4. Selection of Vegetable Crops under Vegetable-Agroforestry System

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Abstract

Tree-crop interactions in agroforestry systems involving vegetable crops have not been studied extensively because previous research in agroforestry focused on agronomic arable field crops. A vegetable-agroforestry system was established at AVRDC – The World Vegetable Center to: 1) study tree-crop interactions in alley-cropping vegetable crops with tropical fruit trees in terms of competition and/or complementarity; 2) investigate the influence of tree crops on natural habitat and insect pest populations in vegetable alley-cropping systems; and 3) evaluate total productivity and economic returns from high value horticultural crops in an agroforestry system. Seedlings of 12 tropical fruit tree species: *Anona reticulata, Artocarpus heterophyllus, Chrysophyllum caimito, Coffea arabica, Eugenia brasiliensis, Eugenia uniflora, Pouteria caimito, Pouteria campechiana, Psydium littorale, Rollinia mucosa, Syzygium samarangense,* and *Tamarindus indica* were established in December 2005 at AVRDC's Organic Vegetable Research Plots. Vegetable crops were grown sequentially in alley beds between tree hedgerows 10 months after tree establishment. Monoculture cropping of vegetables was established for comparison. The trial was conducted using a randomized complete block (RCB) design with four replications. Establishment and initial growth of trees varied according to species. Outstanding species for stand establishment and growth were *A. heterophyllus, C. caimito, T. indicus* and *A. reticulata.* Marketable yields of vegetables varied with species over a period of 3 years and 4 sequential cropping seasons. During the first two seasons, marketable yield levels were not influenced by tree hedgerows, which were in the stage of being established. The effect of tree-crop competition in reducing yield was not apparent. As fruit trees became fully established and developed full canopies, the demand for soil moisture, nutrients and light increased,

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which resulted in significant yield reduction for sweet pepper (64%), tomato (47%), and Chinese cabbage (20%). Cucumber and eggplant were less affected by tree hedgerows, with yield reductions of 1% and 11%, respectively. Shading of vegetables by trees was considered a major factor in decreased yield. With time, yield loss from vegetable crops will be compensated by yield gains in fruit trees as some species were already at the reproductive stage. Incidence of insect pests and economic returns from vegetable production under hedgerow intercropping are presented in the report. Our results suggest that integration of high value vegetable crops during the early stage of tree establishment in agroforestry systems can provide quick economic returns which are of tremendous benefits to livelihoods of smallholder growers as the returns from trees can be obtained later. The early economic return from vegetables compliments the benefits from fruits leading to sustainable vegetable-agroforestry systems which will provide positive incentives for the resource-poor and smallholders in the tropics.

Keywords: Alley cropping, tree-crop interaction, tropical fruit trees, vegetable crops

1. Introduction

Recent emphasis on high-value horticultural crops by the Department of Agriculture (DOA) has triggered research and development efforts in integrating vegetable crops in various farming and cropping systems in the Philippines. High-value horticultural crops including fruits, vegetables and ornamentals are sources of food, medicine and income for small-scale, resource-poor farmers in the tropics (Rao et al., 2004; Palada et al., 2004a; Mercado et al., 2008a). These crops are important components of agroforestry systems and play a significant role by contributing to biological stability, enhancing crop diversity, conserving soil properties, and increasing total productivity (Palada et al., 2004a,b). Agroforestry with horticultural crops can be paired in various systems, including alley cropping or hedgerow intercropping, multilayer tree gardens, home gardens, multipurpose trees in croplands, plantation crop combinations, and taungya (Nair, 1993).

Early studies on tree-crop associations in agroforestry systems were focused on agronomic arable (field) crops such as maize, cassava and beans. Although the principles and knowledge learned from these studies are relevant to horticultural crops, actual results may vary in terms of response to tree-crop interactions. Recent studies indicate that when horticultural crops such as vegetables are integrated into agroforestry systems, the association can be complementary, competitive, supplementary, or neutral (Mercado et al., 2008a). The tree-crop association is influenced by crop species (vegetables and trees), planting system (arrangement), soil properties, and

other variables. It is generally known that trees compete with crops for soil moisture, light and nutrients. Studies on positive and negative effects of trees on intercropped vegetables under agroforestry systems such as alley cropping and hedgerow intercropping have been reported by Chen et al. (1989); Palada et al. (1992a,b; 2004a,b); and Mercado et al. (2008a). For example, Chen et al. (1989) reported that alley-cropping pai tsai (*Brassica chinensis* L.) enhanced yield and plant mineral concentration even with no fertilizer application. Studies in the humid tropics of West Africa indicated that with fertilizer application, yield of vegetables including amaranth (*Amaranthus cruentus*), celosia (*Celosia argentia*), okra (*Abelmoschus esculentus*) and tomato (*Lycopericon esculentum*) grown in an alley-cropping system with a nitrogen-fixing leguminous tree (*Leucaena leucocephala* Lam de Wit) were similar to yield in control plots (monoculture). With no fertilizer applied, yield of alley-cropped vegetables was higher than the control, indicating that alley cropping can reduce fertilizer requirements for vegetable production (Palada et al., 1992a).

