Low-cost protected cultivation: enhancing year-round production of high-value vegetables in the Philippines

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Abstract

Thirty-four protected-cropping structures of various designs were constructed and tested at five project sites in Leyte, the Philippines, to evaluate their technical feasibility for producing vegetable crops. Two types of structures were evaluated: house-type structures, built from either bamboo or coco lumber with an effective growing area of 200 m^2 (5 m × 40 m) and tunnel-/igloo-types made of either bamboo or steel frames, with either plastic or net coverings and a growing area of 60 m^2 (1.5 m × 40 m). The experimental sites at the Visayas State University were used mainly for research on crop suitability, pest and disease impacts, and nutrition. The farmer test sites were used mainly to collect information on yield differences between crops grown under structures and in the open field to support the assessment of economic viability, and production challenges. From 134 treatment comparisons, it was found that average yields were higher under protected cropping compared with the open field for cauliflower, green onion, lettuce, chilli pepper, tomato, sweet pepper, bitter melon (ampalaya), pechay (*Brassica rapa* cv. group pak choi), muskmelon, broccoli and string beans. There was no improvement in yield for sweet corn, cabbage, watermelon, bottle gourd, cucumber or winter squash. Farmers need a certain minimum level of skill to take advantage of protected cropping, especially in relation to effective management of irrigation and in controlling pests and diseases. Protected cropping can result in higher yields in both the wet and dry seasons. Foliage diseases were easier to control under protected-cropping structures but whiteflies, aphids and mites were more difficult to control.

Introduction

The Philippine vegetable industry contributes more than 30% to total agricultural production, and is a major component of gross domestic product (UNDP 2006). However, one of the important challenges to the vegetable industry in the Philippines is to develop a production system that adequately meets the need for year-round production of safe and high-quality goods. It is difficult to meet this need with conventional field production of crops because of high rainfall, which makes vegetable production difficult and leads to fluctuations in supply and prices of the commodities in the market. This is particularly true for Region VIII of the Philippines, the Eastern Visayas, where off-season production constraints are more severe considering its Type IV rainfall pattern. This rainfall pattern is characterised by high annual rainfall (at least 2 m per year), a distinct wet season (July–January), a significant amount of rainfall for the remainder of the year

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and frequent typhoons. This weather pattern makes vegetable growing difficult and, as a result, the Eastern Visayas produces only 47,000 tonnes (t) of vegetables per year, or about 45% of the local demand (FNRI 1993). The shortfall is met by importing from other parts of the Philippines, such as Mindanao and Luzon.

A production system that protects crops from rain and wind, and associated diseases, should improve the viability of vegetable crop production in the Eastern Visayas. Expected benefits include higher yields, better quality, more reliable supply and fewer problems with diseases and weeds. Some farming operations such as planting, spraying and harvesting are simpler but others such as irrigation and pest control can be more difficult under structures than in the open field (FFTC 2007).

The types of protective structures used by growers in Asia range from simple structures such as rain shelters, shade houses, mulches, row covers and plastic tunnels, to permanent structures covered in plastic or glass with computerised environmental controls which can be linked to soil-based or soil-less production systems. This diversity makes the selection of appropriate and cost-effective technology complex. It is essential for the development of an appropriate protected cropping production system that the entire production system be addressed, i.e. plant protection, irrigation, nutrition and types of cultivars.

Filipino farmers generally have low incomes, hence low-cost protected cropping is envisioned to be more attractive. Nevertheless, protected cultivation still requires farmers to invest money to build and maintain the structures. A project was therefore developed to build various low-cost protective structures in the Eastern Visayas, test their suitability under local weather conditions and evaluate the technical feasibility of growing vegetables under low-cost structures.

Review of literature

Protected cultivation in tropical climate creates awareness among growers and policymakers of the potential of the technology to improve yields and quality of vegetables grown in the difficult environment in the humid tropics. Horticultural production under a structure has become increasingly important in recent years. This trend is brought about by the demand for fresh horticultural crops even during the off-season when crop production is limited by adverse climatic conditions. Protected cultivation assures continuous supply of fresh vegetables and fruits throughout the year, particularly during the rainy months, when such products would be difficult if not impossible to grow.

The kinds of protective structures used by growers in Asia range from simple structures such as rain shelters, shade houses, mulches, row covers and plastic tunnels, to permanent structures covered in plastic or glass with computerised environmental controls. Growers in countries where typhoons are common over the summer tend to prefer low-cost structures that can be quickly and cheaply replaced. Greenhouses in such countries generally have walls and roofs of plastic rather than glass, over a metal or even bamboo framework (FFTC 2007). The extent to which these structures improve the yield of vegetable crops depends largely on the extent to which advances in crop protection, plant breeding and crop cultivation have been applied to the production system.

The beneficial effects of protective structures, whether house-type or tunnel, on the growth and yield of vegetable crops has been well documented. Plastic tunnels can be used as a nursery for young plants from sowing to planting in the open air. The low tunnels are more suitable to protect low-growing plants such as melons, squashes and salad crops. However, timing of planting must be considered as it was reported that a plastic cover can increase the air temperature by 10°C and the soil temperature by 2–10°C during daytime when ambient temperatures are comparatively high (Baudoin and Nisen 1990).

Rain shelters have also been observed to have a favourable effect on the quality of produce. Protective structures provide shelter vegetable crops from biotic and abiotic stresses (Palada 2011). This finding is similar to the one reported by Mangmang (2002) that the total fruit yield and high net returns of tomato plants were significantly enhanced by plastic covering.

Growing in a greenhouse enables the plants to mature at up to 30% faster than field-grown crops. Moreover, greenhouse carrots are a real treat because they are sweeter and more tender than those grown outdoors, while greenhouse cucumbers are less bitter in taste than those grown outdoors. Greenhouse lettuce produces fine solid heads and resists tipburn, rot and bolting (Baudoin and Nisen 1990; cited in Mangmang 2002).

