3 Horticultural Production Systems

This chapter examines the diversity of horticultural production systems practised in the tropics. With this knowledge it will then be possible to review the variety and relevance of the specific production practices employed in the successful growing of vegetables (in Chapter 4) and fruits and flowers (in Chapter 5) in the tropical environment.

Production systems that take resources, natural and human, and transform them into horticultural products can be classified according to temporal, spatial, economic and social criteria. Next, within the production systems the particular farming system, the cropping sequence, pattern and management can be further classified according to conformity within specifically defined classes or groups. It must be recognized that no two farms, even if adjacent, would have identical farming systems. This would be even more so for horticultural enterprises than for those producing grain, dairy or meat products, for the diversity of horticultural commodities and their means of production far exceed those of broad-acre and animal-based systems.

In this chapter we explore the variety of horticultural production systems in the tropics, starting with the most basic of subsistence and leading to the most technologically demanding of sophisticated export systems, but first we will consider some of the producer decision making conditioned by the production system, and a discussion of a proposed functional grouping of horticultural species.

3.1 Producer Decision-making

Consciously or not, horticultural producers strive through their decision making to optimize their resource use efficiency. This is so whether their system be subsistence and divorced from markets, or technologically advanced and closely tied to markets. The resources available to the producer will, however, depend heavily upon the nature of the production system. Subsistence horticulture will have as its main resource the availability of household labour, followed by land (whether titled, leased or squatted) and common-good essential resources such as water (as rainfall, surface flow, wells), solar radiation, CO_2, and the more poorly recognized resources such as natural biological pest management.

At the other extreme, commercial production systems will have capital replacing labour as the most finite resource, and will have a plethora of technologies that ensure optimal supply of essential resources, for example nutrients as fertilizer, water via irrigation and even supplements of CO_2 in controlled spaces, such as in greenhouses, to enhance growth (Montero *et al.*, 2011). They often replace biological pest management

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with the use of agrochemical sprays. The transition from subsistence to full commercial systems is accompanied by the change in emphasis on the relative importance of resource use efficiencies (from labour and time, to purchased inputs and technologies), and these will be highlighted in this chapter.

Risk is another important factor that conditions the decisions dealt with by horticultural producers. Risk management focuses on price, yield and resource uncertainty, as well as peace and order situations in some countries. Decisions may range from those that minimize risk of complete crop failure to those of over-supply and depressed commodity prices, and the approaches and principles behind the risk-minimizing decisions differ across production systems.

3.2 Grouping of Vegetable, Fruit and Flower Species

At the outset it is necessary to distinguish briefly between the major types of vegetable and fruit species (Table 3.1), according to their natural and inherent perishability

Table 3.1. Classification of temperate and tropical vegetable, fruit and flower species according to their perishability.[1] (From Thompson, 2003; Wills *et al.*, 2007.)

	Temperate	Tropical
Group 1 High perishability; shelf life normally <1 week and rarely >2 weeks		
Vegetable	Lettuce, broccoli, cauliflower, spinach, asparagus, green beans, peas, spring onion, celery	Bamboo shoots; leafy vegetables such as pak choi, tatsoi, mustard, kang kong; flower vegetables such as kailaan, flowering Chinese chives; breadfruit
Fruit[2]	Strawberry, raspberry, fig, apricot, peaches, black currants	Banana, yellow passion fruit, sapota, dragon fruit
Flowers	*Delphinium*, *Freesia*, tulip, *Gladiolus*, daffodil	*Alstromeria*
Group 2 Reasonable perishability; shelf life rarely <1 week, normally c.2 weeks and rarely up to 4 weeks		
Vegetable	Tomato, radish, cabbage, marrow, turnip	Aubergine, myoga, *Capsicum*, zucchini, okra, chayote, avocado, bottle gourd, sweet corn, yam
Fruit	Grapes, cucumber, cherries, kiwifruit, pears	Papaya, lychee, guava, mango, pineapple, *Opuntia*, purple passion fruit, custard apple, carambola, rambutan, watermelon
Flowers	Carnation, rose	*Anthurium*, *Heliconia*, *Protea*, orchid, ornamental ginger
Group 3 Low perishability; shelf life >1 month and normally <6 months		
Vegetable	Potato, garlic, onion, shallot, carrot, pumpkin, parsnip	Sweet potato, taro, yams, yam bean, Chinese water chestnut, dry chilli
Fruit	Apples, pears	Oranges, grapefruit, tamarind
Flowers	None	*Anthurium*

