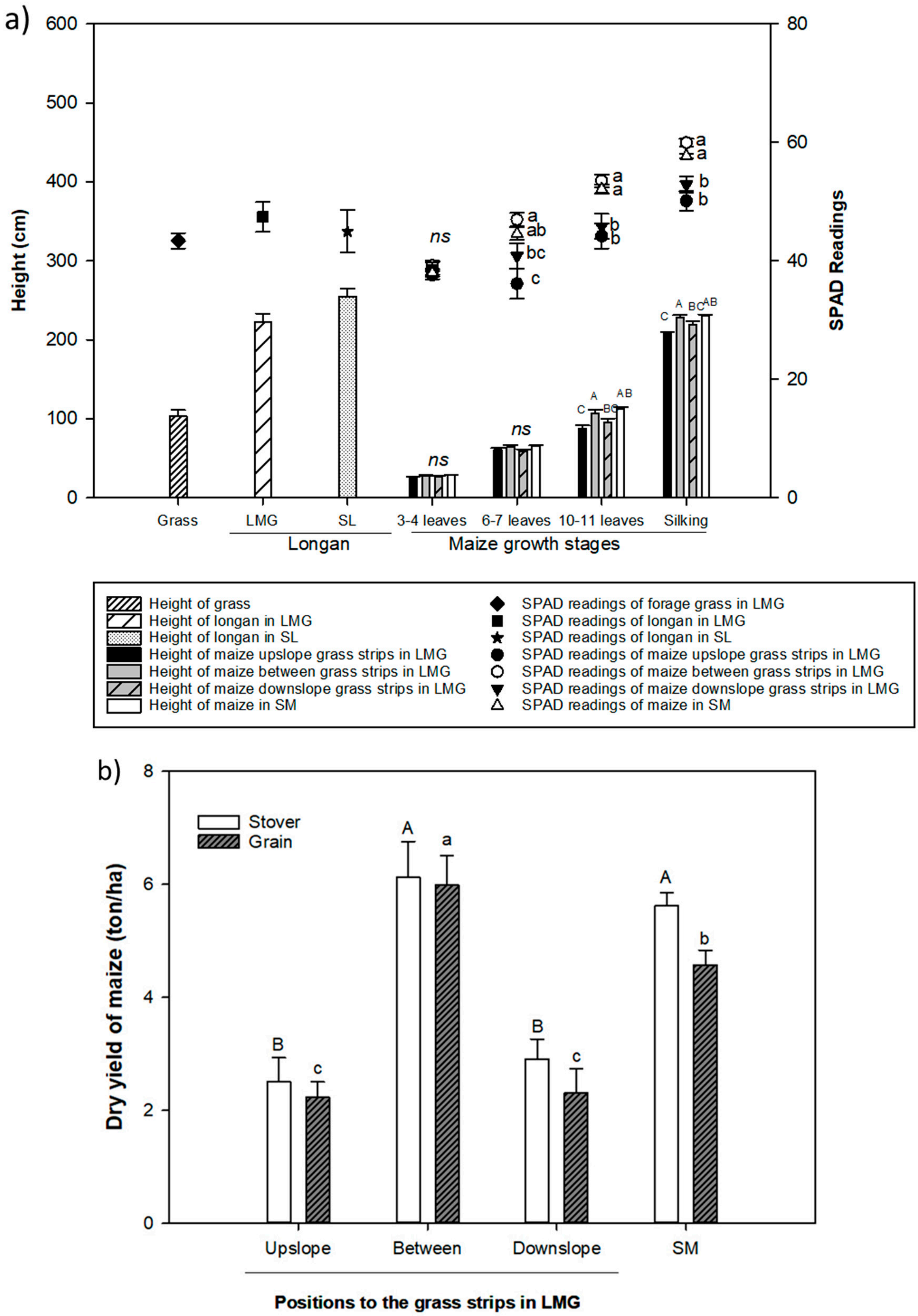

Figure 5. (**a**) Height of the tree and crop components and SPAD (soil plant analysis development) readings in the longan–maize–forage grass (LMG), sole-longan (SL) and sole-maize (SM); (**b**) dry yield of maize growing in different positions (upslope, between, downslope) relative to the grass strips within LMG in year 7. Values are means and standard errors. Bars with different upper case (stover) and lower-case (grain) letters indicate significant differences ($p < 0.05$).

3.4. Profitability

Sole maize had a mean annual investment cost of 670 USD ha^{-1}, while that of the sole-longan and the LMG system was 3.7-fold and 3.2-fold higher, respectively. The average maintenance cost of SL and LMG was 300 and 863 USD ha^{-1} year^{-1}, respectively (Figure 6a). The net profit was related to the cropping system, with an interaction between cropping system and year ($p < 0.05$). The mean net profit of LMG (1018 USD ha^{-1}) was 2.4-fold higher than for SM, while the SL system only achieved a positive profit from year 6 (Table 3). The trend of decreasing net profit of SM across year was partially due to the decreasing selling price of maize over time (presented in the Supplementary Materials Table S2) and lower maize yield in the subsequent compared to the initial years of experiment. From year 2, the net profit from LGM was equal to that from SM, while from year 4 the net profit from LGM was significantly ($p < 0.05$) higher than for SM and SL. In addition, the cumulative profit from LMG was positive from year 2 and higher than that from SM from year 4 (Figure 6a). In contrast, the cumulative profit from SL was still negative in year 7.

Table 3. Net profit from the agroforestry systems and the corresponding sole crop/tree.

	Net Profit (USD ha^{-1})							
Cropping System	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**Mean (±SE)**
SM	1118a	611a	388a	246b	233b	196b	190b	425.9 (±118.9)b
SL	−2463c	−355b	−229b	40b	−41b	112b	947ab	−284.4 (±336.8)c
LMG	−391b	839a	1550a	1179a	1380a	1404a	1168a	1018.2 (±231.6)a
By cropping system					p-value < 0.001			
Cropping system x year					p-value < 0.001			
SST	na	−1422	−290	42	2120	538	3238	704.5 (±632.4)b
STG	na	−1772	3297	2853	3069	2381	3570	2232.9 (±746.6)a
STM	na	−1772	2661	3018	4067	3147	4773	2648.7 (±857.1)a
By cropping system					p-value = 0.005			
Cropping system x year					p-value = 0.72			

SM: sole-crop maize, SL: sole-crop longan, LMG: longan–maize–forage grass, SST: sole-crop son tra, STG: son tra–guinea grass, STM: son tra–mulato grass; na: not applicable since the experiment was established in 2013. Values are means; different letters indicate significant differences ($p < 0.05$).

In the year of establishment, the total input costs were approximately 1772 USD ha^{-1} for both STG and STM, but lower (1422 USD ha^{-1}) for SST. In the following years, STG and STM required higher investment than the sole-tree system, mainly deriving from labour costs for forage-grass harvesting (Figure 6b). There was a significant effect ($p < 0.05$) of cropping system on net profit, with the mean net profit in STG (2233 USD ha^{-1}) and STM (2649 USD ha^{-1}) being around 3.2- and 3.7-fold higher, respectively, than in SST (Table 3). The SST system gave a positive net profit from year 3, but the cumulative profit from STG and STM was positive and higher than from SST from year 2 (Figure 6b).

3.5. Farmers' Perceptions and Aspirations for Fruit Tree-Based Agroforestry

3.5.1. Tree and Crop Performance in Agroforestry

Most farmers were fully aware of possible effects of competition for resources (light, water, nutrients) on the performance of tree and crop components within the agroforestry systems (Figure 7). All interviewees in Van Chan noted that growth and productivity of maize in the longan–maize–forage grass system were lower than in sole-maize cultivation. They attributed this to close distance between trees, crops, and grass leading to competition in the agroforestry system. However, non-hosting village groups claimed that longan trees performed better in agroforestry than in sole cultivation since they believed that longan trees utilised the nutrients applied to the maize. However, the experiment-hosting village, the experiment-hosting farmers in Van Chan, and all interviewees in Tuan Giao reported that growth and productivity of trees in both agroforestry systems were lower than when trees were grown separately.