Certain cultural practices, such as the use of a raised bed and rain shelter, improved survival following a period of intense rain and protect the root system from flooding and presumably anoxic conditions, leading to enhanced crop growth, vigour and fruit yields (Liaw et al. 1993). Likewise, protective structures affect the quality, yield and time of production (Baudoin and Nisen 1990). In tomato, protected cultivation prevented the flowers and pollen grains from falling during heavy rains, leading to an increase in the total number of marketable fruits and total fruit yield of the plants (Apilar 2002). Indeed, protected cultivation is advantageous as it spreads the demand for rural labour over a longer period, produces high-quality fruit as well and provides control over the date of harvest (Kim et al. 1990). Growers who cannot afford the high initial construction costs of net or plastic houses can grow vegetables under temporary net tunnels. The net tunnels are constructed over each bed, using U-shaped iron or aluminum bars, which are covered with nylon netting (Talekar et al. 2003). They normally have no temperature or humidity regulation of the kind generally found in greenhouses. Rain shelters are primarily intended to protect the crops grown beneath them from damage by heavy rain.

A number of insect pest and diseases has been found infesting and infecting vegetable crops. The tobacco thrip *Thrips tabaci* is a dangerous pest of vegetable crops, especially cucumber grown in greenhouses. The rust tick *Aculus lycopersici* is very harmful to 28 species in the Solanaceae family, including tomato, potato, eggplant, pepper, ground cherry and black nightshade. However, in a tunnel experiment on cauliflower, it was reported that insect populations under tunnels roofed with net were reduced by 80%, and that marketable yields were 1.5–2.0 times greater under than in the open field (Palada and Ali 2007). Likewise, growing head cabbage under net tunnels in Solomon Islands reduced insect incidence by 38–72% and resulted in significantly higher economic returns (Neave et al. 2011).

Rain increases the incidence of disease in vegetables by increasing plant wetness. High soil moisture enhances the development of soil-borne pathogens (Magdoff and van Es 2000) including *Phytophthora*, *Pythium* and the bacterial wilt pathogen *Ralstonia solanacearum*. By rain splashing, flooding or excess watering, dispersed spores of pathogens can affect all parts of the plant at all ages. Excess water also damages roots by depriving them of oxygen, and creates condition that favour infection by certain soil-borne pathogen (Graham and Timmer 2003). Thus, irrigation management based on plant needs will help create an environment unfavourable for pathogen survival and disease development. Use of tensiometers or other devises for irrigation scheduling, and avoidance of low-lying areas, can help in disease management strategies (Sammis 1980). Furthermore, the use of protective structures that allow moisture extremes to be regulated create conditions unfavourable to soil-borne pathogens such as *R. solanacearum*

The most prevalent diseases of tomato, sweet pepper and other solanaceous crops in the Philippines include bacterial wilt, damping-off, *Fusarium* wilt, early blight, late blight, leaf curl and tomato mosaic viruses (Soriano et al. 1989). In cucurbits such as bitter melon (ampalaya), diseases including *Cercospora* leaf spot and downy mildew (*Pseudoperonospora cubensis*) may have a drastic effect on yield if not controlled. Bacterial wilt (*Pseudomonas solanacearum*) also attacks the crop (Siemonsma and Piluek 1994). Dimabuyu (2011) reported 0% bacterial wilt infection in bitter gourd under house-type structure and 55% infection in the open field. In squash, anthracnose caused by *Colletotrichum lageranium* is the most destructive disease. It causes defoliation and lesions. Other diseases are powdery mildew (*Erysiphe cichoracearum*), downy mildew (*P. cubensis*), scab (*Cladosporium cucumerinum*) and leaf spot (*Alternaria cucumerina*). Important virus diseases are cucumber mosaic virus (CMV), watermelon mosaic virus (WMV-2), papaya ring spot virus (PRSV-W), zucchini yellow mosaic virus (ZYMV) and squash leaf curl virus (SLCV) (Siemonsma and Piluek 1994).

Materials and methods

The overall approach to answering questions on the technical feasibility of low-cost protected cropping in the Eastern Visayas was to first establish a research site at the Visayas State University (VSU) in Baybay City, Leyte, to test the proposed structure designs and production techniques. Promising designs and techniques were then evaluated on commercial farms in an action (farmers' participatory) research approach. Resistance of the designs to adverse conditions, particularly to the damaging effects of heavy rain and the strong winds that often accompanies it, was monitored. Likewise, incidence/severity of insect pest and diseases infecting vegetable crops under structures and in the open field were assessed and compared. An important part of this project was to test the technical feasibility of protected cropping under actual on-farm conditions; hence, the farm-based trials were a focus of activities.

Project site identification and selection

The identification of the project sites in Ormoc and Maasin was based on the results of a scoping study undertaken in Leyte and Southern Leyte in February 2007 by the Australian Centre for International Agricultural Research (ACIAR) through Dr Les Baxter, Dr Jose Bacusmo, Dr Gordon Rogers and other VSU experts. The project team coordinated first with the local government units (LGUs), especially the mayor and the Office of the City/Municipal Agriculture Officer or officer-in-charge in each identified project site to formalise linkages, including the administrative and technical requirements, and establishing the selection criteria for location sites and farmer-cooperators.

The basic criteria for selection were farming performance and attitude, soil type, availability of water, security and farm-to-market accessibility. Mixes of farmer skill levels were chosen. Nevertheless, the team was careful to include some leading, innovative farmers who would be likely to lead adoption should the protected-cropping techniques evaluated showed positive results.

Memorandums of agreement was signed by the project proponents and LGUs to formalise the project implementation. The agreements included the functions and responsibilities of participating institutions and, under this arrangement, the project proponent from VSU provided the technical expertise for project implementation. LGUs helped with the supervision of farm sites and also took on a coordinating role, especially in relation to farmer field school training.

Farmers' field set-up

The project team provided the technical expertise needed for the design, establishment and other technical requirements of building the protective structures in the farmer-cooperators' fields. The project field sites were situated in lowland and upland areas, as can be found in Ormoc and Maasin. Moreover, the project evaluated essentially two types of structures at the project sites: house-type structures, mainly made of bamboo or coco lumber covered with UV-treated plastic and having an effective growing area of 200 m^2 (5 m × 40 m); tunnel-/igloo-type structures made with either bamboo or steel frames, with either plastic or net coverings, and with a growing area of 60 m^2 (1.5 m × 40 m) (Figure 1). The house-type structure was used for taller and climbing vegetable crops like sweet pepper and bitter melon, while the low tunnel was used for low-lying and spreading crops such as lettuce and muskmelon. The farmer sites were used mainly to collect information on yield differences under structures and in the open field, to support the assessment of economic viability and to monitor for the emergence of new production challenges. On the other hand, the VSU site was used mainly for experimentation on crop suitability, pest and disease impacts, and nutrition.