[1] Perishability from time of consumer acceptance without external intervention to extend shelf life; see Chapter 6 for detail on postharvest practices that reduce perishability.
[2] From time of physiological maturity.

under tropical climate conditions. As mentioned in Chapter 2, horticultural produce, especially vegetables, is in the main harvested well before biological maturity (also known as physiological maturity) and continues to live, respire and transpire once it is harvested. This property limits storability and therefore limits transport and marketing options for horticultural produce to a much greater extent than for grain crops. Grains are harvested after physiological maturity and, because they have low water content, their rates of respiration are magnitudes lower than for most harvested flowers, vegetables and fruits. The extent and adoption of postharvest practices that enhance the transportability and storability is greater for horticultural produce than for grains. These, and marketing that shortens supply chains of fruits, vegetables and flowers in the tropics, are addressed in Chapters 6 and 7, respectively. But for the purposes of this chapter, we consider the systems within which the horticultural commodities are produced.

Three major categories based upon ambient storability across the fruits, vegetables and cut flowers can be identified:

- *Group 1* comprises those horticultural species with the shortest shelf life. Due to their being harvested while in their active growth phase, and their characteristically large surface to volume ratios, their transpirational water loss leads to rapid wilting and/or loss of turgidity (Rotondo *et al*., 2013). Their respiratory breakdown of sugars and other energy sources leads to yellowing, browning and (less likely unless in high temperature high humidity environment) rotting. Leafy vegetables comprise the greatest proportion of vegetable species in this group (Table 3.1). Most cut flower species behave as leafy vegetables, because of their limited carbohydrate reserves, their fast development and their high respiration rate. Both rate of respiration and transpiration increase with temperature, respiration with a Q_{10} of at least two (the ratio of the rate of respiration at one temperature to that at a temperature 10°C lower) and transpiration increases because warmer air has a greater vapour pressure deficit (VPD) than cooler air for a given value of relative humidity (Chapter 2, Fig. 2.14) and therefore a greater capacity to draw moisture from fruits, vegetables and flowers. Once such produce is harvested, whether because of severing of the transpirational stream and/or because of darkness in storage conditions, stomata close and reduce evaporative loss of water, but because cuticles are not completely impervious to water, losses in fresh weight continue to occur. Warm ambient storage conditions in the tropics do not favour long-term storage of this group; produce must be consumed soon after harvest for shelf life decreases exponentially with increase in temperature. Fruit in Group 1 (e.g. banana) can be harvested in the unripe condition and ripening takes place during transport and marketing. This extends the shelf life from harvest to consumption beyond that possible with fruit harvested at the time of optimal consumer quality. Many fruits are, however, harvested at physiological maturity (i.e. when growth is completed and the next stage, a climacteric rise or steady rate of respiration begins – concepts discussed in Chapter 6). They rarely lose marketable quality over the period of 1–2 weeks at ambient tropical temperatures, so this group is not well-represented by fruit. Commercial cut flower species that have a shelf life of less than 2 weeks are common. The consumer expects a long vase life under ambient conditions, hence postharvest management, particularly control of temperature during transport and marketing, is essential in affording flowers with the longest potential vase life.