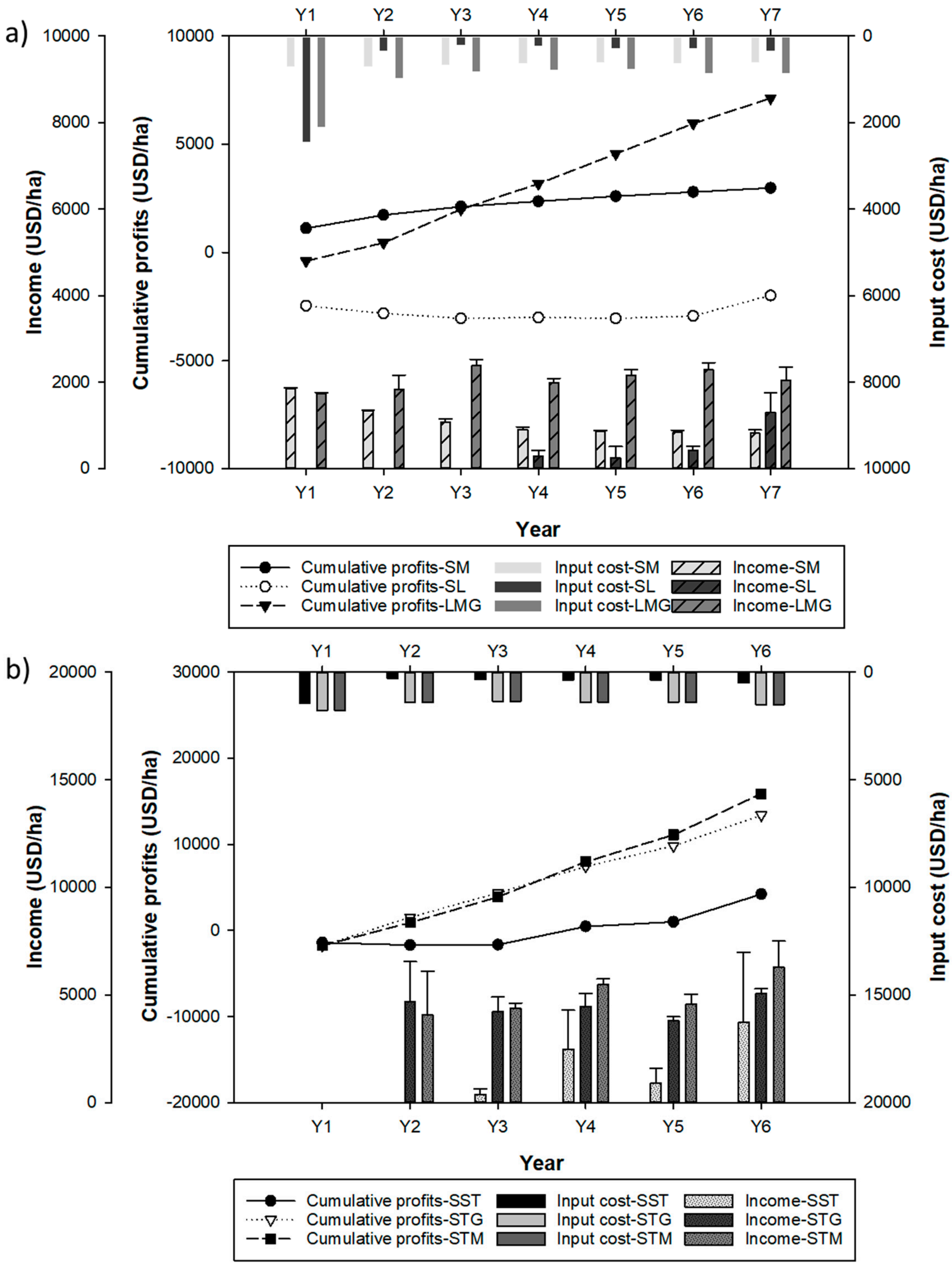

Figure 6. Input costs, income, and cumulative profit from: (**a**) the longan–maize–forage grass (LGM) compared with sole maize (SM) and sole longan (SL); (**b**) the son tra–guinea grass (STG) and son tra–mulato grass (STM) compared with sole son tra (SST).

The interviewees also suggested that the agroforestry systems could be optimised through better management of trees and crops (Figure 7). The groups proposed different solutions to improve the efficiency, such as adding more fertilisers to plants suffering from nutrient deficiency in areas where trees, crops, and grass affected each other's nutrient availability, reducing tree density and pruning to reduce shading. In addition, modifying the planting distance between trees and grass was suggested by groups from both sites. The farmers interviewed also suggested less-competitive crops for the agroforestry systems, e.g., legume species with biological N-fixation such as soybean and groundnut in LMG in Van Chan (3 of 7 groups), and upland rice or cucumber in STG and STM in Tuan Giao (2 of 7 groups).

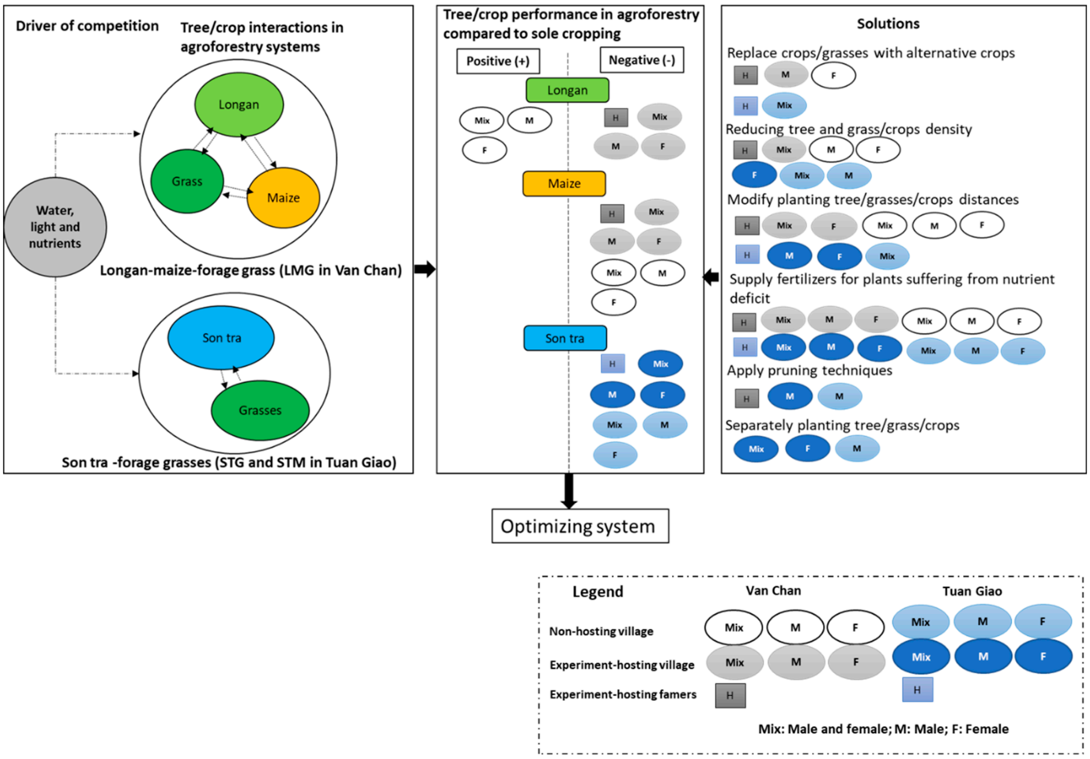

Figure 7. Farmers' perception of the performance of trees and crops in the agroforestry experiments in Van Chan and Tuan Giao compared with that of sole crops/trees. Open-ended questions were used in group interviews with non-hosting and experiment-hosting villages; experiment-hosting farmers were interviewed individually.