Thirty-four protective structures of various types were constructed across all project sites at VSU, Ormoc, Cabintan (high-altitude site), Maasin and Bontoc. An open-field control site was included at each location. Drip irrigation systems were used at the VSU site and in some of the farmer-cooperators' fields at Ormoc and Bontoc sites. Data on temperature, relative humidity, light intensity and rainfall were collected at each site, using either electronic sensors with loggers or manually. Rainfall data collected during the early part of project implementation (2009, only VSU; 2010, Maasin and VSU) and at all the three sites in the third year of implementation are shown in Figure 2. The project team provided technical support to the farmers on crop selection and timing, crop rotation, pest and disease control, and other production issues.

All the materials for the protective structures, such as bamboo, nails, UV-stabilised plastic, labour and related expenses for the structures, were paid for from project funds for the first two cooperators; one in Ormoc and one in Maasin. In all succeeding constructions, a 50:50 split for the project and the LGU was agreed and implemented. The costs of materials and labour for minor repairs to the structure were borne by the farmer-cooperators. The costs of major repairs were borne by the LGU. Farmer-cooperators in Maasin city in particular were made to counterpart or return in pesos one-third of the total cost of the structure. Cropping inputs such as fertiliser and seed were paid for by the project for the first cropping cycle only. After that, farmers were expected to provide their own inputs, but would be subsidised if there was a crop failure due to the experimental nature of the production. Technical assistance was also provided by the project team in terms of the cultural management aspects from land preparation to harvesting, and for controlling insect pests and diseases in preventive and curative control measures. These include cultural control (e.g. sanitation, crop rotation and pruning), mechanical (hand picking and bagging as in the case of bitter melon),

Figure 1. House-type structures made of bamboo (A) or coco (B); and igloo-type structures covered with net (C) or plastic (D).

and chemical (contact and systemic pesticides) with observance of withholding periods, and the use of botanical or organic sprays. In total, there were 18 farmer-cooperators directly involved in the project at the various sites: Ormoc (10), Maasin (6), Bato (1), and Bontoc (1).

The experimental sites at VSU and farmer sites were set up following randomised complete block designs with four replications. Yield was separated into marketable and unmarketable, then numbers and weights of harvestable parts were recorded at each harvest. Individual treatment comparisons were analysed using ANOVA and the mean separations were tested at $P < 0.05$ least significant difference.

Crops were harvested multiple times according to normal commercial practice. Soils samples were taken before each crop was established and tested for total N, P and K, pH, EC, exchangeable cations (K, Na, Ca, Mg) and micronutrients. Plant tissue samples were taken during crop growth and the nutrient content measured as a guide to the nutritional status of the crops. The incidence (counts) of pests and diseases were recorded on crops in years 2 and 3 of the project.

Results and discussion

Effects of protective structures on yield

The average yields of vegetable crops grown under protected cropping over 3 years under house-type structures are shown in Table 1, which is a summary of over 134 separate comparisons. Each trial had an open-field control, and crops were harvested as commercial crops, and the harvested part classified as either marketable or non-marketable. Examples of yield outcomes from individual trials are shown in Tables 2 and 3 for tomato, and Tables 4–6 for sweet pepper, bitter melon and lettuce, respectively. The pooled yields show an increase in average yields