In the semi-arid tropics of the Eastern Caribbean, alley-cropping vegetable crops such as bell pepper (*Capsicum annuum*), eggplant (*Solanum melongena*) and sweet corn (*Zea mays*) with pigeonpea (*Cajanus cajan*), Moringa (*Moringa oleifera*), Gliricidia (*Gliricidia sepium*) and Leucaena resulted in both negative and positive associations. The presence of hedgerows in alley cropping reduced evapotranspiration, lowered wind turbulence, and maintained a slightly higher soil moisture and lower surface soil temperature (Palada et al., 2002a, 2004a).

Studies in vegetable-agroforestry systems (VAF) conducted in the Philippines indicated that under farmers' management, the optimum tree hedgerow spacing was 20-25 m apart, and suitable tree species for the VAF system were *Eucalyptus robusta*, *Eucalyptus torillana* and *Acacia mangium* (Mercado et al., 2008a,b). It was best to prune the trees from 40-60% of their canopies to reduce tree-crop competition. Suitable vegetables species under the vegetable-agroforestry system were common cabbage (*Brassica oleracea capitata*), cauliflower (*Brassica oleracea botrytis*), carrots (*Daucus carota*) and bell pepper. Results showed a positive relationship between net complementary index (NCI) and tree height and amount of canopy left after tree pruning, but NCI had a negative relationship with canopy width.

Most of the vegetable-agroforestry studies reported above involved trees with low horticultural and economic value (timber trees, and firewood). Studies involving high-value tropical fruit trees in agroforestry systems with vegetable crops are few. The combined economic benefit from fruits and vegetables may lead to long-term sustainability of the vegetable-agroforestry system in the tropics.

The major objective of this study was to develop economically viable and ecologically-sound integrated vegetable-agroforestry systems to increase farm productivity and income, and reduce vulnerability and risks. The specific objectives were to: 1) investigate tree-crop interactions in alley-cropping vegetable crops with tropical fruit trees in terms of competition for soil water, nutrients, and light and complementary associations in the lowland tropics; 2) investigate the influence of tree crops on natural habitat and insect pest population in vegetable alley-cropping systems; and 3) evaluate total productivity and economic returns from high-value horticultural crops in an agroforestry systems. This paper focuses on objective 1, with more emphasis on vegetable yield performance and variety selection under agroforestry systems.

2. Materials and Methods

2.1 Tropical fruit tree establishment

Twelve species of tropical fruit trees including Bullock's heart (*Anona reticulata*), Biriba (*Rollinia mucosa*), coffee (*Coffea arabica*), tamarind (*Tamarindus indica*), jackfruit (*Artocarpus heterophyllus*), Brazil cherry (*Eugenia brasiliensis*), Surinam cherry (*Eugenia uniflora*), strawberry guava (*Psidium littorale*), Nam Pheung honey (*Syzygium samarangense)*, star apple (*Chrysophyllum caimito*), Canistel (*Pouteria campechiana*) and Abiu (*Pouteria caimito*) were established on December 9, 2005 at AVRDC – The World Vegetable Center's Organic Farm. Trees were planted on raised beds 50 cm high and 1.5-3.0 m wide depending on species. The distance between tree hedgerows was 8.0 m. Organic fertilizer (compost) at 10 t/ha was applied in each planting hole (30 cm depth) before planting. Because of the limited number of tree seedlings provided by the Horticulture Department at National Pingtung University of Science and Technology, Taiwan, seedlings of each tree species were planted in one row with varying length (25.7 m to 44.0 m) as shown in Figures 1 and 2. Tree spacing within the bed varied from 1.5 m to 3.0 m.