3.5.2. Benefits of the Agroforestry Systems

All famer groups in Van Chan and Tuan Giao shared the opinion that the experimental agroforestry systems produced earlier and more diverse products and gave higher economic benefit than the sole crop/tree (Figure 8a). Most interviewees reported that after 3–4 years, when the trees began to bear fruit, the income from agroforestry was much higher than from sole-crop cultivation. They also reported ecological benefits of the agroforestry systems in terms of reduced erosion, weed control, enhanced soil moisture and fertility, and greater resilience to extreme weather conditions (drought, snow, and frost) compared with sole-crop cultivation (Figure 8a). However, no group mentioned any benefits regarding pests and diseases, while only one group (the host farmers in Van Chan) mentioned terrace formation as an advantage (Figure 8a,b). Female and mixed groups in Tuan Giao claimed that the soil was less fertile and soil moisture lower in agroforestry than sole-tree cultivation, because the very dense forage grass used much water and nutrients within the agroforestry system (Figure 8b). Only the groups in Van Chan and the host farmer group in Tuan Giao expressed appreciation of the reduced labour requirement for harvesting forage from the grass strips in the agroforestry system (Figure 8b). These groups mentioned the possibility of using the forage to feed livestock, produce green manure, and provide earlier income when sold on the local market.

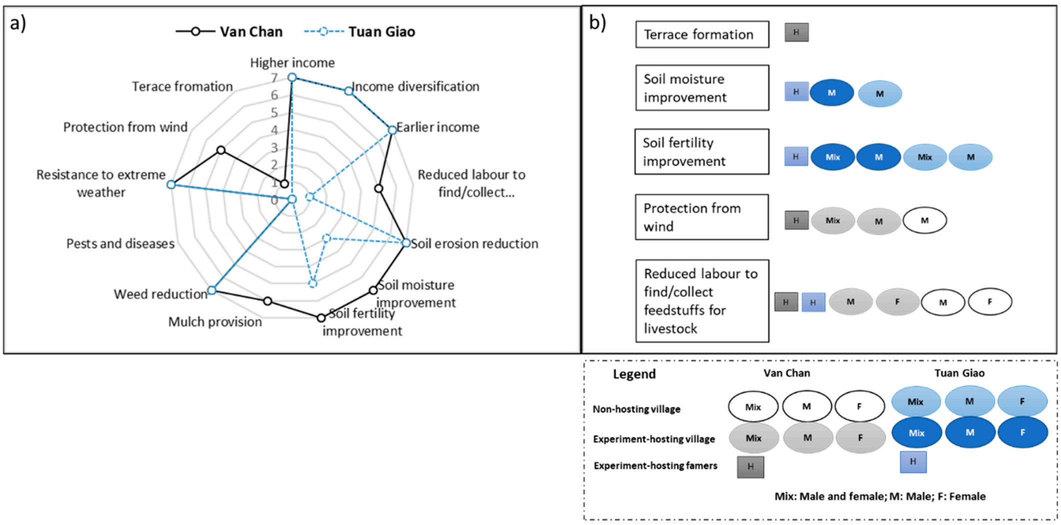

Figure 8. (**a**) Farmers' perceptions about benefits of agroforestry systems and number of farmer groups mentioning each of the identified benefits; (**b**) perceived benefits and the farmer groups in Van Chan and Tuan Giao that mentioned each. Open-ended questions were used in group interviews with non-hosting and experiment-hosting villages; experiment-hosting farmers were interviewed individually.

3.5.3. Constraints to Uptake of Agroforestry

Most of the farmer groups recognised and listed constraints to the uptake of agroforestry and proposed possible solutions to improve uptake in the local region (Figure 9). At both Tuan Giao and Van Chan, all groups indicated that the investment costs were higher than for sole-crop cultivation, making it difficult for poor households to adopt agroforestry. Management of pests and diseases in agroforestry was also more complicated, with more tree and crop components. An unstable market and low prices for products were other constraints to the uptake of agroforestry in the region.

All groups in Van Chan indicated that harsh weather events such as drought and lack of awareness among farmers of the benefits of agroforestry (4 of 7 groups) were the main drawbacks to the uptake of agroforestry. In Tuan Giao, all farmer groups considered that it would be difficult to combine traditional free grazing of livestock on crop residues with agroforestry. The forage grass was not considered valuable, since in this area with only free-grazing livestock farmers are not accustomed to collecting fodder. Extreme weather such as snow and frost and lack of techniques for implementing agroforestry were reported as other constraints to the adoption of agroforestry.

The farmers interviewed proposed solutions to address these issues (Figure 9). At Van Chan and Tuan Giao, all farmer groups mentioned training in agroforestry techniques, support in obtaining seedlings and fertilisers, and financial support or access to low-interest loans/credits as important incentives for implementing agroforestry. Development of market links for agroforestry products and a stable market were also considered key factors for agroforestry adoption by all farmer groups, but the suggested schemes differed. In Van Chan, the interviewees envisaged creating a stable market by building a farmers' cooperative to improve product quality to meet market demand and a processing factory to produce secondary products from longan fruit. The interviewees wanted maize replaced with other, higher-value annual crops. In Tuan Giao, the interviewees wanted a market link to a processing factory that would buy and add value to son tra and create a stable market.

All farmer groups in Van Chan and Tuan Giao saw a need for plant protection interventions to control pests and weeds as a way to reduce the labour costs of implementing agroforestry. According to farmers in Tuan Giao, shifting from free grazing to captive grazing and promoting livestock production to utilise the forage grass would increase the feasibility of agroforestry in the region. Although drought is a major concern in Van Chan, only the experiment-hosting farmers and the female farmer groups mentioned construction of water storage facilities as a solution. They saw a need for an electric pump and water tanks on the top of hills to supply water for tree/crops during drought periods.