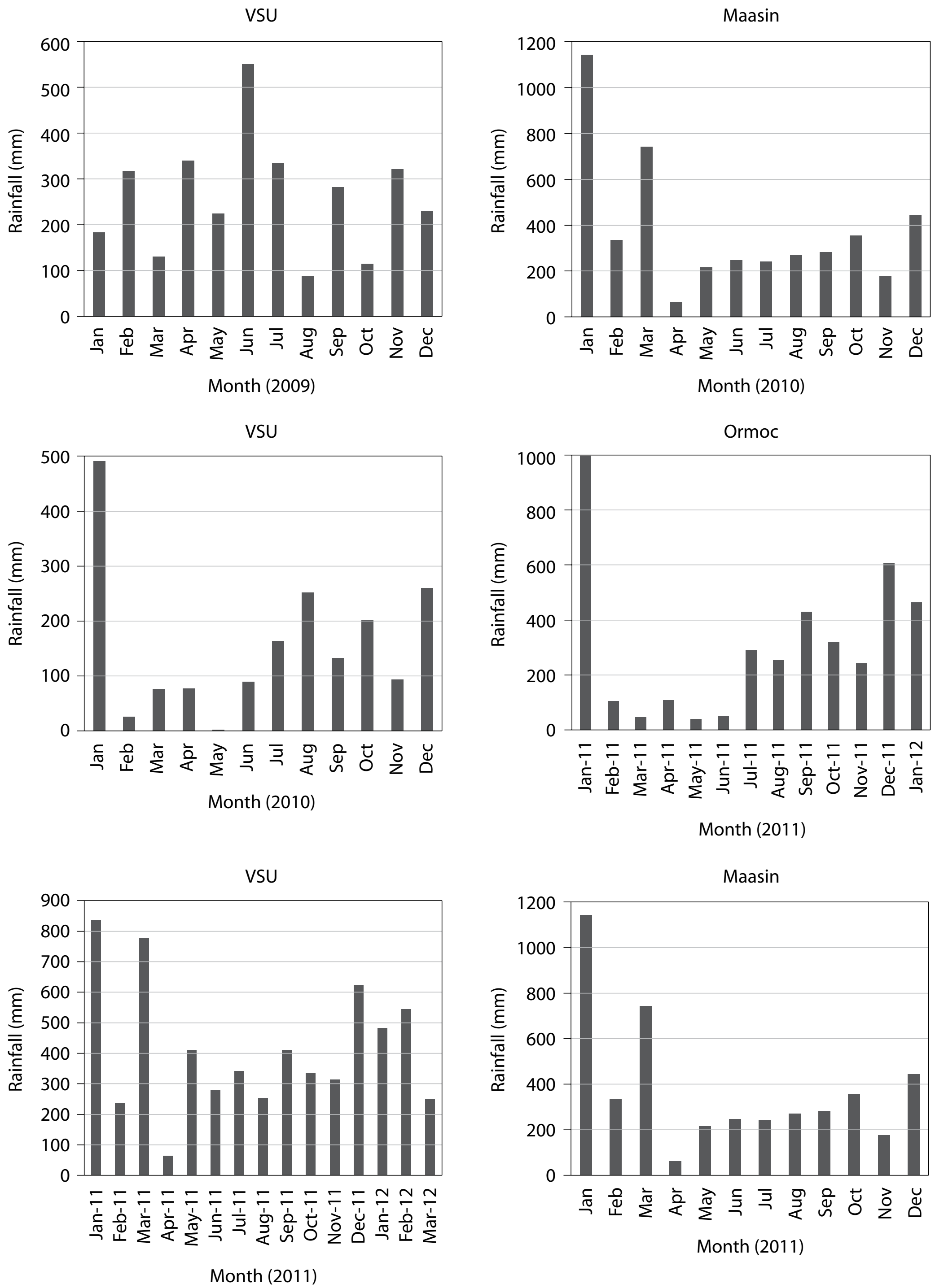

Figure 2. Total monthly rainfall at Ormoc, Visayas State University (VSU) and Maasin sites on 2009 2010 and 2011

under protected cropping for cauliflower, green onion, lettuce, chilli pepper, tomato, sweet pepper, bitter melon, pechay (*Brassica rapa* cv. group pak choi), muskmelon, broccoli and string beans. There was no improvement in yield for sweet corn, cabbage, watermelon, bottle gourd, cucumber or winter squash. Comparisons within sites for the four most 'successful' crops under protected cropping—tomato, sweet pepper, bitter melon and lettuce—have generally shown significantly higher yields under protected cropping, and the data shown in Tables 2–6 are typical. However, in some cases yields for these four crops were actually lower under protected cropping, or there were no significant differences. These results were included in the overall yield averages presented in this paper and could be attributed to either a low level of farmer skill, especially ineffective irrigation, or to uncontrolled pest or disease outbreaks. This issue has been examined and quantified by another paper in these proceedings (Armenia et al. 2012).

Four crops—tomatoes, sweet pepper, bitter melon and lettuce—consistently performed better under protected cropping than in the open field (Figures 3 and 4). The average yields for these crops were consistently higher under protective structures than in open field over the 3-year trial period in the Visayas.

Growing vegetable crops under protective structures is not new, and the reasons for yield increases are well documented. They include reduced periods of leaf wetness creating conditions less favourable for diseases to infect, fruit protected from direct contact with soil, reduced weed growth, moderate soil and air temperatures, and reduced leaching of nutrients from soils (De La Pena and Hughes 2007). The lower yields obtained from open-field-grown crops was attributed mainly to direct exposure to rain, especially during months with heavy precipitation (Figure 1). In tomato, clear plastic rain shelters prevent waterlogging and rain impact damage on developing fruit and consequently improved tomato

Table 1. Average yearly data of vegetables grown in Leyte during cropping years 2009, 2010 and 2011 under house-type protective structures and in the open field

Crops	Marketable yield (tonnes/ha[a])						Number of comparisons[b]
	2009		2010		2011		
	Open	Under structure	Open	Under structure	Open	Under structure	
Cauliflower	0	6.4	2	2.7	–	–	4
Green onion	–	–	–	–	17	60	2
Lettuce	4.6	13.3	21.3	22.7	–	–	10
Chilli pepper	–	–	6.9	16.8	–	–	2
Tomato	16.9	35.9	22.6	33.8	12.6	39.4	21
Sweet pepper	–	–	17.2	30	14	31	23
Bitter gourd	–	–	8.2	11.2	15.2	32.5	26
Pechay (pak choi)	–	–	7.1	29.7	–	–	3
Muskmelon	10.2	21.3	–	–	7	10.1	7
Broccoli	0.9	0.9	3	3.7	–	–	6
String beans	–	–	17.5	16.4	17.8	23.6	5
Snap beans	–	–	–	–	8	16	2
Sweet corn	–	–	2.9	3.3	–	–	2
Cabbage	8	8.1	8.8	12.2	–	–	5
Watermelon	–	–	17.1	8.6	57.4	56.2	8
Bottle gourd	–	–	41	41.1	–	–	3
Cucumber	–	–	–	–	89	76	2
Squash	–	–	44	36.5	–	–	3
Total							134

[a] Average yield in kg/plot from each crop. converted to tonnes/hectare pooled for 3 years across all sites
[b] Separate set-ups for 3 years across all sites
– = No trials conducted

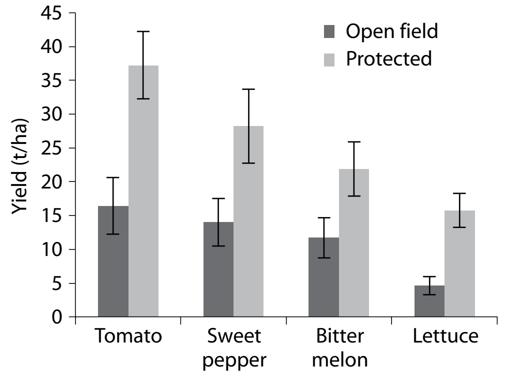

Figure 3. Yields of tomato, sweet pepper, bitter melon and lettuce under house-type protected cropping and in the open field, Leyte, Philippines (average of 3 years data). The vertical bars are standard errors (SE $P < 0.05$) and give an indication of the estimate of the amount that an obtained mean may be expected to differ by chance from the true mean.

yields (Apilar 2002; Mangmang 2002; Midmore et al. 1992).

Interaction between protected cropping and season

Despite there being a general trend for higher yields under protected cropping (Figure 3), the assumption has been that the main benefits occurred in the wet season, and that there was little advantage to growing crops under structures in the dry season, since there is no heavy rain or typhoons at that time of the year. To test this idea, the authors grouped yield data according to whether the crops had been grown predominantly in the dry season or the wet season. Wet season crops were those grown between July and January, and dry season crops were those grown between February and June. For tomato (Figure 4) the highest yields were obtained in the dry season rather than the wet season. While a reasonable yield of 22 t/ha could be obtained in the dry season in the open field, a much more impressive yield of 45 t/ha was obtained, on average, under protected cropping. During the wet season,

