Opportunities and Constraints for Improved Vegetable Production Technology in Tropical Asia

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Keywords: review, vegetables, vegetable production technologies, harvest date planning, year-round supply, tropical Asia

Abstract

A description of the characteristics of vegetable production in tropical Asia is presented. The description is followed by a discussion of the opportunities and constraints of improved non-seed vegetable production technologies. Sowing of seeds and seedling emergence, transplant production, irrigation, mulching, fertiliser use, crop protection and weed control methods, protected cultivation and harvest date planning are discussed in relation to their use and impact. Conditions for successful introduction of new technologies and the role of outside actors are discussed. It is argued that in order to increase the success of adoption of improved technologies, farmers and public and private institutions should work together. With increasing prosperity, the demand for vegetables, especially in the expanding urban areas, will increase, leading to the intensification of production and higher profitability. With better profitability, the application of mulch, drip irrigation, fertigation and protected cultivation will become more common. With increasing production, harvest date planning as related to year-round city market demand, will become essential to improve profitability. It is recommended that, next to the development and introduction of improved production technologies, research and extension on vegetables in tropical Asia, should also focus on methods to improve harvest date planning and year-round supply.

INTRODUCTION

Vegetable production and the demand for vegetable products in tropical Asia is rapidly changing (Midmore and Poudel, 1996; Ali, 2000; Johnson et al., 2008). Growing demand due to population increase, urbanisation and growing incomes, has resulted in the intensification of production and a rise in the level of production technology applied. The ever increasing degree of urbanisation in many countries results in a higher share of production being marketed to the urban consumer, which involves more complex logistical arrangements and year-round supply planning. This paper discusses the opportunities and constraints of improved vegetable production technologies, as deemed relevant to countries in tropical Asia. Emphasis is on India, Indonesia, the Philippines, Thailand and Vietnam. The paper starts with a brief overview of climate and vegetable production characteristics in these countries (Fig. 1).

GENERAL CHARACTERISTICS

Climate

Climate is basically determined by geographic location and the solar position during the year. In the tropical parts of Asia, average monthly temperatures during the year do not vary very much and are roughly between 25 and 30°C (Fig. 2). In the northern parts of countries that are situated close to or around the tropic of Cancer, like Vietnam and India, the climate becomes subtropical or even temperate. Around Hanoi, average temperatures may reach 18°C or even lower during the winter season. With each 100 m rise in altitude above sea level, the average temperature decreases by 0.6°C, leading to much lower temperatures in the highlands (Oldeman, 1977). Relative humidity is generally high, often above 80% throughout the year. The highest relative humidity is found during the night and is lowest during the day time in the dry season. There is not much variation in day length around the equator, but differences in day length during the year increase with distance from the equator.

Mean daily global radiation is influenced by the solar position during the year and by seasonality in rainfall (Fig. 3), which in turn is influenced by the amount and the intensity of cloud cover. Available radiation may be less in the highlands as compared to the lowlands due to more cloud cover.

Precipitation is difficult to estimate generically as the amount of annual rainfall and the distribution pattern throughout the year varies greatly with the local climate and local conditions, such as mountain ranges or proximity to oceans. Invariably, vegetable cultivation periods are heavily influenced by the variation in precipitation. This most often results in seasonal variations in the supply (Darmawan and Pasandaran, 2000; Librero and Rola, 2000; Nguyen et al., 2000; Sootsukon et al., 2000; Subramanian et al., 2000).

Soils

In general, vegetables are grown on light to moderately heavy, fertile, structurally stable soils, with a pH between 5.0 to 7.0. Soils used for vegetable cultivation, however, vary greatly with location and cultivation systems. They may vary from rather acid, low fertility soils, low in organic matter, of alluvial origin, such as around Hanoi (Everaarts et al., 2006), to rich, well-drained, neutral soils with high organic matter and volcanic origin as in the highlands of Java (Thrower and Dudal, 1956). Cultivation of vegetables is often on raised beds, to facilitate surface drain-off during heavy rainfall and furrow irrigation during dry periods (Everaarts et al., 2006).