2.2 Vegetable crops

Vegetable crops were grown in alley beds between tree hedgerows starting in October 2006, ten months after the tree establishment. During the first cropping season (hot-dry), nine vegetable species were planted; these were tomato, sweet pepper, chili pepper, cauliflower, broccoli, Chinese cabbage, common cabbage, radish and cucumber. In the second season (dry-cool), the same vegetables were grown but for broccoli and common cabbage. In the third season, crops were planted during the hot-wet season (April-June 2007), including okra, eggplant, lettuce, cucumber, sweet corn and yard-long bean. This was followed by the fourth cropping (October 2007-April 2008) with plantings of tomato, eggplant, cucumber, Chinese cabbage and common cabbage. Table 1 shows the vegetable species and varieties grown. AVRDC standard recommended cultural practices were followed for each vegetable crop which included irrigation as required. With the exception of tomato, plot size and plant spacing for all vegetable species was 4.5 m^2 (1.5 m x 3.0 m) with two rows and between plant spacing of 0.5 m. For tomato the same plot size was used, but four rows were transplanted to each plot. All crop cultural management practices followed an organic system; the use of synthetic fertilizers and pesticides was avoided.

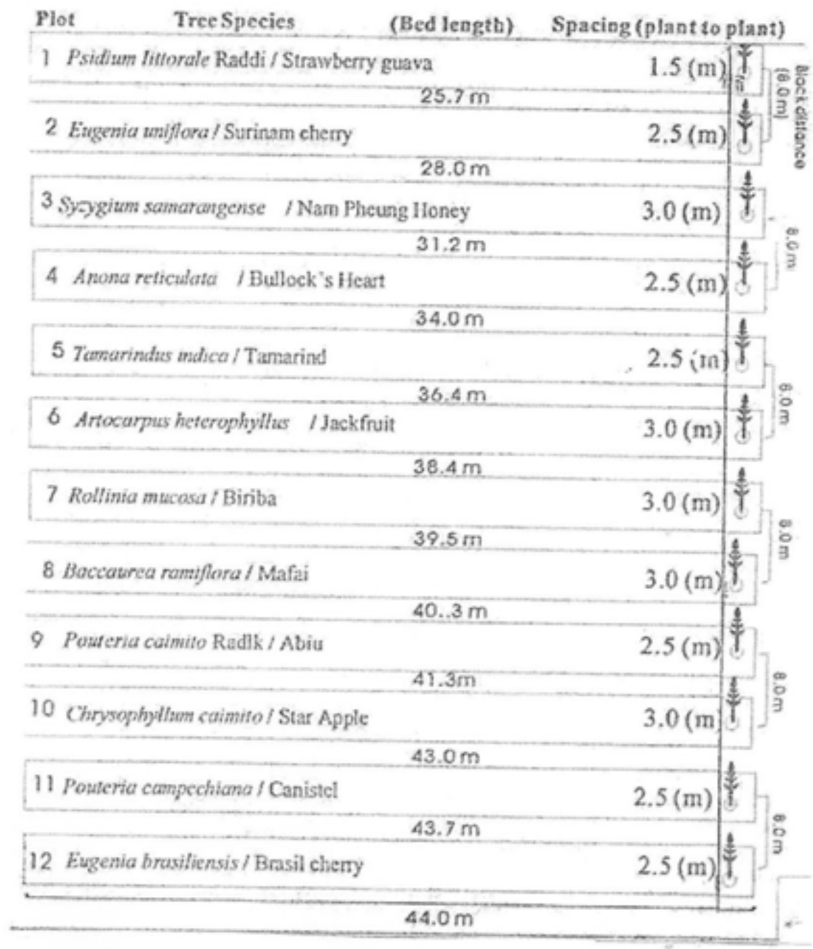

Figure 1. Field layout of vegetable-agroforestry trial at AVRDC – The World Vegetable Center.

Figure 2. General view of the vegetable-agroforestry trial at AVRDC – The World Vegetable Center (October 2007).

Table 1. Vegetable species and varieties grown in AVRDC vegetable-agroforestry trial, 2006.

Vegetable species	Varieties
Broccoli	KY-AM00532 x 905
Cauliflower	Early Autumn
Chinese cabbage	Yu-Hong, Hybrid 686, Express
Common cabbage	Gao-Hung, Chau-Shi
Cucumber	Hun-Yan, Sin-Yan, Ar-Shin
Eggplant	Known-You, Hua-Lang, Masu-lon
Hot pepper	Delicacy 05-193
Lettuce	Empire, Stem-Let
Malabar spinach	Local Big Purple Leaf
Okra	3442, 1524, 556, 3141, 549
Radish	Jung-Shi, Jueun-Ki
Sweet corn	Pa-Guing, Sung-Hua
Sweet pepper	Hazera, V20230, Blue Star
Tomato	TLCV32, FMT847, CHT501, CLN2026, TLCV2, TLCV15
Yard-long bean	Pia-Hou, Spring 81, Spring 40