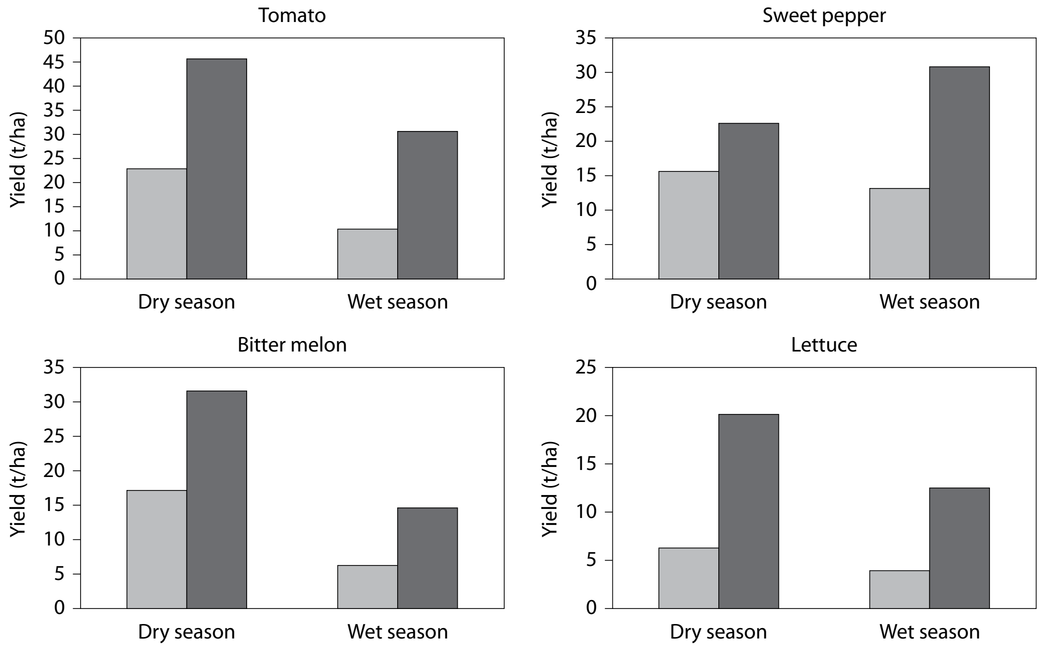

Figure 4. Yields of tomato, sweet pepper, bitter melon and lettuce under house-type protected cropping and in the open field during the wet and dry seasons in Leyte, Philippines. The data are an average of the results of 3 years of trials, with 21, 23, 26 and 10 datasets for tomato, sweet pepper, bitter melon and lettuce, respectively. The wet season is from July to January and the dry season from February to June.

open-field-grown, off-season tomatoes yielded less than 10 t/ha while, under protective covering, the same tomato cultivar produced 30 t/ha, which was higher even than that from regular dry-season tomato cropping in farmers' fields. Very similar trends were observed for bitter melon and lettuce (Figure 4). The result for sweet pepper was different from the other three crops, in that the greatest benefit of protected cropping was achieved during the wet season. The average wet-season yield was 30 t/ha, compared with only 12 t/ha in open-field production. This was because *Cercospora* leaf spot, a serious disease of sweet pepper during the wet season, was unable to infect the protected crop, since the dry and warm

Table 2. Yield data for tomatoes grown under a bamboo structure or in the open field (8 February – 24 June 2011) at Lao, Ormoc

Treatments	Marketable fruit/40 m^2		Non-marketable fruit/40 m^2		Total yield (t/ha)
	Number	Weight (kg)	Number	Weight (kg)	
Under structure	10,769a	401a	79b	1.9	100.79a
Open field	4,145b	133b	371a	6.8	34.88b
CV (%)	10.91	7.99	26.29	40.904	8.27

Means within a column having the same letters and those without letters are not significantly different at 5% level of significance based on DMRT.

Table 3. Yield data for tomatoes variety 'D' max' grown under a bamboo structure or in the open field (15 July – 21 October 2011) at Curva, Ormoc

Treatments	Marketable fruit/40 m^2		Non-Marketable fruit/40 m^2		Total yield (t/ha)
	Number	Weight (kg)	Number	Weight (kg)	
Bamboo	4,640a	211.00a	200.33	4.55	53.89a
Open field	1,522b	54.83b	84.33	2.17	15.52b
CV (%)	3.47	14.78	51.52	38.48	9.19

Means within a column having the same letters and those without letters are not significantly different at 5% level of significance based on DMRT.

Table 4. Yield data for sweet pepper grown under a bamboo structure or in the open field (22 June – 21 March 2012) at Lao, Ormoc

Treatments	Marketable fruit/40 m^2		Non-marketable fruit/40 m^2		Total yield (t/ha)
	Number	Weight (kg)	Number	Weight (kg)	
Under structure	8,592.00a	230.03a	368.67a	6.23a	59.06a
Open field	1,020.33b	23.55b	198.67b	2.35b	6.47b
CV (%)	0.50	3.20	17.90	18.90	3.30

Means within a column having the same letters and those without letters are not significantly different at 5% level of significance based on DMRT.

Table 5. Yield data for bitter melon variety 'Galaxy' grown under a bamboo structure or in the open field (23 March – 12 July 2011), Curva, Ormoc

Treatments	Marketable fruit/100 m^2		Non-marketable fruit/100 m^2		Total yield (t/ha)
	Number	Weight (kg)	Number	Weight (kg)	
Bamboo	1,895.00a	456.25a	69.50b	7.30	26.60
Open field	1,116.00b	255.00b	70.00a	6.02	15.55
CV (%)	2.86	3.44	12.19	10.88	49.82

Means within a column having the same letters and those without letters are not significantly different at 5% level of significance based on DMRT.

Table 6. Yield data for lettuce variety 'General' grown under coco house 1 or in the open field (25 May – 28 June 2010) at Visayas State University site

Treatments	Marketable yield/39.5 m^2		Head size (cm)		Total yield (t/ha)
	Number	Weight (kg)	Polar	Equatorial	
Coco 1	269a	41.37a	13.75	12.40	10.47a
Open field	142b	22.04b	12.95	11.77	5.58b
CV (%)	4.65	15.44	2.80	2.78	15.62

Means within a column having the same letters and those without letters are not significantly different at 5% level of significance based on DMRT.

conditions under the structure are not conducive to its proliferation.

The rainfall pattern in the Eastern Visayas could explain the seasonal effect on crop yields. While there is less rain during February and March, and a period of high rainfall of between 400 and 1000 mm per month for the rest of the year, there is still sufficient rainfall during the so-called dry season to cause significant problems for growing vegetable crops such as tomato, lettuce, sweet pepper and bitter melon that are susceptible to waterlogging.