Location

Commercial vegetable cultivation is most often found in two distinct locations: (1) the peri-urban type of cultivation. Located around the big cities, highly perishable, leafy types of vegetables are cultivated. Here, vegetables may be cultivated permanently, but also in rotation with crops like corn or flooded rice (Jansen et al., 1996; Anh et al., 2004); (2) the highlands, at altitudes between 1000 and 1500 m, at some distance from large metropolitan centres. Less perishable vegetables, often of temperate origin, are usually cultivated here.

Crops

In tropical Asia, a large variety of vegetable crops are grown (Siemonsma and Piluek, 1994) on a substantial area (Table 1). Many important vegetable crops belong to the Brassicaceae, Cucurbitaceae, Leguminosae or Solanacae. Seedlings of many crops are raised in nurseries and transplanted into the production field (Table 2), thus making better planning possible and saving time on the length of the crop growth period. The number of days to the first harvest and the length of the harvest period vary with the crop. The variety in crops and length of growing periods, contributes to the enormous variation in cultivation systems found in tropical Asia, allowing for flexibility in planning and further crop diversification.

PRODUCTION TECHNOLOGIES

Sowing of Seeds

Rapid and uniform germination of seeds and rapid and uniform emergence of seedlings is essential for good crop establishment and subsequent growth and yield. Although seed treatments to improve field germination, such as priming, pelleting or film-coating with additives, have been available for some time (Taylor et al., 1998; Andreoli and Andrade, 2002; Cantliffe, 2003), their use for tropical vegetable seeds is limited. With farmer saved seeds, there is no treatment. Seeds of some commercially available seeds may be treated with fungicides. A recent promising development is film-coating of tropical vegetable seeds with insecticides, analogous with the effective insect control after transplanting achieved with coating seeds of temperate vegetables (Ester et al., 2003).

Sowing of seeds is often done by hand, with equipment like a dibbling stick, resulting in placement at unequal depths. The resulting variation in time of emergence will lead to differences in growth and size between individual plants (Benjamin, 1990; Shanmuganathan and Benjamin, 1992) and consequently extends crop growth duration until the moment that the last individual plant, or its product, reaches marketable size. Gray (1976) showed that between 60-90% of the variation in mature head weight and the date of head maturity of lettuce could be accounted for by variation in the date of seedling emergence. No reference was found which quantifies these effects under tropical field conditions, but there is no doubt that reducing the variation in time of seedling emergence by more careful sowing, or the use of simple, small hand-powered one-wheel machinery, will significantly contribute to improved crop uniformity and to a reduction in the length of the crop growth period.

Use of Transplants

The use of transplants, mass produced in trays under protected cultivation, and planted by machines, is common in temperate vegetable production (Schrader, 2000; Parish, 2005). Despite the fact that many important vegetable crops in tropical Asia are transplanted (Table 2), transplants are still often produced in a small plot near the home or in a small part of the production field, mostly situated at the edge of the field where growing conditions may be poor. In field production, seeds are usually broadcasted, resulting in unequal distribution of seeds and subsequently uneven emergence and growth of seedlings. When deemed large enough, seedlings are uprooted by hand, selected for size and the absence of pests and diseases, and planted by hand in the production field. Field observations in Vietnam show considerable variation in uniformity and quality of transplants (Everaarts et al., 2006). Different sizes or weights of seedlings and different degrees of transplant shock will decrease crop uniformity.

In some places, farmers raise transplants on raised beds in a production field. Transplants may be produced in simple bamboo plastic houses in small banana leaf pots or in small transparent plastic bags.

In recent years, especially in those areas where commercial vegetable production is concentrated, the production of transplants in trays and more sophisticated plastic houses is developing. The success of these operations depends upon the skills of the transplant producer and the purchasing power of the grower. In this respect, the small farm size and limited numbers of plants needed may be an impediment for further expansion.

The composition of growing substrates is usually locally pioneered, depending on the availability of material such as peat or compost. Rice husks, carbonised or not, may be added for substrate improvement, or be the main component. Initially trays are imported. Many questions related to substrates, nutrition during growth and optimum transplant age remain to be resolved. Strategies and economies of scale for transplant production, whether by a few large companies with long supply and tray return lines, or by farmer groups operating small mobile net houses near the production field, are issues that need to be addressed.