2.3 Experimental design

The agroforestry field trial was laid out using a randomized complete block design (RCBD) with four replications. The hedgerow tree species were not replicated because of the limited number of tree seedlings. Thus, the whole agroforestry field was divided into four blocks and each block represented a replicate. The vegetable varieties were randomly planted within each block at right angle to the rows of three species, such that each vegetable species was on average given equal chance of interacting with each fruit tree species. The compost fertilizer treatments were superimposed on vegetable species. Three sources of organic fertilizer (compost) were applied and evaluated as to their effects on growth and yield of vegetable crops. Compost treatments were: 1) Compost I (rape+soybean+sesame); Compost II (castor seed); and 3) Compost III (combination of Compost I and II). Table 2 shows the nutrient (NPK) analysis of compost materials used, and Table 3 shows the rates of application. In the fourth cropping cycle, a vegetable monoculture system (no tree hedgerows) was established on the field adjacent to the agroforestry trial plot. Using an identical experimental field design (RCBD) similar vegetable varieties were randomly planted into four blocks. The vegetable crops received three sources of compost fertilizer similar to that used in the agroforestry plot. The two field trials (agroforestry and monoculture system) were treated independently (separate experiments). Thus, separate statistical analysis of data was performed for each experiment.

Table 2. Nutrient content of compost materials applied on vegetable crops under VAF system.

Compost material	Ingredients	Nutrient content (%)			Organic component (%)
		N	P_2O_5	K_2O	
I	Rape+soybean+castor+ sesame	4.0	3.0	2.0	80-92
II	Castor seed	4.0	1.2	1.2	90-94
III	Combination of I & II	4.0	2.1	1.6	85-93

Sources: Compost I – Fu-Suo Company; Compost II – Chin-Chen Company.

2.4 Data collection

Data were collected from fruit trees and vegetable crops as follows:

- Tree crops – during the first and second year, data were collected on survival and plant height.

- Vegetable crops – data were collected on plot yield and incidence of pests and diseases.

- Tree-crop interactions – only visual observations were taken on tree-crop competition for soil moisture and light starting when fruit trees have fully grown and developed full canopy.

- Beneficial insects – population of natural enemies was monitored on selected tree species using sticky traps once in April 2007.

- Cost and returns analysis – performed for selected vegetables to determine the economic benefits of vegetable-agroforestry system.

Table 3. Rate of compost application on vegetable crops grown under VAF system.

Vegetable	Compost I N-P-K (kg/ha)	Compost II N-P-K (kg/ha)	Compost III N-P-K (kg/ha)
Broccoli	203-152-101	203-61-61	311-163-124
Cauliflower	203-152-101	203-61-61	311-163-124
Chinese cabbage	182-137-91	182-55-55	293-154-117
Common cabbage	182-137-91	182-55-55	293-154-117
Cucumber	224-168-112	204-67-67	329-173-132
Hot pepper	203-152-101	203-61-61	311-163-124
Radish	182-137-191	182-55-55	293-154-117
Sweet pepper	203-152-101	203-61-61	311-163-124
Tomato	203-152-101	203-61-61	311-163-124

3. Results and Discussion

3.1 Tree establishment

Establishment and initial growth of tropical fruit trees varied according to species. Among the 12 species, 9 had a 100 percent survival rate and three species (*R. mucosa*, *E. brasiliensis* and *A. heterophyllus*) had a mortality rate ranging from 9 to 62 percent (Table 4). Some species were fast growing while others were slow. The outstanding species in terms of establishment and growth were *Artocarpus heterophyllus*, *Chrysophyllum caimito* and *Anona reticulata*. As shown in Figure 3, fast-growing tree species were *R. mucosa* (Biriba), *C. arabica* (coffee), *C. caimito* (star apple), *P. caimito* (Abiu), *S. samarangense* (Nam Pheung honey), *A. reticulata* (Bullock's heart), and *E. uniflora* (Surinam cherry). These trees attained plant height of 2 to 3 m four years after planting (2008-2009).

Table 4. Plant survival rate of twelve tropical fruit tree species 3 years after establishment in vegetable-agroforestry system. AVRDC, Taiwan.

Tree species	No. of trees established (2005)	No. of living trees (2008)	Plant survival (%)
Psidium littorale	19	19	100
Eugenia uniflora	12	12	100
Syzgium samarangense	12	12	100
Anona reticulata	15	15	100
Tamarindus indica	10	10	100
Artocarpus heterophyllus	11	10	91
Rollinia mucosa	8	3	38
Coffea arabica	13	13	100
Pouteria caimito	13	13	100
Chrysophyllum caimito	14	14	100
Pouteria campechiana	16	16	100
Eugenia brasiliensis	10	6	60

3.2 Vegetable yield as influenced by secies and compost application

Yield response of vegetables to compost (organic fertilizer) application varied according to species. In trial 1, significant differences in yield between compost types were observed in cucumber and eggplant, but not with lettuce, sweet corn, and yard-long bean (Table 5). Yield of cucumber with combination fertilizer (Compost III) was significantly higher than with single-source compost (Compost I or II). For eggplant, yield was higher with castor seed-compost (Compost II). In trial 2, yield response was significant for all vegetables and generally marketable yields were higher in crops applied with Compost I and II than Compost III (Table 6). Yield of Chinese cabbage applied with Compost I was twice that with Compost III. The yield response due to application of Compost I is more evident in Chinese cabbage, common cabbage, cucumber, radish and tomato compared to broccoli, hot pepper, okra and sweet pepper (Table 6).