Another factor could be that the environment inside greenhouses is generally more favourable to plant growth and development, especially for warm-season crops. Environmental stress is the primary cause of crop losses worldwide, reducing the average yields for most major crops by more than 50% (Boyer 1982; Bray et al. 2000). The lower yields in the wet season, particularly for plants grown in the open field, were likely due to high rainfall. During the 3 years of trials, the rainfall distribution followed a distinct trend—higher from July to January (wet) and lower from February to June (dry). Frequent heavy rain during the wet season would mean high soil moisture, which enhances the development of soil-borne pathogens (Magdoff and van Es 2000). In addition, rain splashing or flooding can help to disperse disease spores and infect plants (Graham and Timmer 2003).

Arthropod pests and diseases

Table 7 shows the major arthropods pests (insect and mites) commonly infesting vegetables, both under structures and in the open field. The data revealed that the incidence of most of the arthropod pests was generally higher under structures than in the open-field-grown plants. The red spider mite (*Tetranychus kanzawai*) and broad mite (*Polyphagotarsonemus latus*) were found to be most damaging in sweet pepper, especially under structures. In string beans, the pod borer (*Maruca vitrata*), thrips (*T. tabacci*) and leafhopper (*Empoasca* sp.) were the dominant species encountered, with the first two species seriously attacking flowers and newly formed pods. In the bitter melon, the aphid (*Aphis gossypii*) and the leaf folder (*Diaphania indica*) were consistently observed in all the croppings, greatly affecting the performance of the crop when left unchecked. In the case of watermelon, the broad mite was observed to be very damaging, greatly affecting the growth of the crops at the early vegetative stage. On the other hand, the leaf miner was found to be quite serious in the musk melon, although the data were more or less comparable under structures and in the open field. Moreover, in tomato, the major species were the leaf miner and the fruitworm (*Helicoverp armigera*). However, data show that their incidence was lower under structures than in the open field, which could be due to the use of net enclosure in one of the structure at the farmer sites.

Although the incidence of the insect pests and mites was generally higher under structures, especially during the rainy season, in some cases this difference was not very pronounced during the dry months, at which time arthropod incidence between the two set-ups was comparable. Insects and mites, especially minute, soft-bodies species, are sensitive to water splashes, which can easily dislodge them from the plant. They are also sensitive to the higher temperatures, which may cause desiccation. The structures provided protections to these insects during the rainy season, thus resulting to their higher incidence at that time. However, in the absence of rain (dry months) their incidence was usually comparable between protected and unprotected circumstances.

Major diseases that were commonly found affecting vegetable crops inside structures and in the open field include leaf spotting, caused mainly by *Cercospora* spp., and affecting bitter melon and sweet pepper; downy mildew caused by *P. cubensis*, affecting mainly the cucurbits, including bitter melon, squash and cucumber. Bacterial wilt caused by *R. solanacearum* was also a major problem in some areas, affecting tomato and sweet pepper. In lettuce, *Sclerotium* wilt caused by *Sclerotium rolfsii* was the main problem.

The incidence of these diseases was generally higher in the open field than under protective structures (Table 8). This was because excessive moisture in the open field, especially during heavy rains in the form of surface water, is conducive to the motile bacterial-wilt pathogen *R. solanacearum*. Surface water run-off to other areas of the field also favours the dissemination of the water-borne inoculum to more of the area planted. Inside protective structures, moisture extremes are regulated and this is unfavourable to soil-borne pathogens such as *R. solanacearum*.

In case of downy mildew and *Cercospora* diseases, high moisture in the leaves of the plants favours fungal spore germination and infection of these airborne fungal diseases. Inside structures, drip or trickle irrigation was usually practised, such that the water was directly applied to the roots, minimising application of water to the foliage of the plants. This also minimised the germination, penetration and infection of wind-borne inocula of fungi that might have landed on the foliage. Rain splashes are also not present inside structures, this being another way whereby inoculum from the soil can be introduced to the leaves or upper parts of the plant. Rain splashes can also transfer pathogen propagules such as fungal spores from leaf to leaf or from one plant to another.

In summary, moisture regulation inside protective structures is the main cause of lower disease incidence, and this could partly explain the longer life spans and higher yields of crops grown under protective structures.

The incidence of virus diseases inside or outside usually depends on whether or not conditions are favourable for the insect vectors of the viruses, so there are times when the incidence of virus diseases inside structures may be either lower or higher than outside. Sooty mould on the other hand is favoured inside structures, because this fungus is attracted to the honeydew secreted by insects such as aphids, which find the environment inside structures very mush to their benefit.

Potential of low-tunnel structures

Low tunnels can be used for low-growing crops such as muskmelon, cabbage, lettuce and cauliflower where yield increases can be achieved, especially when the tunnels are covered with fine netting (Figure 5). These structures have great potential because they are cheap to construct, can be removed during the dry season and the net covering allows water to penetrate, reducing the need to irrigate. For the abovementioned crops, the plastic covering was no better than the open

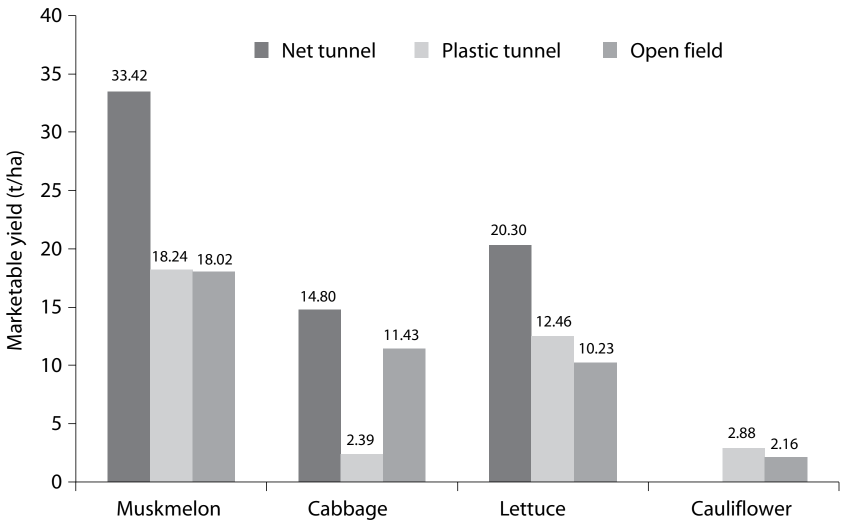

Figure 5. Yield data for muskmelon, cabbage, lettuce and cauliflower grown under low tunnels covered with plastic or net