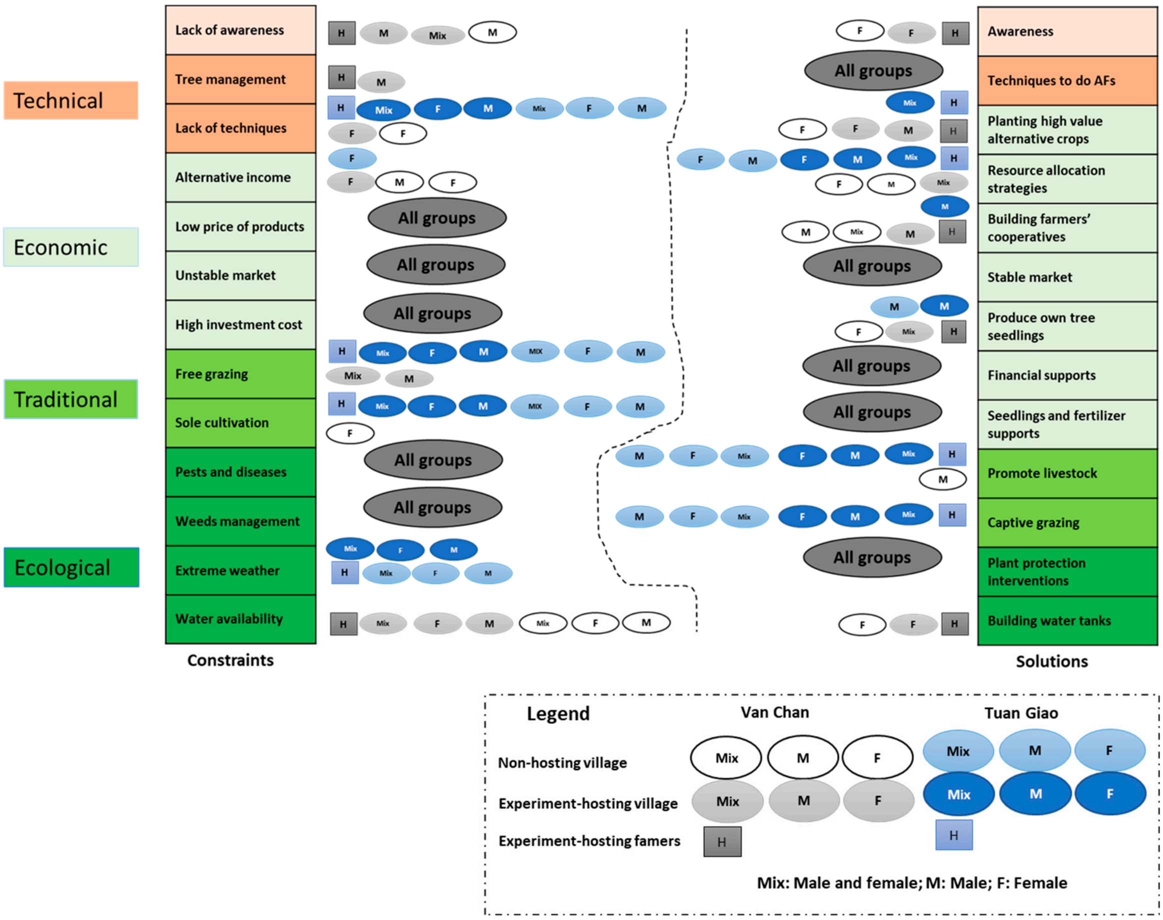

Figure 9. Farmers' perceptions of constraints (left) and solutions (right) to the uptake of agroforestry (AF) in Van Chan and Tuan Giao, and (centre) the farmer groups that mentioned the respective constraint/solution. Open-ended questions were used in group interviews with non-hosting and experiment-hosting villages; experiment-hosting farmers were interviewed individually.

All farmer groups interviewed mentioned a need to reduce the investment costs of agroforestry (Figure 9), e.g., by producing their own fruit-tree seedlings (3 of 7 groups in Van Chan and male groups in Tuan Giao). Some groups suggested offsetting the investment costs by planting higher-value crops to replace maize in Van Chan (4 of 7 groups) and forage grasses in Tuan Giao (2 of 7 groups). In addition, all farmers in Tuan Giao and 3 of 7 groups in Van Chan (Figure 9) indicated that resource allocation strategies could help reduce the maintenance cost of implementing agroforestry. They believed that during the first three years of the experiments, when the trees had not yet produced fruit, the farmers prioritised the annual crops and grasses to generate annual income. Later, when the trees were maturing and bearing fruit, farmers prioritised the trees.

3.5.4. Factors Enabling Expansion

The farmers at both Van Chan and Tuan Giao indicated that large-scale annual crop production on sloping land is an unstable system (land degradation, low yield). However, the ownership of land by local farmers is suited to implementing agroforestry. In addition, agroforestry has potential in both areas because it can bring economic and ecological benefits for local farmers. The local climate conditions are suitable for longan trees in Van Chan and for son tra trees in Tuan Giao, so both species can produce high yield. Recently, many farmers in Van Chan have shifted from sole-maize production to fruit trees and intercropping of fruit trees with annual crops, while farmers in Tuan Giao expressed interest in grafted son tra seedlings because they start to produce fruit rapidly. Local farmers saw potential for intercropping high-value trees (e.g., longan, mango, plum) and high-value crops (e.g., medicinal plants, soybean, green bean) in Van Chan, or amomum (*Amomun xanthioides* Wall.) in Tuan Giao (Figure 10).

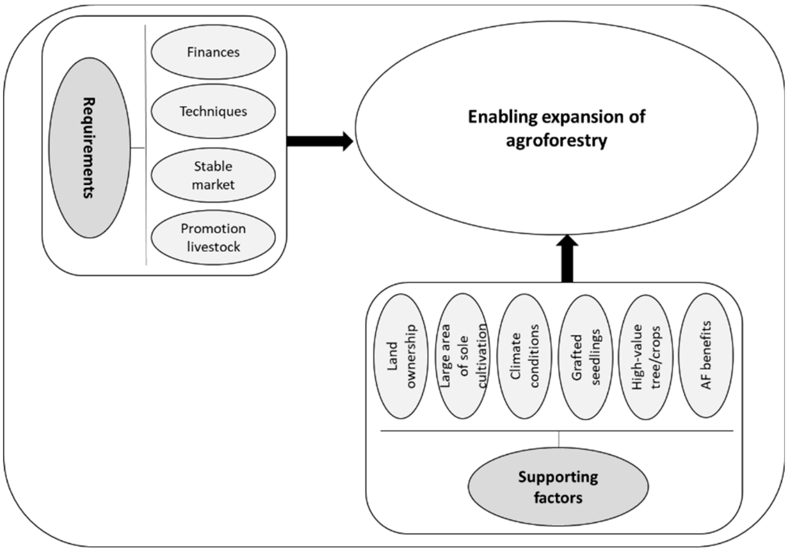

Figure 10. Farmers' perspectives about factors enabling expansion of agroforestry in Van Chan and Tuan Giao.

However, based on the interview responses, techniques to implement agroforestry, a stable market for products, and financial support for farmers in the establishment year(s), in combination with expansion of livestock production, would be required to expand agroforestry in northern upland areas of Vietnam (Figure 10).

4. Discussion

4.1. Effects of Competition for Resources on Tree and Crop Performance in Agroforestry and Ways to Improve the Systems

Total income was higher in the agroforestry systems than in the sole-cropping systems studied, but individual crop components generally grew more slowly in agroforestry systems than in sole-crop/tree systems, most likely due to competition for light, water, and nutrients [38]. The tree species in maize agroforestry systems may contribute differently to tree–crop interactions, e.g., leguminous tree species have been shown to compete less with maize for N than non-leguminous species [39–41]. The presence of tree roots, especially in the maize-cropping zone, also affects the competition with maize, and is determined by e.g., inherent rooting patterns, management, and soil conditions [41,42]. Conversely, maize restricts root development of trees in the cropping zone of agroforestry systems. A study on maize-based agroforestry systems in the sub-humid highlands of western Kenya indicated that the length of fine roots of intercropped trees (*Grevillea robusta* and *Senna spectabilis*) decreased in the maize root zone because of competition and damage to tree roots during weed hoeing [43]. In addition, maize uses the C4 photosynthetic pathway and is sensitive to shading [44] and may therefore be more negatively affected by tree shading in agroforestry systems than C3 species. Such competition was evident in the LMG system in our study, with slower growth and lower yield of longan and maize in areas where trees and crops were close to each other. This was particularly evident in year 7, when SPAD measurements showed competition for N between trees, crops, and grass growing close to each other (Table 2 and Figure 5).

In our experiments, the grass component of the agroforestry systems was competitive and negatively affected N uptake and growth of trees and maize. A previous study of maize intercropped with guinea grass in northwest Vietnam [45] found that aboveground biomass of maize at positions downslope and upslope of grass strips was around 60% and 40% lower, respectively, than that of maize 3 m from grass strips and sole maize, as we found for the LMG system (year 7). The farmer groups interviewed confirmed that maize downslope and upslope of grass strips showed lower growth and yield compared with maize farther from grass strips and sole maize, and that longan also had lower growth and yield as an intercrop than as a sole crop.

In our experiment, the yield from sole-longan planting was 2–4-ton ha^{-1} at the seventh year after tree planting. However, higher yield can be expected with e.g., improved irrigation. For example, in Hung Yen province of the Red River Delta region of Vietnam, the longan yield could reach 20 ton per ha^{-1} in the eighth year after tree planting [46]. Thanks to better market access including for export, partially due to the proximity to Hanoi as the country's capital and urban centre, the farmers in the province could derive high income from selling longan, and they partially allocate the income to improving irrigation systems [46]. The farmers in the province have been cultivating longan for decades.