Irrigation

As expected, high quality water for crop irrigation is becoming scarcer in many areas. In recent years, research on saving water for crop growth through drip irrigation has received a lot of attention. The benefits of drip irrigation, in combination with mulching and fertilizer application (fertigation), have been demonstrated for many crops including tomatoes (Shrivastava et al., 1994; Singandhupe et al., 2003; Hebbar et al., 2004), eggplant (Manjunatha et al., 2004; Aujla et al., 2007), sweet pepper (Antony and

Singandhupe, 2004), okra (Tiwari et al., 1998), cabbage (Tiwari et al., 2003) and chilli (Shinde et al., 2002) (Table 3). Although research and practise have shown that drip irrigation, especially in combination with black mulch, will increase yields and quality, the benefit-cost ratio is not always high and farmers may be reluctant to invest in equipment. Srivastava et al. (2003) designed a model to support investment decisions for drip irrigation. In general, however, drip irrigation, especially in combination with non transparent plastic mulch and high yielding, often hybrid cultivars, is a leading trend in modernising vegetable production.

Mulch

Mulching of crops contributes to a reduction in weed growth, reduces soil evaporation in dry periods, reduces soil erosion and prevents the splashing of soil particles onto crops. Mulching with plant material like rice straw adds organic matter to the soil. In recent years, the use of polyethylene plastic mulch, mostly black coloured, has become common in many areas, especially for commercial highly profitable crops in combination with drip irrigation. Plastic mulch facilitates the run-off of excess water from raised beds during high intensity rainfall. When available, mulching with organic material is advised. Mulching with black plastic is superior (Hedau et al., 2001; Sannigrahi and Borah, 2002; Singh and Mir, 2005), but brings higher up-front investments and there is not always a good solution available for discarding spent plastic.

Trellising and Staking

The positive effect of trellising or staking on yield, quality, disease incidence and ease of harvesting crops like tomato or cucumber, has been known for some time (Konsler and Strider, 1973). Positive results of staking or trellising on tomato yield, quality or disease incidence were reported from India (Bhardwaj et al., 1995; Singh et al., 2000; Singh and Lal, 2003). There are indications that in some areas, the non availability of suitable staking material like bamboo, limits the practise of staking. However, in general, trellising or staking Cucurbitaceous crops, tomatoes or climbing beans is widely accepted. Recent internationally published research results on the effects of staking or trellising in tropical Asia, however, appear to remain scarce.

Fertiliser Use

The application of manure and fertilizers contributes to increased yields and quality. Nevertheless, there is increasing concern about the judicious use of fertilizers in vegetable growing, especially in rice-based vegetable cultivation systems (Bouman et al., 2002; Nguyen et al., 2007; Shrestha and Ladha, 2002). The high use of nitrogen leads to nitrate pollution of the groundwater. High inputs of nitrogen may also result in high levels of nitrate in vegetable products, especially the leafy ones (Anjana et al., 2007). Although with crop specific fertiliser application, loss of nitrogen can be limited, an often neglected source of nitrogen loss is crop residues (Everaarts, 2000). Therefore, apart from determining optimum crop and site specific fertilizer application recommendations, to reduce nitrogen losses, a cropping systems approach for especially the intensive vegetable cultivation systems appears necessary (Alam and Ladha, 2004).

Crop Protection

Correct application of pesticides serves to protect the crop against pests and diseases. There is, however, general and serious concern about excessive pesticide use for crop protection, leading to environmental and human health hazards (Alam et al., 2003). To reduce insecticide use, integrated pest management (IPM) strategies have been developed for a number of vegetable crops (Kitamura et al., 2004; Sardana et al., 2004; Singh and Singh, 2005; Alam et al., 2003, 2006). The commitment of all farmers in the community to field sanitation and the continuity of technical supplies, such as pheromones, however, require long term efforts and initial support from outside parties (Alam et al., 2003, 2006). In general, the correct identification of pests or diseases and their matching with safe and effective biocides, together with the promotion of the use of optimum spraying equipment and application practises, will contribute to a reduction in pesticide use, while maintaining effective control.