Table 5. Effect of compost organic fertilizers on marketable yield (t/ha) of vegetable crops grown under VAF system, Trial 1. AVRDC, 2006.

Vegetable crop	Organic Fertilizer – Compost[1]			Mean
	Compost I (RSCS)	Compost II (CS)	Compost III (RSCS+CS)	
Cucumber	19.0 b	20.4 b	25.1 a	21.5
Eggplant	26.7 b	39.1 a	29.0 b	31.6
Head lettuce	2.9 a	3.1 a	2.9 a	2.9
Sweet corn	5.7 a	6.7 a	6.8 a	6.4
Yard-long bean	9.4 a	9.5 a	10.0 a	9.6
Mean	12.7	15.8	14.8	

[1]RSCS = Rape seed+soybean+castor seed+sesame; CS = Castor seed

For each crop, means followed by common letters in the same row are not significantly different ($P=0.05$).

Table 6. Effect of compost organic fertilizers on yield (t/ha) of vegetable crops grown under VAF system, Trial 2. AVRDC, 2006.

Vegetable crop	Organic Fertilizer – Compost[1]			Mean
	Compost I (RSCS)	Compost II (CS)	Compost III (RSCS+CS)	
Broccoli	12.9 a	11.5 a	6.2 b	10.2
Cauliflower	Bolted	Bolted	Bolted	-
Chinese cabbage	62.2 a	56.0 a	34.4 b	51.9
Common cabbage	26.8 a	28.8 a	17.2 b	24.3
Cucumber	56.1 a	60.9 a	40.7 b	52.6
Hot pepper	17.5 a	16.7 a	9.3 b	14.5
Okra	11.5 b	16.3 a	11.0 b	12.9
Radish	38.4 a	27.0 b	18.4 c	27.9
Sweet pepper	15.0 a	13.0 a	9.6 b	12.5
Tomato	36.7 a	30.5 b	17.4 c	28.2
Mean	30.8	28.9	18.2	

[1]RSCS = Rape seed+soybean+castor seed+sesame; CS = Castor seed

For each crop, means followed by common letters in the same row are not significantly different ($P=0.05$).

The results of the initial vegetable cropping indicated that vegetable species respond to application of organic fertilizers (compost), and that varieties within vegetable species significantly differ in marketable yield. Visual observations showed no negative effect of tree hedgerows on associated vegetable species in terms of growth and suggest that the integration of vegetable crops in a vegetable-agroforestry system can provide quick economic returns.

3.3 Vegetable yields in monoculture and agroforestry systems

During the last two cropping seasons (fall-winter and winter-spring, 2008-2009) five vegetable species including Chinese cabbage, cucumber, eggplant, sweet pepper and tomato were grown in vegetable-agroforestry and monoculture systems to determine the influence of tree hedgerows on marketable yield when fruit trees were fully mature and have developed full canopies 4 years after establishment. It was our objective to observe generally how yields in agroforestry plots compare with yields in monoculture plots although combined statistical analysis was not performed. Therefore, the comparison was numerical rather than statistical. During the hot-dry season, the yield response of vegetable crops grown in agroforestry system varied with species and varieties. As shown in Table 7, marketable yields of Chinese cabbage, common cabbage and cucumber were higher under the vegetable-agroforestry system compared to monoculture. Greatest yield increase (+100.3%) was observed with Chinese cabbage followed by cucumber (+20.7%) and common cabbage (+8.9%). In contrast, marketable yields of eggplant and tomato decreased by 47%; for eggplant, yield was reduced by 53% in the vegetable-agroforestry system.