However, the degree of competition may differ between grass species. A study in Costa Rica showed that when guinea grass and mulato grass were planted 0.9 m from *Eucalyptus deglupta* they produced similar grass biomass, but root length density (RLD) at 0–0.4 m depth was up to three-fold higher under guinea grass than under mulato grass [47]. At 0–0.4 m depth but 0.45 m from *E. deglupta* trees, RLD of guinea grass was up to four-fold higher than that of mulato grass. Thus *E. deglupta* growth was significantly reduced by the presence of guinea grass, and to a lesser extent by mulato grass, compared with sole-crop *E. deglupta* [47]. The STG and STM systems in our study confirmed the competition from guinea grass and mulato grass strips with the trees. In these systems, the forage grasses were planted 1 m from son tra rows, resulting in lower growth and yield of son tra trees with guinea grass than with mulato grass or sole-tree cultivation, while the two grasses produced similar grass biomasses.

It is possible to reduce competition between trees and crops by pruning the trees [41], as proposed by farmer groups in our study. Another option may be to intercrop C3 crops instead of C4 crops, as previous studies have indicated that yields of C3 crops are less reduced in agroforestry systems [48,49]. In our study, farmer groups suggested improving the efficiency of the agroforestry systems by planting legume species such as soybean and groundnut instead of maize in LMG, and by planting upland rice or cucumber to replace forage grasses in STG and STM. Greater planting distance between trees, crops, and grass strips would reduce competition. Supplying more fertiliser to plants suffering from nutrient deficiency in competition zones was also suggested in the group interviews.

4.2. Productivity Benefits and Ecosystem Services of Agroforestry Systems

Evaluation of the agroforestry systems tested in this study indicated that they provided earlier products than sole-tree systems and more diverse products than sole-maize systems. They also gave higher total productivity for farmers than the sole-crop systems from the second year onwards. During the first three years, total productivity was mainly from forage grasses and maize, with the LMG, STG, and STM systems giving forage-grass biomass for farmers from the second year. The products became more diverse from year 4, when the trees started to bear fruit, with yield increasing in subsequent years.

We found that the LMG agroforestry system was more productive than sole maize and longan from year 2 onwards, as indicated by LER ranging from 1.1 to 1.9 (Figure 4a). In a previous study on agroforestry systems based on apple (*Malus domestica*), e.g., apple/maize, apple/peanut, and apple/millet, LER was found to be 1.2–1.3 after the apple trees started bearing fruit from year 6 [50]. In our study, LER of the STM system was >1.0 from year 3, when the son tra started bearing fruit. However, in the STG system LER was <1.0, which can probably be explained by competition, as previously shown [47]. Other studies on forage grasses have reported that guinea grass [33] produces more biomass than mulato grass [34] in sole-grass cultivation. It may therefore affect the LER of the STG agroforestry system. Management of tree and crop components of a fruit tree-based agroforestry system thus needs to change from the year of establishment to when trees are maturing and high-producing, so that farmers can overcome competition effects and optimise the efficiency of land use [50]. In this study, the farmer groups interviewed suggested that a resource allocation strategy could improve the productivity of different components of the agroforestry systems. In the first three years, when the trees had not yet produced fruit, their main priority was the annual crop and grasses, whereas they paid more attention to the trees when they started bearing fruit. The farmers needed the short-term income from annual crops to support the long-term benefits from the fruit trees.

Growing forage grasses can be an incentive to improve smallholder livestock production by improved the daily weight gain of cattle and reducing labour in finding feedstuffs [51]. In this study, farmer groups confirmed that growing forage grasses reduces the labour requirement for finding/collecting feedstuffs for livestock in areas where captive grazing is common practice. This may be particularly beneficial for rural women in the study region, as 60% of the workload in farming is carried out by women [11]. In areas where free grazing is common practice like in Tuan Giao district, farmers will be less motivated/perceive less benefit from growing forage grass. This can be a "temporary" constraint for agroforestry adoption in the areas because along with population growth and higher demand for agricultural lands, the area of free-gazing lands will become more limited in the future. Therefore, we strongly considered fodder grass as one of main components of the tested agroforestry systems. Moreover, agroforestry systems with grass have been identified as the most suitable practice for northwest Vietnam to reconcile livelihood and erosion control [9].

Sole-maize cultivation on steep slopes in the northwest region of Vietnam produced annual soil loss that reached up to 174 ton ha^{-1} [15]. However, growing forage grass along the contour lines can play a significant role in reducing soil loss, especially on the steep slopes of the study region [15]. All experiments in our study were conducted in lands with about 27% slope, and measurement of soil erosion was not part of our study. However, a study in the northwest region that measured and compared soil erosion rate in agroforestry and sole-crop plantations clearly showed that soil erosion was substantially reduced in agroforestry [52]. The study found that the erosion rate in longan–mango–maize–forage grass agroforestry was 43% lower than that measured in sole-maize cultivations, and the rate in son tra–coffee–forage grass was 34% lower than that measured in sole-coffee plantations. All agroforestry systems and sole-coffee plantations observed in the study were three years old. A higher reduction in the soil erosion rate can be expected in more mature agroforestry such as in our experiments that have larger tree-canopy cover.

Ecological benefits or ecosystem services noted by farmers in this study were the effect of grass strips in reducing soil erosion and maintaining soil moisture and fertility, but also in forming terraces on the steep slopes [52]. In steeply sloping areas, the terraces formed could significantly increase agricultural productivity and enhance water-use efficiency when combined with other agricultural techniques [53].

4.3. Economic Benefits of Agroforestry Systems and Possibilities for Improvement

The agroforestry systems evaluated here showed higher profitability than the sole-crop systems from year 2 onwards. However, the initial investment cost for agroforestry was high: 2122 USD ha^{-1} for LMG and 1772 USD ha^{-1} for STG and STM. Farmers in the region lack the financial resources to shift to new practices [10]. New practices thus need to be shown to be safe and ensure food security before smallholders risk changing from their current system. The main incentive for farmers to adopt agroforestry is increasing yield and stable prices for their products. When comparing production and profitability, a cycle of some years must be considered, because it takes longer to establish perennial trees than annual crops and the financial input is higher in agroforestry systems. Therefore, initial investment funding (possibly organised by farmers themselves), subsidies, or loans will be necessary to compensate for the high investment and maintenance costs in the first few years of agroforestry [16].

The farmer groups interviewed proposed some ways to make implementation of agroforestry more profitable. First, the establishment of agroforestry will require financial support or access to low-interest loans/credits. In addition, implementing agroforestry with fodder-grass strips would become more beneficial for local people if changing from free to captive grazing were promoted. To achieve both in the study region, local farmers can seek support from the Vietnamese government through e.g., the National Target Programme (NTP) on New Rural Development [54] or the NTP-Sustainable Poverty Reduction and 135 Programme [55]. In addition, they can seek loans (low interest rate) from formal actors such as the Vietnam Bank for Agriculture and Rural Development, the Vietnam Bank for Social Policy, and People's Credit Funds [56].

Second, the farmers interviewed suggested producing their own low-cost tree seedlings to reduce the investment cost. These could be grown in community nurseries, where all members share costs and provide inputs [57]. The project Agroforestry for Livelihoods of Smallholder Farmers in Northwest Vietnam (2012–2016), together with relevant stakeholders, has provided training for farmers on the establishment and management of smallholder and group nurseries, producing tree seedlings by seedling propagation, grafting, and marcotting techniques. The project has published various technical extension materials on producing different tree-species seedlings suitable for local conditions. These technical sources could be useful for local farmers producing their own tree seedlings [58].