Weed Control

Hand weeding is still commonly practised for the control of weeds. Various types of hand-held equipment may be used (Everaarts, 1977), but there appears to be limited development in this kind of equipment. The use of herbicides, however, is becoming more widespread in the larger commercial centres of cultivation. A recent development is soil solarisation for weed control. During hot, sunny periods, the soil is heated by being covered with transparent polyethylene plastic. Although positive results of soil solarisation on weed control and crop yield have been reported (Das and Yaduraju, 2001; Kumar et al., 2001), the necessity for a period of continuous high intensity sunshine, and the absence of crop cultivation and income during solarisation, limits its application in many instances. Solarisation could be an option though for part-time fallow field nurseries (Chopra and Chopra, 2004).

Protected Cultivation

Cultivation of transplants (Kang and Sidhu, 2006) or crops in plastic houses (Singh et al., 2005; Gunadi et al., 2007; Singh and Sirohi, 2006; Singh et al., 2007) or net houses (Talekar et al., 2003), requires higher investments in construction and equipment than open field cultivation, but can be attractive to reduce pesticide use and to increase profits. Although protected cultivation, especially under plastic, is mostly found in the highlands, systems are being developed for the tropical lowlands (Hemming et al., 2006).

In a survey of sweet pepper growers near Lembang in West Java, Indonesia, it was found that in traditional bamboo constructed plastic houses, yield per season per m^2 using drip irrigation and carbonised rice husks in plastic bags as a substrate, was around 6.6 kg (Gunadi et al., 2007). Construction with bamboo is quite heavy and the light level inside a bamboo plastic house can be as low as 50%. Improved construction using wood and a light metal top frame improved the level of radiation inside the plastic house and resulted in significantly increased yields and profits (Table 4). Further improvements in plant arrangement, stem density and the number of stems per plant raised yields up to more than 19 kg per season per m^2 (Table 5). The profitability, however, was optimum at the lowest yield with the highest number of stems per plant, due to lower seed costs. The results of this work show that locally significant improvements in crop cultivation in plastic houses can be achieved.

Harvest Date Planning

Vegetable production in tropical Asia shows a strong seasonality in production and consequently there is much seasonality in supply and prices (Ali, 2000). In temperate areas, while much work has been done on crop scheduling and harvest date prediction to reduce the variation in supply (Everaarts, 1999; Wurr et al., 2002), for the Asian tropics, precious little work seems to have been done. In the Philippines, profitable site-specific planting calendars were developed based on local agro-climate, water availability and avoidance of pests and adverse conditions (Alquiza et al., 2005). As seasonality in supply causes large variations in price, it would be attractive to design cropping systems that supply vegetables in traditional off-season periods, ultimately aiming for year-round supply. Since temperatures are rather constant during the year (Fig. 1) and as there is moderate variation in radiation availability (Fig. 2), most of the seasonality in production is related to local rainfall patterns and water availability.

A number of techniques are available to manipulate crop growth and harvest date in relation to rainfall and water availability. Protected cultivation of transplants and crops, irrigation (furrow, drip), transplants of different size, different varieties, different planting distances and time intervals between plantings, are some of the techniques that could be explored to reduce the seasonality in supply and price. With low temperatures, as experienced in the highlands, young crops can be covered with polypropylene fleece, increasing crop temperature and thereby advancing plant development. In more northern areas, some crops can be supplied year-round by making use of cultivation both in the lowlands and in the highlands (Table 6).

It is expected that with increasing production and a growing share of production sold through high-end supermarkets, harvest planning for fixed time and year-round supply, as related to market demand throughout the year, will become essential. Future research and extension should focus on these aspects, to improve profitability for growers and availability at an affordable price for consumers.

SYNTHESIS

Given the enormous area of vegetable cultivation in tropical Asia and the great diversity in crops and cultivation systems (Ali, 2000), it is impossible in the scope of this paper to analyse in detail the factors that determine the successful introduction of improved production technologies from outside to the farming communities themselves. Nevertheless, without resorting to self-evidence, four main conditions for the introduction of new technologies have to be fulfilled:

(i) The technology has to be known to the farmer. Without knowledge of the new technology, it cannot be applied. Public knowledge providers and commercial companies play a role here;

(ii) The technology has to be accessible. The new knowledge has to be easily available at the local knowledge provider or it must be able to buy the new equipment at the local village agro-shop;

(iii) The technology has to be affordable. The price level has to be such that the farmer can afford to buy the technology; and

(iv) There has to be a strong incentive to adopt the improved technology. Usually there will be a direct financial gain or a reduction in labour. A rise in social standing as a 'modern' farmer may also induce adoption.