- *Group 2* comprises species that may easily be stored for up to 2 weeks under ambient conditions, and is represented in the main by tropical vegetable species for which the fruits are consumed as vegetables. With transpiration rates (in reality mainly evaporation rates, for fruits have few stomata per unit surface area) per unit fresh weight less than those of leafy vegetables, and with a greater buffer of stored carbohydrate to satisfy respiration, these vegetables are better able than Group 1 species to cope with high temperature storage in the tropics, and as such have a longer shelf life. Many horticultural fruits, including those consumed as vegetables, fall within this group but only hardy tropical cut flower species such as *Heliconias* and ornamental gingers (e.g. the Red Ginger, *Alpinia purpurata*) and orchids, store for similar periods.
- *Group 3* comprises vegetable species that are harvested for their vegetatively reproduced propagules typified by corms, tubers, storage roots and bulbs – plant organs that are specifically adapted to bridge the time gap between death of one plant generation and the beginning of the subsequent plant generation. Not only does the specific adaptation by these species permit the spanning of ambient conditions unfavourable for growth (e.g. a cool dry season as for Chinese water chestnut, a hot dry season such as for taro), such adaptation also facilitates their use as stored planting propagules between seasons, with minimal need for intervention by horticulturalists in the management and control of storage conditions. Suberized layers over the external surface, the periderm, of modified stems (potato tubers) and roots (sweet potato) confine gas exchange and water loss to lenticels, and with the dense carbohydrate reserves and low respiration rates the propagules can survive for a number of months. These properties are important as they ensure that supply of the vegetable produce from this group can be spread over a period well beyond the harvest, into times when species from Groups 1 and 2 may not be available. True fruits are also represented in this group with respect to duration of storage. The skins of apples and pears, for example, are covered with lenticels which may become blocked with surface waxes and further reduce water loss. Indeed, even without wax, lenticel density of apple at *c*.6–11 cm^{-2} is orders of magnitude less than stomatal density on leafy vegetables (e.g. *c*.120 mm^{-2} for lettuce), although direct comparison is not recommended. Comparisons in terms of the transpiration coefficient (a measure of the loss of water per unit fresh weight, per unit time, per unit of VPD) are made in Chapter 6. Suffice to illustrate differences here with lettuce having a value of *c*.7400 $mg\ kg^{-1}\ s^{-1}\ MPa^{-1}$ versus *c*.40 $mg\ kg^{-1}\ s^{-1}\ MPa^{-1}$ for apple. Durable fruits with a strong exocarp, the outermost distinct layer covering a fruit, resist water loss; but even a loss of *c*.6% of water content is reflected in a non-turgid feel and loss of consumer acceptance and is to be avoided through implementation of practices that optimize storage conditions, as discussed in Chapter 6.

In terms of market share Group 2 vegetables comprise the largest and most important group in most countries worldwide.

From an Asian perspective on the vegetable groupings, Group 3 vegetables, those with the longest shelf life, are more common in South Asia, while Group 1 vegetables, the most perishable, form a greater proportion of the market in South-east Asia.

With this understanding of our arbitrary classification of fruit, vegetable and flower species, we can now turn to the different types of horticultural production systems in the tropics.

3.3 Types of Production System

The most common basis for classification of horticultural production systems is that based upon the degree of market integration and specialization, and this approach will be followed here. In essence the systems that lend themselves to analysis at a level of aggregation that avoids too much attention to fine detail can be assembled into four groups, and will be analysed as:

- Subsistence
- Home garden
- Semi-intensive mixed commercial
- Very intensive commercial

In addition, other important qualifying considerations for horticultural production systems in the tropics would revolve around altitude and geographic location as they affect crop performance (discussed in Chapter 2) and the agroecological zoning (e.g. spatial co-relations, proximity to conurbations), the scale of production, the extent of organic involvement, the degree of disassociation from soil-based growing media and the concordance with principles of sustainability. These latter considerations can permeate one or other of the two commercial categories.

The specifics of a particular production system at any location will be in response to the needs of the producer and of the consumer (not forgetting that at times the two are the same), and will take into account the biophysical, economic and social contexts within which that system is situated. In terms of sustainability, production will be inherently more sustainable where the necessary inputs for production, nutrients, water, heat and solar radiation are adequately supplied by the environment; deficiencies in any of these will need to be remedied at additional costs and risks to the producer.

3.3.1 Subsistence

True subsistence production systems in the tropics, with horticultural commodities as their main focus, are most probably non-existent except where our definition of vegetable extends to include subsistence staple crops such as the Group 3 carbohydrate-dense yam, sweet potato, taro and other root crops. Examples of subsistence do exist, most particularly in the South Pacific hot tropics where, in Samoa for example, taro is the mainstay staple food in the economy. There *c.*20% of GDP was attributable to non-monetary agricultural production before taro blight (*Phytophthora colocaciae*) in 1993 destroyed most of the taro crop. Production has now recovered thanks to the introduction of blight-resistant cultivars from the Philippines and Micronesia. A cool tropical climate example is afforded by potato cultivation in the highlands of South America. In most subsistence farming systems between 2000 and 2500 masl in the Andes potato is the main cultivated crop. This is expressed in the Quechua term for potato, 'kawsay' – meaning food for all.

With the exception of these two major systems, subsistence production systems tend to depend upon a diverse range of species, with reliance upon a number of commodities including fruits (often harvested from non-cultivated plants), vegetables and sources of carbohydrate and (often hunted) meat. Much current attention is directed towards these systems because they harbour plentiful indigenous knowledge relevant to the realms of bio-prospecting, and are creating interest both commercial and ethical.