Third, the interviewees believed that they could achieve stable production by forming growers' cooperatives and could improve product quality to meet market demand. The cooperatives could provide production services, including inputs for farm households, fertilisers, feed ingredients, plant protection chemicals, and vaccines for livestock. They could also mediate between entrepreneurs and farmers, representing and protecting the rights of farmer members in contracting to supply raw materials to processing enterprises and export agricultural products [11]. In rural development work, agricultural service cooperatives can make a significant contribution [11]. Recently, the Vietnamese government introduced a programme to develop 15,000 cooperatives and effective agricultural cooperative unions in rural areas, with the government providing institutions, mechanisms, and policies to support the programme [59]. This offers an opportunity for farmers in the region to develop cooperatives to ensure stable production of agricultural products.

5. Conclusions

Agroforestry systems based on fruit trees, grass, and crops had higher productivity, higher profitability, and earlier returns on investment than sole-crop fruit systems, but also higher initial investment costs. The agroforestry systems produced a diversity of products and provided ecosystem services such as erosion control and soil fertility improvement. However, challenges such as higher investment cost and an unstable market for agroforestry products make it uncertain whether agroforestry can be easily promoted in the area.

During development of the agroforestry systems, there were negative effects on growth and productivity of the different components, most likely due to competition. There was evidence of competition for nitrogen between tree, grass, and crop components at positions upslope and downslope of the grass strips. These competition effects need to be considered when designing agroforestry systems and formulating management regimes.

Future fruit tree-based agroforestry systems should apply adaptive management while the agroforestry system is maturing and consider measures such as widening the planting distance between trees, crops, and grass; supplying fertiliser to plant components suffering from nutrient deficiency; and pruning trees in competition zones. Introducing high-value crops or biological N-fixing species to reduce competition and support the growth of trees can also be considered in order to optimise the systems.

To enable uptake and expansion of agroforestry in northwest Vietnam, financial support to meet the higher investment costs for agroforestry and for better value chains with market stability are prerequisites for farmers. Local farmers can produce their own tree seedlings to reduce the investment cost for agroforestry in the region.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-445X/9/11/451/s1, Table S1: Fertilisation regime applied in the sole-crop and agroforestry systems in Van Chan and Tuan Giao; Table S2: Cost of cropping inputs and prices paid for products at the study sites, 2012–2018 (data provided by the provincial extension department); Table S3: Groups selected for farmer group discussions (FGD); Table S4: List of questions used in farmer group discussions.

Author Contributions: Conceptualization, V.H.D., I.Ö., and N.L.; methodology, V.H.D., I.Ö., and N.L.; formal analysis, V.H.D.; investigation, V.H.D., H.T.P., and V.T.N; writing—original draft preparation, V.H.D.; writing—review and editing, I.Ö., G.B., A.S.D., R.M., N.L., H.T.P., and V.T.N. All authors have read and agreed to the published version of the manuscript.

Funding: This study was part of the project "Developing and promoting market-based agroforestry and forest rehabilitation options for northwest Viet Nam" (short name AFLI) led by World Agroforestry (ICRAF) and funded by the Australian Centre for International Agricultural Research and the CGIAR Research Programme on Forests, Trees and Agroforestry, in cooperation with the Swedish University of Agricultural Sciences (SLU) within the Swedish Research Council Formas funded project 2019-00376.

Acknowledgments: We highly appreciate the support of researchers and technical staff from the AFLI project at World Agroforestry (ICRAF) and national partners in Vietnam. Our thanks to researchers at the Northern Mountainous Agriculture and Forestry Science Institute and Forest Science Centre of Northwest Vietnam for their assistance. We are grateful to Chu Van Tien, Tran Quang Khanh, and Vu Dinh Chi, who hosted experiments in Van Chan, to Giang Dung Vu, Mua A Do, and Vang A Sua, who hosted experiments in Tuan Giao, and to the local authorities and farmers in the study sites for their support during field research.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. United Nations General Assembly. Transforming Our World: The 2030 Agenda for Sustainable Development, A/RES/70/1, New York. 2015. Available online: https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1=E (accessed on 10 June 2020).
2. United Nations. Sustainable Development Goals: 17 Goals to Transform Our World. 2015. Available online: https://www.un.org/sustainabledevelopment/sustainable-development-goals/ (accessed on 27 October 2020).
3. Catacutan, D.C.; Van Noordwijk, M.; Nguyen, T.H.; Öborn, I.; Mercado, A.R. *Agroforestry: Contribution to Food Security and Climate-Change Adaptation and Mitigation in Southeast Asia. White Paper*; World Agroforestry Centre (ICRAF): Bogor, Indonesia, 2017.
4. Van Noordwijk, M.; Bayala, J.; Hairiah, K.; Lusiana, B.; Muthuri, C.; Khasanah, N.; Mulia, R. Agroforestry Solutions for Buffering Climate Variability and Adapting to Change. In *Climate Change Impact and Adaptation in Agricultural Systems*; Fuhrer, J., Gregory, P.J., Eds.; CABI Publishing: Wallingford, UK, 2014; pp. 216–232.
5. Roshetko, J.M.; Mercado, A.R.; Martini, E.; Prameswari, D. *Agroforestry in the Uplands of Southeast Asia. Policy Brief no. 77. Agroforestry Options for ASEAN Series no. 5*; World Agroforestry (ICRAF) Southeast Asia Regional Program: Bogor, Indonesia, 2017; Available online: http://www.awg-sf.org/www2/wp-content/uploads/2017/12/ANNEX-10.-PB5-Upland-AF-in-SEA.pdf/ (accessed on 27 October 2020).
6. Tacio, H.D. Sloping Agricultural Land Technology (SALT): A Sustainable Agroforestry Scheme for the Uplands. *Agrofor. Syst.* **1993**, *22*, 145–152. [CrossRef]
7. Nair, P.R.; Nair, V.D.; Kumar, B.M.; Showalter, J.M. Carbon Sequestration in Agroforestry Systems. *Adv. Agron.* **2010**, *108*, 237–307. [CrossRef]
8. Schreinemachers, P.; Holger, L.; Fröhlich, H.L.; Clemens, G.; Stahr, K. From Challenges to Sustainable Solutions for Upland Agriculture in Southeast Asia. In *Sustainable Land Use and Rural Development in Southeast Asia: Innovations and Policies for Mountainous Areas*; Fröhlich, H.L., Schreinemachers, P., Stahr, K., Clemens, G., Eds.; Springer: New York, NY, USA, 2013; pp. 3–23.
9. Hoang, L.T.; Roshetko, J.M.; Huu, T.P.; Pagella, T.; Mai, P.N. Agroforestry—The Most Resilient Farming System for the Hilly Northwest of Vietnam. *Int. J. Agric. Syst.* **2017**, *5*, 1–23. [CrossRef]
10. Zimmer, H.; Le Thi, H.; Lo, D.; Baynes, J.; Nichols, J.D. Why Do Farmers Still Grow Corn on Steep Slopes in Northwest Vietnam? *Agrofor. Syst.* **2017**, *92*, 1721–1735. [CrossRef]