With regards to the technologies discussed in the previous section, three groups can be identified in relation to the outside, non-farmer, actors involved:

(i) The prevention or reduction of nitrogen and pesticide pollution is an environmental and human health affair. Public institutions are the major actors in introducing improved technologies here. The possible financial gain for farmers, when introducing technologies to reduce fertilizer and pesticide use, while maintaining yield and quality, often is a neglected incentive;

(ii) The introduction of new material such as plastic mulch, or drip tape, is a matter for the commercial companies. Often the new technology is introduced by seed companies together with new high yielding hybrid varieties. Farmer field schools, organised by outside parties, can be a good medium for spreading non-material technologies (Aganon et al., 2005); and

(iii) The increase in income for farmers by harvest date planning to supply product in the traditional off-season, is a matter of introducing new technologies and integrating the farmer into the supply chain.

For all actors, the challenge for the successful introduction of new technologies is to identify 'smart' technologies that combine all the conditions. A good example may be seed coating with an insecticide film for the control of pests after crop establishment or transplanting (Ester et al., 2003). The coated seed is likely to be supplied to even distant village shops by seed traders, the price is affordable, the product is effective in pest control, it increases income by reducing plant losses, it saves labour by reducing spraying, and it greatly reduces pesticide use and occupational health hazards.

RECOMMENDATIONS

It is recommended that, in order to increase the success of adoption of improved technologies, farmers and public and private institutions work together to identify opportunities and constraints for potential new vegetable production technologies in tropical Asia.

It is expected that, with increasing prosperity and rapid urbanization, the demand for vegetables will increase, leading to an intensification of production and higher profits. With better profitability, the application of mulch, drip irrigation, fertigation and protected cultivation, will become more common (Table 7), as the value of these technologies has been proven. With increased production, the importance of harvest date planning will increase to achieve better integration in the supply chain. As basic knowledge on harvest date planning of tropical vegetables is scarce, it is recommended that research and extension on vegetables in tropical Asia, should focus on methods to improve harvest date planning and year-round supply.

ACKNOWLEDGEMENTS

We thank G. Grubben and F. van Koesveld for critically reading the manuscript and Klondy T. Dagupen, Benguet State University, for the provision of data about the Philippines.

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Tables

Table 1. Vegetable areas (ha×10^3) in India, Indonesia, the Philippines, Thailand and Vietnam in 2006 (FAOStat database).

Crop	India	Indonesia	Philippines	Thailand	Vietnam
Asparagus			1.5	2.0	
Beans, green	150.0	150.0	4.9	23.0	
Cabbages and other brassicas	290.3	64.3	7.3	24.0	40.0
Carrots and turnips	25.4	24.7	4.2		
Cauliflowers and broccoli	238.2		1.2	6.3	1.6
Chicory roots			0.4		
Chillies and peppers, green	5.8	173.8	4.5	1.3	
Cucumbers and gherkins	18.6	53.1	1.6	26.9	
Eggplants (aubergines)	530.3	43.0	20.9	12.0	
Garlic	144.1	3.3	4.4	13.3	
Leeks, other alliaceous veg		45.4	1.5		
Leguminous vegetables, nec				0.2	
Lettuce and chicory	122.4			0.04	
Maize, green		85.0		38.7	
Okra	358.3		3.2		
Onions (inc. shallots), green			0		
Onions, dry	549.1	85.5	8.4	19.2	76.0
Other melons (inc. cantaloupes)	32.0		1.0		
Peas, green	276.7		2.5	3.0	
Pumpkins, squash and gourds	378.4	9.0	22.7	18.5	
Spinach		37.0	0.1		
String beans			14.7		
Tomatoes	497.6	50.0	17.1	11.5	
Vegetables, nec	3400.0	57.0	500.0	145.0	525.0
Watermelons	21.2		6.9	30.0	28.0
Vegetables (inc. melons) total	7038.4	881.0	629.4	375.1	670.6

nec = not elsewhere classified.