Table 7. Major arthropod pest (insects and mites) attacking vegetables under protective structure

Crops	Pest incidence (%)		
Sweet pepper	Spider mite (*Tetranychus kanzawai*)	Broad mite (*Polyphagotarsonemus latus*)	
Under structure	23.50	31.40	
Open field	9.90	23.18	
String beans	Pod borer (*Maruca vitrata*)	Thrips (*Thrips tabacci*)	Leafhopper (*Empoasca* sp.)
Under structure	25.00	24.00	20.00
Open field	22.50	25.00	10.00
Bitter gourd	Aphids (*Aphis gossypii*)	Leaf folder (*Diaphania indica*)	
Under structure	38.50	13.50	
Open field	19.50	12.75	
Water melon	Broadmite (*Polyphagotarsonemus latus*)		
Under structure	25.00		
Open field	10.00		
Muskmelon	Leaf miner (*Liriomyza* sp.)		
Under structure	24.00		
Open field	25.10		
Tomato	Leaf miner (*Liriomyza* sp.)	Fruit worm (*Helicoverpa armigera*)	
Under structure	9.25	3.00	
Open field	14.50	18.00	

Table 8. Incidence of major diseases infecting vegetables grown under a protective structure

Crops/structure	Disease incidence (%)		
Bitter melon	*Cercospora* leaf spot (*Cercospora* spp.)	Downy mildew (*Pseudoperonospora cubensis*)	Virus
House-type structure	11.05	68.22	21.08
Open field	23.75	96.55	48.59
Sweet pepper	*Cercospora* leaf spot (*Cercospora* spp.)	Bacterial wilt (*Ralstonia solanacearum*)	Virus
House-type structure	10.75	0.10	4.16
Open Field	21.90	33.13	7.06
Tomato	Bacterial wilt (*R. solanacearum*)		
House-type structure	1.92		
Open field	30.58		
Squash	Downy mildew (*P. cubensis*)		
House-type structure	6.08		
Open field	42.40		
Cucumber	Downy mildew (*P. cubensis*)		
House-type structure	20.00		
Open field	100.00		
Lettuce	*Sclerotium* wilt (*Sclerotium rolfsii*)		
Plastic tunnel	0.61		
Net tunnel	9.68		
Open field	15.34		

field, which may have been due to high temperatures inside the tunnel.

Temperatures were higher under the tunnel covered with plastic than in net-covered tunnels and the open field (Figure 6) and this appeared detrimental to the growth of lettuce, which is a cool-season crop. Air temperatures under plastic tunnels were about 2°C higher than under net, and 5°C higher than in the open field. This observation is similar to the one reported by Baudoin and Nisen (1990) that tunnels covered with plastic increased the air and soil temperature by 2–10°C during daytime, much greater increases than those under house-type structure (Figure 7). It is clear that the use of net covering has potential for growing vegetables, since such tunnels are better ventilated than those with plastic roofing,

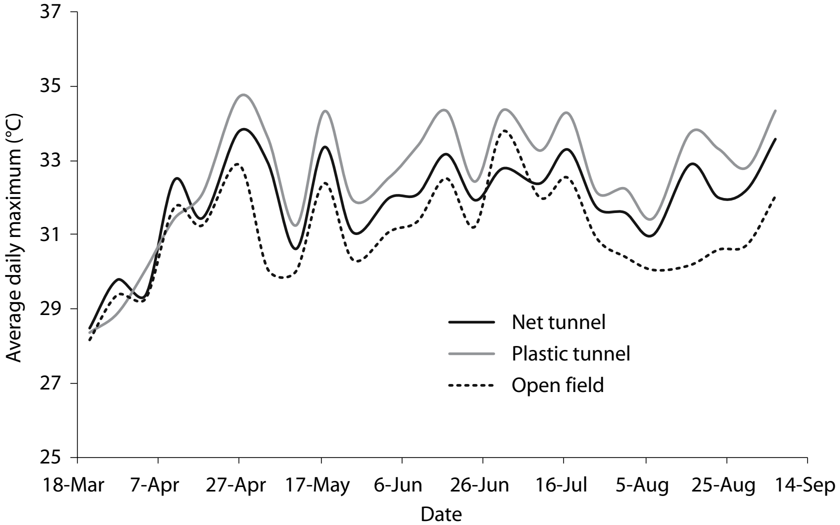

Figure 6. Average daily temperatures under tunnel-type structures and in the open field

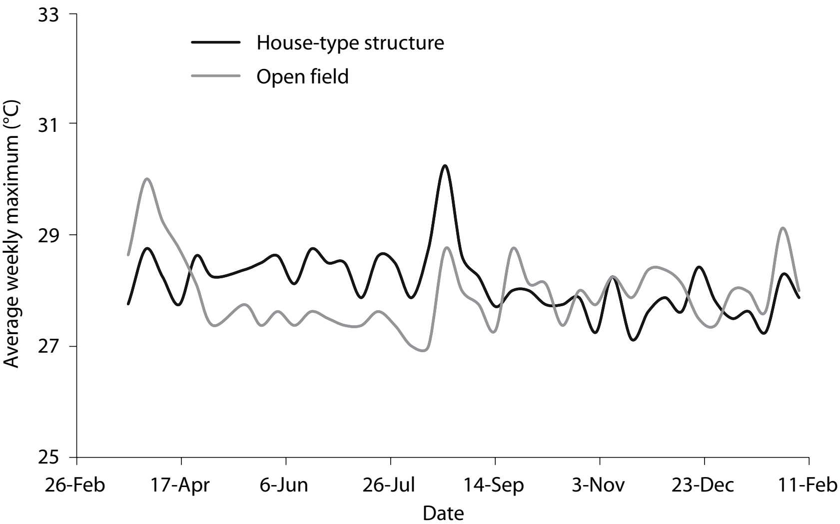

Figure 7. Average daily temperatures under house-type structures and in the open field

hence the lower temperatures inside. In times of heavy rain, the net also moderates the impact of the rainwater reaching the plant, but allows adequate penetration of light rain.