11. Staal, S.; Tran, D.T.; Nguyen, D.P.; Vu, D.H.; Nguyen, S.; Nguyen, T.T.L.; Nguyen, T.S.; Le, N.T.; Ngo, T.H.; Truong, Q.C.; et al. *A Situational Analysis of Agricultural Production and Marketing, and Natural Resources Management Systems in Northwest Vietnam*; International Livestock Research Institute for CGIAR Research Program: Kenya, Nairobi, 2014; Available online: http://humidtropics.cgiar.org/wp-content/uploads/downloads/2014/09/Situational-Analysis-NW-Vietnam-Report.pdf/ (accessed on 10 September 2020).
12. Wezel, A.; Luibrand, A.; Thanh, L.Q. Temporal Changes of Resource Use, Soil Fertility and Economic Situation in Upland Northwest Vietnam. *Land Degrad. Dev.* **2002**, *13*, 33–44. [CrossRef]
13. Clemens, G.; Fiedler, S.; Cong, N.D.; Van Dung, N.; Schuler, U.; Stahr, K. Soil Fertility Affected by Land Use History, Relief Position, and Parent Material Under a Tropical Climate in NW-Vietnam. *Catena* **2010**, *81*, 87–96. [CrossRef]
14. Schmitter, P.; Dercon, G.; Hilger, T.; Le Ha, T.T.; Thanh, N.H.; Lam, N.; Vien, T.D.; Cadisch, G. Sediment Induced Soil Spatial Variation in Paddy Fields of Northwest Vietnam. *Geoderma* **2010**, *155*, 298–307. [CrossRef]
15. Tuan, V.D.; Hilger, T.; Macdonald, L.; Clemens, G.; Shiraishi, E.; Vien, T.D.; Stahr, K.; Cadisch, G. Mitigation Potential of Soil Conservation in Maize Cropping on Steep Slopes. *Field Crop. Res.* **2014**, *156*, 91–102. [CrossRef]
16. Do, H.; Luedeling, E.; Whitney, C. Decision Analysis of Agroforestry Options Reveals Adoption Risks for Resource-Poor Farmers. *Agron. Sustain. Dev.* **2020**, *40*, 1–12. [CrossRef]
17. General Statistics Office of Vietnam. *Statistical Yearbook of Dien Bien, Yen Bai and Son La province*; General Statistics Office of Vietnam: Hanoi, Vietnam, 2018.
18. Hoang, T.L.; Mamo, A.E. *Son tra, the H'mong Apple*; World Agroforestry (ICRAF): Ha Noi, Vietnam, 2015; Available online: http://blog.worldagroforestry.org/index.php/2015/07/01/son-tra-the-hmong-apple/ (accessed on 27 October 2020).
19. Ministry of Agriculture and Rural Development. *Decision No. 4961/QD-BNN-TCLN. Promulgating a List of Main Tree Species for Planting Production Forests and a List of Main Tree Species for Afforestation According to Forest Ecological Regions*; Ministry of Agriculture and Rural Development: Hanoi, Vietnam, 2014; Available online: https://thuvienphapluat.vn/van-ban/tai-nguyen-moi-truong/Quyet-dinh-4961-QD-BNN-TCLN-2014-Danh-muc-cay-chu-luc-trong-rung-san-xuat-vung-sinh-thai-lam-nghiep-259936.aspx/ (accessed on 30 September 2020).
20. Do, T.; Mulia, R. Constraints to Smallholder Tree Planting in the Northern Mountainous Regions of Vietam: A Need to Extend Technical Knowledge and Skills. *Int. For. Rev.* **2018**, *20*, 43–57. [CrossRef]
21. Nguyen, M.P.; Mulia, R.; Nguyen, Q.T. *Fruit Tree Agroforestry in Northwest Vietnam: Sample Cases of Current Practices and Benefits (A Report in Vietnamese Language)*; World Agroforestry (ICRAF): Ha Noi, Vietnam, 2020.
22. TCVN 8941:2011. Soil Quality—Determination of Total Organic Carbon–Walkley Black Method. 2011. Available online: https://vanbanphapluat.co/tcvn-8941-2011-chat-luong-dat-cac-bon-huu-co-tong-so-phuong-phap-walkley-black#van-ban-goc/ (accessed on 11 September 2020).
23. TCVN 6498:1999. Soil Quality—Determination of Total Nitrogen−Modified Kjeldahl Method. 1999. Available online: https://vanbanphapluat.co/tcvn-6498-1999-chat-luong-dat-xac-dinh-nito-tong-phuong-phap-kendan#van-ban-goc/ (accessed on 11 September 2020).
24. TCVN 8940:2011. Soil Quality—Determination of Total Phosphorus–Colorimetry Method. 2011. Available online: https://vanbanphapluat.co/tcvn-8940-2011-chat-luong-dat-xac-dinh-phospho-tong-so-phuong-phap-so-mau#van-ban-goc/ (accessed on 11 September 2020).
25. TCVN 8660:2011. Soil Quality—Method for Determination of Total Potassium. 2011. Available online: https://vanbanphapluat.co/tcvn-8660-2011-chat-luong-dat-phuong-phap-xac-dinh-kali-tong-so#van-ban-goc/ (accessed on 11 September 2020).
26. TCVN 8942:2011. Soil Quality—Determination of Available Phosphorus—Bray and Kurtz (Bray II) Method. 2011. Available online: https://vanbanphapluat.co/tcvn-8942-2011-chat-luong-dat-xac-dinh-phospho-de-tieu-phuong-phap-bray-kurtz#van-ban-goc/ (accessed on 7 July 2020).
27. Minolta. *SPAD-502 Owner's Manual*; Industrial Meter Division, Minolta Corporation: Ramsey, NJ, USA, 1989.
28. Wolfe, D.W.; Henderson, D.W.; Hsiao, T.C.; Alvino, A. Interactive Water and Nitrogen Effects on Senescence of Maize. II. Photosynthetic Decline and Longevity of Individual Leaves. *Agron. J.* **1998**, *80*, 865–870. [CrossRef]
29. Argenta, G.; Da Silva, P.R.F.; Sangoi, L. Leaf Relative Chlorophyll Content as an Indicator Parameter to Predict Nitrogen Fertilization in Maize. *Ciência Rural* **2004**, *34*, 1379–1387. [CrossRef]