Table 2. Examples of major vegetable crops in tropical Asia and an approximation of crop growth duration and harvest period (Siemonsma and Kasem Piluek, 1994 and personal estimates).

Family Species	Common name	S[1], T, C	Days to first harvest	Harvest period (d)
Brassicaceae				
Brassica rapa	Caisin, Chinese cabbage	T	40-80	10
Brassica oleracea var. *capitata*	White cabbage	T	60-90	10-15
Compositae				
Lactuca sativa	Lettuce	T	60-80	1-5
Convolvulaceae				
Ipomoea aquatica	Water spinach	S, C	30-40	1
Cucurbitaceae				
Citrullus lanatus	Water melon	T	65-90	10
Cucumis sativus	Cucumber	T	60-70	30-40
Benincasa hispida	Wax gourd	T	100-160	30
Leguminosae				
Phaseolus vulgaris	French bean	S	45-50	20
Vigna unguiculata	Yard long bean	S	40-50	30-60
Solanaceae				
Capsicum annuum	Hot pepper	T	60-90	150-180
Lycopersicon esculentum	Tomato	T	60-90	90-120
Solanum melongena	Eggplant	T	60-90	90

[1]S=direct seeded, T=transplanted, and C=cuttings.

Table 3. The effect of drip irrigation on yield (t ha^{-1}), water use efficiency (WUE, kg product mm^{-1}) and benefit/cost ratio (B/C) of vegetable crops.

Crop	Yield			WUE		B/C	
	Surface/ furrow	Drip	Drip+ mulch	Surface/ furrow	Drip	Surface/ furrow	Drip
Cabbage[1]	65.7	106.7	111.7	164.2	266.7	8.2	7.0
Eggplant[2]	15.7	21.1		35.2	54.7	1.7	1.5
Eggplant[3]	65.6	76.8		55.1	64.5		
Tomato[4]	59.5	71.9					
Tomato[5]	32.0	46.0	43.0	57.0	81.0	2.1	2.1
Tomato[6]	27.0	29.0		62.2	108.4		
Okra[7]	8.4	13.1	14.5	12.7	19.6	1.6	1.8
Sweet pepper[8]	6.5	7.4					

Source: [1]Tiwari et al., 2003; [2]Manjunatha et al., 2004; [3]Aujla et al., 2007; [4]Hebbar et al., 2004; [5]Shrivastava et al., 1994; [6]Singandhupe et al., 2003; [7]Tiwari et al., 1998; [8]Antony and Singandhupe, 2004.

Table 4. Effect of type of plastic house on marketable yield and relative profit of sweet pepper (p<0.05; Gunadi et al., unpublished results, Lembang, 2005).

Plastic house	Yield (kg m^2)
Traditional bamboo construction	7.2 a
Wood-metal construction	9.3 b

Table 5. The effect of number of stems per plant on marketable yield of sweet pepper at a stem density of 8.3 stems/m^2 (p<0.05; Gunadi et al., unpublished results, Lembang, 2006/7).

Stems per plant	2	3	4
Yield (kg m^2)	19.3 a	19.4 a	16.6 b

Table 6. Potential for year-round supply of a number of *Brassica* crops combining lowland and highland production (Everaarts et al., 2008).

Species	Common name	Lowlands (0-500 m)		Highlands (1000-1500 m)	
		Apr.-Oct. 25-30°C	Nov.-Mar. 15-20°C	Apr.-Oct. 15-25°C	Nov.-Mar. 10-15°C
Brassica rapa	Chinese cabbage	-	+ + +	+ + +	+
Brassica oleracea var. *botrytis*	Cauliflower	-	+ + +	+ + +	+ +
Brassica oleracea var. *capitata*	White cabbage	+	+ + +	+ + +	+ +
Brassica oleracea var. *gongylodes*	Kohlrabi	-	+ + +	+ +	+ +
Brassica oleracea var. *italica*	Broccoli	-	+ + +	+ + +	+ +
Raphanus sativus	Radish	-	+ + +	+ + +	+ +

- = no cultivation advised, + + + + = very good cultivation possibilities.