Results obtained from trials conducted during the cool-dry season (2008-2009) also showed differences in marketable yield of vegetable species as influenced by variety and cropping system (Table 8). For each vegetable species, there were differences in marketable yield between varieties in both cropping systems. In general, marketable yield of vegetables was reduced under vegetable-agroforestry systems. However, for the same vegetable crop, some varieties performed better (higher yield) than other varieties in the agroforestry system. For example, AVRDC tomato varieties WVCT-1 and CLN3149 produced significantly higher yield than 'A Red Points' under agroforestry systems (Table 8). Likewise, cucumber variety 'Hun-Yun' yielded significantly more than 'Siu-Yan' and 'Ar-Shin.' Marketable yield of Chinese cabbage variety 'New King' was greater than 'Yi-Hung' and 'Early Autumn' (Table 8).

The influence of tree hedgerows became more apparent during the cool-dry season than the hot-dry season. Marketable yields of all vegetable crops grown under a vegetable-agroforestry system were lower than in the monoculture system (Table 8). Yield reduction was greatest with sweet pepper (65%), followed by tomato (27%) and Chinese cabbage (20%). Cucumber and eggplant were less affected by tree hedgerows with yield reduction of 1% and 11%, respectively. Shading of vegetables by the associated tree crop was considered a major factor in decreased yield, for vegetable crops received optimal irrigation and nutrient supply. As fruit trees reached maturity and developed a full canopy, competition for light, soil moisture and nutrients became evident. With time and over the longer term, yield loss from vegetable crops will be compensated by yield gain in fruit trees when trees start bearing fruit. Indeed, some tree species started producing fruit in the third and fourth years after establishment.

Findings from this study support those reported previously: intercropping vegetables in tree hedgerows significantly reduced yield of intercropped vegetables. The reduction can be attributed to negative tree-crop interaction due to competition for light, water and nutrients in favor of trees (Palada et al., 1992b, 2004a; Mercado et al., 2007, 2008a; Manurung et al., 2008). However, competition can be reversed into a positive tree-crop association resulting in higher complementarity and supplementarity indices as reported by Mercado et al. (2007; 2008a,b). This can be achieved by using compatible tree-crop combinations and tree spacing (tree line distance from vegetable crops). The selection of vegetable species and varieties within species with tolerance to shading and less sensitivity to soil moisture stress would improve tree-crop complementation, resulting in increased yield.

3.4 Benefit-cost from vegetable production under vegetable-agroforestry system

Cost and returns analyses were performed for each vegetable crop using the average marketable yield across varieties and compost fertilizer treatments. Yield data for the trial conducted during the cool dry season of 2008-2009 was used for this analysis. Data in Table 9 show that net returns were higher from vegetable crops grown in monocultures than in vegetable-agroforestry systems. However, net returns from cucumber were negative for both cropping systems. This can be attributed to low yields and high variable costs. In general, variable cost for crops under the vegetable-agroforestry system was slightly greater (mainly labor cost) than monoculture, resulting in lower net returns; and negative net returns for sweet pepper and cucumber grown under the vegetable-agroforestry system (Table 9). This shows that under vegetable-agroforestry systems, some vegetables were more profitable to grow than others and vegetable farmers should consider producing vegetable species that fetch good market prices. This study shows that Chinese cabbage, tomato and eggplant can be grown profitably under a vegetable-agroforestry system after 2 years of fruit tree growth, but not profitably as in monoculture.

Table 7. Marketable yield of vegetable crops grown in monoculture and Vegetable Agroforestry systems. AVRDC, hot-dry season, 2008.
For each vegetable crop, means in columns with common letters are not significant (*P=0.05*) by LSD.

Vegetable crop	Variety	Monoculture (t/ha)	VAF (t/ha)	Variation (%)
Chinese cabbage	Chin-Ha	27.5 b	53.2 b	
	C.C. Top	37.4 a	78.9 a	
	Day 55	24.3 b	46.4 c	
	Mean	**29.7**	**59.5**	**+100.3**
Common cabbage	Chu-Chu A	44.5 a	47.6 a	
	Chu-Chu	40.4 a	45.9 a	
	Hau-Fun	43.6 a	46.3 a	
	Mean	**42.8**	**46.6**	**+8.9**
Cucumber	Siiu-Yan	35.6 a	45.7 a	
	Si-Yi	29.2 b	41.8 ab	
	Ar-Shin	24.1 c	37.7 b	
	Mean	**29.6**	**41.7**	**+20.7**
Eggplant	Pingtung Long	154.7 a	84.6 a	
	Harvest Long	165.3 a	69.8 b	
	Market True	135.1 a	59.1 c	
	Mean	**151.7**	**71.2**	**-53.1**
Tomato	Known-You	140.1 a	84.1 a	
	WVCT-1	217.9 a	87.2 a	
	CLN3149	145.6 a	95.2 a	
	Mean	**167.9**	**88.8**	**-47.1**

3.5 Observations on incidence of insect pests, diseases and natural enemies

General visual observations were performed on the incidence of insect pests in tree hedgerows and vegetable crops. Various insect pests commonly attacking vegetable crops were seen in all cropping cycles. Insect species varied with the type and species of vegetable crops. Natural enemies (beneficial insects) were present in both the tree hedgerows and intercropped vegetables. Because the vegetable-agroforestry system was a part of the organic research farm, the use of biological and non-chemical methods of controlling insect pests encouraged the presence of beneficial insects.