30. Viana, M.C.M.; Da Silva, I.P.; Freire, F.M.; Ferreira, M.M.; Da Costa, É.L.; Mascarenhas, M.H.T.; Teixeira, M.F.F. Production and Nutrition of Irrigated Tanzania Guinea Grass in Response to Nitrogen Fertilization. *Rev. Bras. Zootec.* **2014**, *43*, 238–243. [CrossRef]
31. Sritontip, C.; Khaosumain, Y.; Changjeraja, S. Different Nitrogen Concentrations Affecting Chlorophyll and Dry Matter Distribution in Sand-Cultured Longan Trees. *Acta Hortic.* **2014**, 227–233. [CrossRef]
32. Mead, R.; Willey, R.W. The Concept of a 'Land Equivalent Ratio' and Advantages in Yields from Intercropping. *Exp. Agric.* **1980**, *16*, 217–228. [CrossRef]
33. Cook, B.G.; Pengelly, B.C.; Brown, S.D.; Donnelly, J.L.; Eagles, D.A.; Franco, M.A.; Hanson, J.; Mullen, B.F.; Partridge, I.J.; Peters, M.; et al. *Tropical Forages: An Interactive Selection Tool*; [CD-ROM]; CSIRO, DPI&F (Qld), CIAT, ILRI: Brisbane, Australia, 2005.
34. Argel, P.J.; Miles, J.W.; Guiot García, J.D.; Cuadrado Capella, H.; Lascano, C.E. *Cultivar Mulato II (Brachiaria hybrid CIAT 36087): A High-Quality Forage Grass, Resistant to Spittlebugs and Adapted to Well-Drained, Acid Tropical Soils*; International Center for Tropical Agriculture (CIAT): Cali, Colombia, 2008; pp. 1–3. Available online: http://ciat-library.ciat.cgiar.org/Articulos_CIAT/mulato_ii_ingles.pdf/ (accessed on 25 March 2020).
35. Aganga, A.A.; Tshwenyane, S. Potentials of Guinea Grass (*Panicum maximum*) as Forage Crop in Livestock Production. *Pak. J. Nutr.* **2004**, *3*, 1–4.
36. Bacorro, T.J.; Reyes, P.M.; Loresco, M.M.; Angeles, A.A. Herbage Dry Matter Yield, Nutrient Composition and In Vitro Gas Production of Mulato II Mombasa Grasses at 30-and 45-Day Cutting Intervals. *Philipp. J. Vet. Anim. Sci.* **2018**, *44*, 86–89.
37. Vietnamese Government. *Decision No. 59/2015/QD-TTg. Promulgating Multiple Dimensional Poverty Levels Applicable during 2016-2020*; Vietnamese Government: Hanoi, Vietnam, 2015. Available online: https://thuvienphapluat.vn/van-ban/Van-hoa-Xa-hoi/Decision-No-59-2015-QD-TTg-promulgating-multiple-dimensional-poverty-levels-applicable-301414.aspx/ (accessed on 9 September 2020).
38. Malezieux, E.; Crozat, Y.; Dupraz, C.; Laurans, M.; Makowski, D.; Lafontaine, H.O.; Rapidel, B.; De Tourdonnet, S.; Valantin-Morison, M. Mixing Plant Species in Cropping Systems: Concepts, Tools and Models. A Review. *Agron. Sustain. Dev.* **2009**, *29*, 43–62. [CrossRef]
39. Okorio, J.; Byenkya, S.; Wajja, N.; Peden, D. Comparative Performance of Seventeen Upperstorey Tree Species Associated With Crops in the Highlands of Uganda. *Agrofor. Syst.* **1994**, *26*, 185–203. [CrossRef]
40. Bertomeu, M. Growth and Yield of Maize and Timber Trees in Smallholder Agroforestry Systems in Claveria, Northern Mindanao, Philippines. *Agrofor. Syst.* **2011**, *84*, 73–87. [CrossRef]
41. Nyaga, J.; Muthuri, C.W.; Barrios, E.; Öborn, I.; Sinclair, F.L. Enhancing Maize Productivity in Agroforestry Systems Through Managing Competition: Lessons From Smallholders' Farms, Rift Valley, Kenya. *Agrofor. Syst.* **2017**, *93*, 715–730. [CrossRef]
42. Van Noordwijk, M.; Lawson, G.; Hairiah, K.; Wilson, J. Root Distribution of Trees and Crops: Competition and/or Complementarity. In *Tree-Crop Interactions: Agroforestry in a Changing Climate*, 2nd ed.; Ong, C.K., Black, C.R., Wilson., J., Eds.; CAB International: Wellington, UK, 2015; pp. 221–257.
43. Livesley, S.J.; Gregory, P.; Buresh, R. Competition in Tree Row Agroforestry Systems. 1. Distribution and Dynamics of Fine Root Length and Biomass. *Plant Soil* **2000**, *227*, 149–161. [CrossRef]
44. Chirko, C.P.; Gold, M.A.; Nguyen, P.; Jiang, J. Influence of Direction and Distance From Trees on Wheat Yield and Photosynthetic Photon Flux Density (Qp) in a Paulownia and Wheat Intercropping System. *For. Ecol. Manag.* **1996**, *83*, 171–180. [CrossRef]
45. Tuan, V.D.; Hilger, T.; Vien, T.D.; Cadisch, G. Nitrogen Recovery and Downslope Translocation in Maize Hillside Cropping as Affected by Soil Conservation. *Nutr. Cycl. Agroecosystems* **2014**, *101*, 17–36. [CrossRef]
46. Hung, V.; Hung, N. Effect of Pruning and Flower and Fruit Thinning on Growth, Yield and Quality of 'PHM 99.1.1' Late Longan in Hung Yen Province. In *VI International Symposium on Lychee, Longan and Other Sapindaceae Fruits*; Van Hau, T., Mitra, S.K., Drang Khanh, T., Eds.; Acta Hortic: Brussels, Belgium, 2019; pp. 143–148.
47. Schaller, M.; Schroth, G.; Beer, J.; Jiménez, F.; Jiménez, F. Root Interactions Between Young Eucalyptus Deglupta Trees and Competitive Grass Species in Contour Strips. *For. Ecol. Manag.* **2003**, *179*, 429–440. [CrossRef]
48. Rao, M.R.; Nair, P.K.R.; Ong, C.K. Biophysical Interactions in Tropical Agroforestry Systems. *Agrofor. Syst.* **1997**, *38*, 3–50. [CrossRef]

49. Thevathasan, N.; Gordon, A. Ecology of Tree Intercropping Systems in the North Temperate Region: Experiences from Southern Ontario, Canada. *Agrofor. Syst.* **2004**, *61*, 257–268. [CrossRef]
50. Xu, H.; Bi, H.; Gao, L.; Yun, L. Alley Cropping Increases Land Use Efficiency and Economic Profitability Across the Combination Cultivation Period. *Agronomy* **2019**, *9*, 34. [CrossRef]
51. Bush, R.D.; Young, J.R.; Suon, S.; Ngim, M.S.; Windsor, P.A. Forage Growing as an Incentive to Improve Smallholder Beef Production in Cambodia. *Anim. Prod. Sci.* **2014**, *54*, 1620–1624. [CrossRef]
52. Birgitta, S.; Hanna, T. Impact of Agroforestry on Soil Loss Mitigation in the Sloping Land of Northwest Vietnam. Master's Thesis, Swedish University of Agricultural Sciences, Uppsala, Sweeden, May 2020.
53. Chai, Q.; Gan, Y.; Turner, N.C.; Zhang, R.-Z.; Yang, C.; Niu, Y.; Siddique, K.H. Water-Saving Innovations in Chinese Agriculture. *Adv. Agron.* **2014**, *126*, 149–201. [CrossRef]
54. Vietnamese Government. *Decision No. 800/2010/QD-TTg. Approving the National Target. Program. on Building a New Countryside During 2010-2020*; Vietnamese Government: Hanoi, Vietnam, 2010. Available online: https://thukyluat.vn/vb/decision-no-800-qd-ttg-approving-the-national-target-program-on-building-1ad9a.html?hl=en#VanBanTA/ (accessed on 9 September 2020).
55. Vietnamese Government. *Decision No. 551/2013/QD-TTg. Approved the 135 Program. on Supporting Investment in Infrastructure, Production Development for Extremely Difficult Communes, Border Communes, Safety Zone Communes*; Vietnamese Government: Hanoi, Vietnam, 2013. Available online: http://vanban.chinhphu.vn/portal/page/portal/chinhphu/hethongvanban?class_id=2&_page=1&mode=detail&document_id=166543/ (accessed on 9 September 2020).
56. JICA. *Data Collection Survey on the Needs for Agriculture Productivity Improvement in Northern Six Provinces*; Japan International Cooperation Agency, Vietnam Ministry of Agriculture and Rural Development: Hanoi, Vietnam, 2016. Available online: https://openjicareport.jica.go.jp/pdf/12261343.pdf/ (accessed on 9 September 2020).
57. FAO. *Sustainable Forest Management (SFM) Toolbox*; The Food and Agriculture Organisation of the United Nations: Rome, Italy, 2018; Available online: http://www.fao.org/sustainable-forest-management/toolbox/modules/agroforestry/basic-knowledge/en/ (accessed on 9 September 2020).
58. La, N.; Catacutan, D.C.; Nguyen, M.P.; Do, V.H. *Agroforestry for Livelihoods of Smallholder Farmers in Northwest. Vietnam—Final Report, Canberra ACT 2601*; Australian Government, Australian Center for International Agricultural Research: Canberra, Australia, 2019; pp. 10–34. Available online: https://aciar.gov.au/publication/technical-publications/agroforestry-livelihoods-smallholder-farmers-northwest-Vietnam-final-report/ (accessed on 10 September 2020).
59. Vietnamese Government. *Decision No. 461/2018/QD-TTg. Approving the Scheme on the Development of 15,000 Cooperatives and Unions of Agricultural Cooperatives With Effective Operation up to 2020*; Vietnamese Government: Hanoi, Vietnam, 2018. Available online: https://thuvienphapluat.vn/van-ban/Doanh-nghiep/Quyet-dinh-461-QD-TTg-2018-De-an-phat-trien-15000-hop-tac-xa-lien-hiep-hop-tac-xa-nong-nghiep-380877.aspx/ (accessed on 9 September 2020).