Table 7. An approximation of the past and future importance of a number of technologies for vegetable growers in tropical Asia (1 = not important; 5 = very important).

Cultivation technique	Importance in past 3 years					Importance in future 3 years				
	1	2	3	4	5	1	2	3	4	5
Machine sowing of seeds	×						×			
Transplants produced in trays in protected cultivation nurseries		×							×	
Irrigation by driptape	×								×	
Fertigation	×							×		
Organic material mulch	×							×		
Black plastic mulch				×					×	
Trellising or staking				×					×	
Weed control by herbicides		×						×		
Integrated pest management		×								×
Harvest date planning		×							×	
Cultivation in net houses, lowlands	×							×		
Cultivation in net houses, highlands		×							×	
Cultivation in plastic houses, lowlands	×							×		
Cultivation in plastic houses, highlands		×							×	

<u>**Figures**</u>

Fig. 1. Map of tropical Asia.

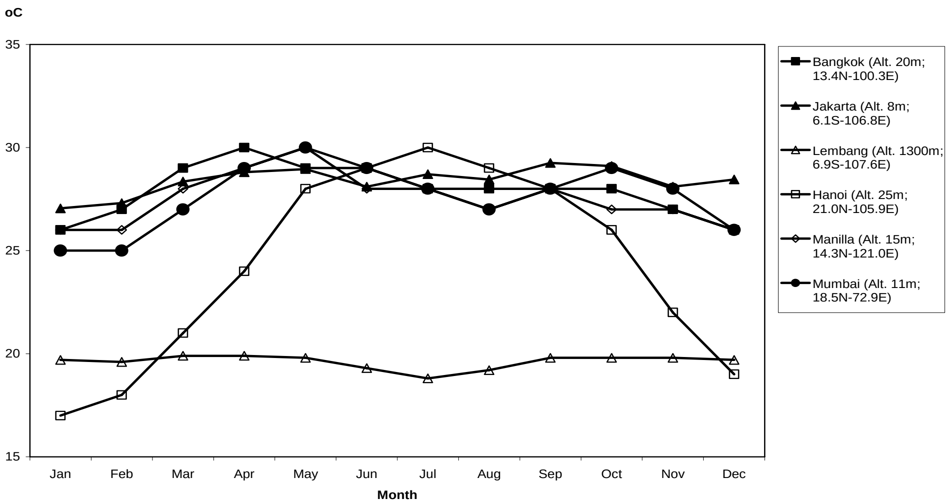

Fig. 2. Mean monthly temperature (data from various public sources).

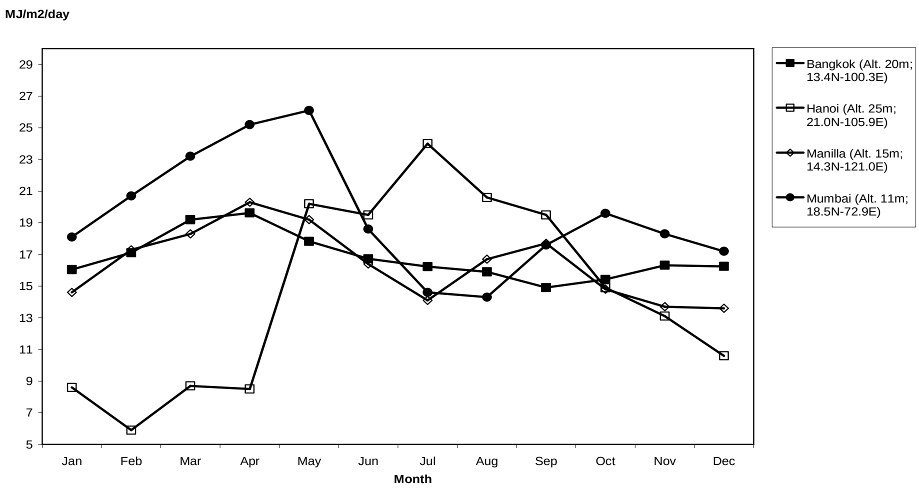

Fig. 3. Mean monthly global radiation (data from various public sources).