Conclusion

House-type structures made of bamboo are stronger than those made from coco lumber and are more suited to taller crops such as tomatoes, sweet pepper, bitter melon and beans. Low tunnels have great potential for low-growing crops such as lettuce, pechay and muskmelon, especially when roofed with fine netting rather than plastic. Generally, the crops grown under protective structures, regardless of the design and type of structure, have higher yields than those grown in open fields. Yields obtained, however, were found to be highly dependent on crop management, especially in relation to the choice of crop, irrigation management and pest control.

Protected cropping led to higher yields of vegetables in both wet and dry season. Disseminating this technology to other poor areas in Region VIII would help alleviate poverty and malnutrition, vegetables being a source of income and having a vital role in human nutrition and health.

References

Armenia P.T., Menz K.M., Rogers G.S., Gonzaga Z.C., Gerona R.G. and Tausa E.R. 2012. Economics of vegetable production under protected cropping structures in the Eastern Visayas, Philippines. In 'Smallholder HOPES—horticulture, people and soil', ed. by J. Oakeshott and D. Hall. ACIAR Proceedings No. 139, 112–122. Australian Centre for International Agricultural Research: Canberra. [These proceedings]

Apilar E.G. 2002. Horticultural and morphological responses of two (2) tomato (*Lycopersicon esculentum* Mill) varieties to open field and protected cultivation. PhD thesis, Leyte State University, Philippines.

Baudoin W.O. and Nisen A. 1990. Protected cultivation in the Mediterranean climate. FAO Plant Production and Protection Paper No. 90. FAO: Rome.

Boyer J.S. 1982. Plant productivity and environment. Science 218, 443–448.

Bray E.A., Bailey-Serres J. and Weretilnyk E. 2000. Responses to abiotic stresses. Pp 1158–1249 in 'Biochemistry and molecular biology of plants', ed. by W. Gruissem, B. Buchannan and R. Jones. American Society of Plant Physiologists: Rockville, MD.

De La Peña R.C. and Hughes J.d'A. 2007. Improving vegetable productivity in a variable and changing climate. At <ejournal.icrisat.org/specialProject/ sp1.pdf>, accessed 8 March 2013.

Dimabuyu H.B. 2011. Growth and yield of pruned ampalaya under structure and in the open field. Undergraduate thesis, Visayas State University, Philippines.

FFTC (Food and Fertilizer Technology Center) 2007. Protective structures for improved crop production. At <http://www.fftc.agnet.org/library.php?func=view&id=2011072812351&type_id=1>, accessed 20 April 2013.

FNRI (Food and Nutrition Research Institute) 1993. Fourth National Nutrition Survey. FNRI, Department of Science and Technology: Manila, Philippines.

Graham J.H. and Timmer L.W. 2003. Phytophthora diseases of citrus. Soil and Water Science Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, SL127. Accessible at <polkhort.ifa.ufl.edu/documents/publications/Phytophthora%20Diseases%20of%20Citrus.pdf>.

Kim J.Y., Hong Y.P., Shin H.K. and Shin R.W. 1990, Studies on the cultivation of year round cut flower in gerbera-I. Variety characteristics and yield trial. Research Reports of the Rural Development Administration Horticulture 36(1), 56–63.

Liaw F.S., Chang T.R. and Chen Y.H. 1988. Cultivation of tomato under the protective environment in summer. Reports of vegetable crops improvement, Series 5, 76–79. Asian Vegetable Research and Development Center: Shnahua, Taiwan.

Magdoff F. and van Es H. 2000. Building soils for better crops, 2nd edn. Handbook Series Book 4. Sustainable Agriculture Network: Beltsville, MD.

Mangmang J.S. 2002. Performance of three (3) tomato (*Lycopersicon esculentum* Mill) cultivars grown under protected cultivation and in the open field. Undergraduate thesis, Visayas State University, Philippines.

Midmore D.J., Roan Y.C. and Wu M.H. 1992. Management of moisture and heat stress for tomato and hot pepper production in the tropics. Pp. 453–460 in 'Adaptation of food crops to temperature and water stress', ed. by C.G. Kuo. Asian Vegetable Research and Development Center: Shanhua, Taiwan.

Neave S.M., Kelly G. and Furlong M.J. 2011. Field evaluation of insect exclusion netting for the management of pests on cabbage (*Brassica oleracea* var. *capitata*) in the Solomon Islands. In 'Abstracts from the Sixth International Workshop on Management of the Diamondback Moth and Other Crucifer Insect Pests', 21–25 March 2011, Kasetsart University, Nakhon Pathom, Thailand. Publication No. 11-746. Asian Vegetable Research and Development Center: Shanhua, Taiwan.

Palada M.C. 2011. Vegetable production under cover. Year-round vegetable production systems. Asian Vegetable Research and Development Center: Shanhua, Taiwan. Accessible at <http://www.slideshare.net/warwick.easdown/vegetable-production-under-cover>.

Palada M.C. and Ali M. 2007. Evaluation of technologies for improving year-round production of safe vegetables in peri-urban agriculture of Southeast Asia. Acta Horticulturae 762, 271–281.

Sammis T.W. 1980. Comparison of sprinkler, trickle, subsurface, and furrow irrigation methods for row crops. Agronomy Journal 72, 701–704.

Siemonsma J.S. and Piluek K. (eds) 1994. Plant resources of South-East Asia No. 8. Pudoc Scientific Publishers: Wageningen: Netherlands.

Soriano J.M., Villareal R.L. and Roxas V.P. 1989. Tomato and pepper production in the Philippines. In AVRDC (ed) 'Tomato and pepper production in the tropics', ed. by ACRDC. Proceedings of an international symposium on integrated management practices, 21–26 March 1988, Shanhua. Asian Vegetable Research and Development Center: Shanhua, Taiwan.

Talekar N.S., Su F.C. and Lin M.Y. 2003. How to produce safer leafy vegetables in nethouses and net tunnels. Asian Vegetable Research and Development Center, Shanhua, Taiwan. Accessible at <http://www.avrdc.org/LC/cabbage/nethouse.pdf>.

UNDP (United Nations Development Programme) 2006. A logistical evaluation of the vegetables subsector. Globalization and corporate citizenship (Project ID00014496), from seed to shelf, a logistic evaluation of the vegetables sub-sector. In AVRDC 2008, 'The vegetable industry in tropical Asia: Philippines'. Asian Vegetable Research and Development Center, Shanhua, Taiwan.