Natural enemies were sampled with yellow and white sticky traps placed within the tree rows. Identification of natural enemies on five tree species (Brazil cherry, abiu, star apple, mafai and coffee) was conducted (Table 10). Natural enemies found included orb web spinning spiders (Araneae: Araneidae), jumping spiders (Araneae: Salticidae), other unidentified spiders, and at least three species of parasitic wasps (Hymenoptera), predatory ladybird

Table 8. Marketable yield of vegetable crops grown in monoculture and Vegetable Agroforestry systems. AVRDC, cool-dry season, 2008-2009.

Vegetable crop	Variety	Monoculture (t/ha)	VAF (t/ha)	Variation (%)
Chinese cabbage	Yi-Hung	43.8 c	34.8 c	
	New King	77.6 a	66.2 a	
	Early Autumn	62.7 b	46.0 b	
	Mean	**61.4**	**49.0**	**-20**
Cucumber	Hun-Yan	15.6 a	12.8 a	
	Siu-Yan	7.5 b	7.9 b	
	Ar-Shin	5.0 c	7.1 b	
	Mean	**9.4**	**9.3**	**-1**
Eggplant	Known-You	57.3 a	48.3 a	
	Hua-Lang	55.1 a	47.0 a	
	Masu-Long	41.9 b	41.5 a	
	Mean	**51.4**	**45.6**	**-11**
Sweet pepper	Blue Star	19.9 b	6.3 b	
	EVG103	24.1 a	8.1 a	
	Susan	11.6 c	5.5 b	
	Mean	**18.5**	**6.6**	**-65**
Tomato	A Red Points	75.9 a	45.4 c	
	WVCT-1	74.5 a	55.2 b	
	CLN3149	79.2 a	66.0 a	
	Mean	**76.5**	**55.5**	**-27**

For each vegetable crop, means in columns and rows with common letters are not significant (*P=0.05*) by LSD.

beetles (Coleoptera: Coccinellidae) and ants (Hymenoptera: Formicidae). Natural enemies were especially abundant on star apple and mafai. Due to limited data, it is difficult to conclude other than that the addition of these five tree species to vegetable agroecosystems would enhance natural enemy populations, which could increase levels of natural pest control on nearby vegetables.

3.6 Tree-crop competition

Based on visual observations tree-crop competition was not apparent during the early establishment of trees and vegetable crops. Yields of vegetable crops were comparable to yields obtained in the local area. Trees did not compete with vegetables for environmental resources; however, competition became obvious when the trees reached maturity and full canopies developed 3 years after establishment. Although quantitative measurement on tree-crop competition was not performed in this study due to limited resources, it was apparent that trees competed with vegetable crops for soil moisture, despite regularly scheduled drip irrigation for vegetables. The greatest factor in tree-crop competition was the amount of light received by intercropped vegetables. Shading of vegetables by tree hedgerows was apparent, especially for

fast-growing tree species; mature tree hedgerows reduced the available light for normal growth of vegetable crops. However, competition for soil nutrients was not very apparent, and most vegetable crops did not show any symptoms of nutrient deficiencies.

Table 9. Cost and returns from vegetable crops grown under monoculture and vegetable-agroforestry systems. AVRDC, 2008. Note: NT = Taiwan Dollar.

Vegetable crop	Parameter	Monoculture	VAF System
Chinese cabbage	Yield (kg/m^2)	6.1	4.9
	Price (NT$/kg)	24.9	24.9
	Gross return (NT$/m^2)	151.9	122.0
	Variable cost (NT$/m^2)	25.4	26.8
	Net return (NT$/m^2)	126.5	95.2
	B/C ratio	**4.98**	**3.55**
Cucumber	Yield (kg/m^2)	0.9	0.9
	Price (NT$/kg)	33.2	33.2
	Gross return (NT$/m^2)	29.9	29.9
	Variable cost (NT$/m^2)	33.5	35.5
	Net return (NT$/m^2)	-3.6	-5.6
	B/C ratio	**-0.11**	**-0.16**
Eggplant	Yield (kg/m^2)	5.1	4.6
	Price (NT$/kg)	24.9	24.9
	Gross return (NT$/m^2)	127.0	112.6
	Variable cost (NT$/m^2)	62.3	64.3
	Net return (NT$/m^2)	64.7	48.3
	B/C ratio	**1.04**	**0.75**
Tomato	Yield (kg/m^2)	7.7	5.6
	Price (NT$/kg)	32.6	32.6
	Gross return (NT$/m^2)	227.2	164.8
	Variable cost (NT$/m^2)	62.1	64.0
	Net return (NT$/m^2)	165.1	100.8
	B/C ratio	**2.66**	**1.58**
Sweet pepper	Yield (kg/m^2)	1.9	0.7
	Price (NT$/kg)	44.4	44.4
	Gross return (NT$/m^2)	84.4	31.1
	Variable cost (NT$/m^2)	32.6	34.4
	Net return (NT$/m^2)	51.8	-3.3
	B/C ratio	**1.59**	**-0.09**

4. Summary and Conclusions

This is the first study that integrates vegetable crops into agroforestry systems at AVRDC – The World Vegetable Center. The study has demonstrated the technical and economic feasibility of vegetable-agroforestry systems (VAF) in which vegetable and tree crop associations can contribute to improving total economic returns from the combined revenues of high-value horticultural crops. It was shown that at the early stage of tree establishment, tree-crop competition did not influence economic yield of intercropped vegetables. As the trees became fully mature and developed dense canopies, the competition with vegetable crops for light, soil moisture, and nutrients was apparent. However, decreases in yields varied with vegetable crop species and varieties. Marketable yields of the more sensitive vegetable crops such as sweet pepper and tomato were reduced under vegetable-agroforestry systems, regardless of cropping season. In the hot dry season, vegetable-agroforestry systems favored growth and yield of Chinese cabbage, cucumber and eggplant, with greater yields than those obtained under monoculture. However, during the last cropping cycle (cool-dry season), yields of all vegetable crops were lower in agroforestry systems than in monoculture systems. Sweet pepper and tomato resulted in greatest yield reduction.

Table 10. Natural enemies caught on sticky traps on five tree species at AVRDC Headquarters, Shanhua, Taiwan on 16 April 2007.

Tree Species	Sticky Trap color	Orb web spinning spiders[1]	Jumping spiders[2]	Other spiders[3]	Parasitic Wasp Species A[4]	Parasitic Wasp Species B[5]	Other parasitic Wasp[6]	Predatory Lady bird Beetles[7]	Ants[8]
Brazil Cherry	Yellow	4		4	1	3			
	White	1		4				1	
Abiu	Yellow	1		4		1	1		1
	White	1		5					
Star apple	Yellow	2	1	5	3		3	3	
	White	2	1	20		1			
Mafai	Yellow	1	2	8	11		2		2
	White	1	2	5			2	1	7
Coffee	Yellow			3	5			2	
	White	1		4				1	

[1]Araneae:Araneidae; [2]Araneae:Salticidae; [3]Araneae; [4]Hymenoptera:Braconidae; [5]Hymenoptera; [6]Hymenoptera; [7]Coleoptera:Coccinellidae; [8]Hymenoptera:Formicidae.

Although some vegetable species performed poorly under the system, economic assessment may show positive returns, which are attributed to their high market prices. Positive benefit-cost (B/C) ratios were obtained from Chinese cabbage, tomato, and eggplant, whereas cucumber and sweet pepper showed negative B/C ratios. Thus, under a vegetable-agroforestry system some vegetable species are more profitable to grow than others, and vegetable farmers should consider selecting and producing vegetables that are better adapted and could fetch good market prices. Lastly, yield loss in vegetable crops due to negative tree-crop associations can be compensated in the long term by harvesting and marketing fruits produced by fruit trees in a vegetable-agroforestry system. Combined production of high-value crops eventually will contribute to increased economic returns and sustainability of the vegetable-agroforestry system.

Besides the level of total income, the shorter time period before returns accrue from vegetable agroforestry compared to monoculture trees is very critical for livelihoods of small-scale farmers adopting such agroforestry system (VAF). This is because a typical small-scale farmer in a developing country cannot wait very long before getting returns from tree crops, as commonly seen in most of the on-farm tree plantation systems. Thus, with suitable combinations of vegetable species within an agroforestry system (VAF), we can address one of the leading shortcomings and barriers of commonly observed agroforestry system of farming, so that smallholder farmers can maximize their benefits from adopting vegetable agroforestry. Because they are of shorter duration than cereals and other crops, vegetables have an obvious advantage in this system over other crops. In addition, vegetables are more flexible in terms of cropping patterns in the tree systems than many of the cereals, hence with proper cropping plan, vegetable-agroforestry like farming system has high potential to enhance adoption of agroforestry system by many small-scale farmers in the developing countries.

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