Because external resource input is negligible, subsistence production depends to a greater degree than commercial production systems upon recycling of resources, particularly nutrients. And particularly where soils are poor, as characterized by many tracts of tropical forests in which most nutrients are tied up in the canopy, subsistence production depends on shifting cultivation that involves slash and burn of native vegetation prior to cultivation, and relocation once current land capacity to produce is exhausted. Such systems support a population density of *c.*1–10 persons km^{-2}, very low compared to the 100–400 persons km^{-2} supported by modern-day agriculture (the ranges depending upon quality of land and dietary intake). Much has been written on the social and environmental consequences of slash and burn shifting agriculture, its quasi-conservationalist practice of mimicking secondary and primary ecosystems and its role in retaining ethnographic diversity. These documented paradigms of subsistence production are counterbalanced by the contribution of slash and burn to release of greenhouse gases and associated global warming, its major impact on loss of biodiversity and its more recently recognized negative social and environmental impact through the production of smoke. Some described it as wasteful, primitive and inefficient and certainly it would be if it were the only production system to feed the current world population. Indeed, many resources have been spent to encourage the subsistence peasant to join the ranks of the marketplace, but an understanding of the subsistence ethic and reason is necessary if such investment is to truly be effective and attract the subsistence peasant to the market economy. The whole process of slash and burn and shifting cultivation is well adapted to the often poor, infertile soils where it is practised (e.g. the ultisols of much of the Amazon basin) and it is ecologically efficient in terms of food and fuel production, building materials and subsequently income generation (Kleinman *et al.*, 1995). It fails when the return period is shorter than a critical minimum to allow for sufficient recycling of nutrients to support a new recurrence of cropping after clearing. The length of the fallow period is critical for this, as it is to minimize erosion losses of organic matter (OM) and soil nutrients. A whole new research genre has been under way for two decades within the international research community that seeks to understand the relationship between slash and burn and its underlying causes and driving forces (ASB, n.d). For the purposes of this current discussion, the contributions of slash and burn shifting cultivation to tropical horticultural production can be considered as negligible.

3.3.2 Tropical home gardens

Tropical home gardens, or household gardens (for they may not always be at the homestead) can be defined as: ‘mixed croppings of fruits, vegetables, trees and condiments that serve as supplementary sources of food and/or income’ (Midmore *et al.*, 1991). Home gardens provide an age-old survival strategy in the developing world and even in the developed world during times of adversity. They represent an important remedy towards reducing the vulnerability of the poor and contributing to their food security and survival. Time-tested complex home garden systems are often characterized by the spectrum of diversity of plant species that they contain, and by the high degree of recycling of nutrients within the home garden continuum. Tradition rather than science underpins the recycling strategy, and it has been said that the virtues of traditional home gardens are recognized more by intuition than by measured quantities.

Home gardens have been subjected to very little deductive (i.e. hypothesis testing) scientific research. Most studies concentrate on structure and floristics. Nevertheless, home gardeners are forever ‘experimenting’, with exchange and introduction of species, varieties and management practices, with or without the assistance of researchers (Watson and Eyzaguirre, 2002). Indeed, home gardens are considered as evolutionary stepping-stones for crop domestication, and in the Amazon for example they constitute a resource that is largely untapped for agroforestry. Research projects have attempted to promote the cultivation of new horticultural species. Named as ‘Agroforestry Tree Products’ by Simons and Leakey (2004), the products of domestication must be market-led and farmer-driven, and when external agencies are involved they may be supported by participatory research and development methodologies. *Dacryodes edulis* (safou in West and Central Africa) and *Malpighia glabra* (the Barbados cherry, also known as acerola) are examples of recent horticultural domestications in the tropics that should have benefitted from past researcher involvement. Indeed, there was much interest in the Barbados cherry as a rich source of vitamin C by the processing industry (Nakasone *et al*., 1968), but commercial production never took off. Likewise, the perishability of safou fruit (it would be classified as a Group 1 fruit) was a factor limiting potential commercial success, although both species are widely grown outside of their native origins. Other ‘Cinderella’ species, with perhaps more promising futures, are listed in Sanchez *et al*. (1997).

The diversity of arrangements and numbers of species in gardens is great. A study of 80 home gardens in Bangladesh (Millat-e-Mustafa *et al*., 1997) revealed 92 perennial species, the majority ‘food and fruit’ species. It is often this diversity that allows for sequential but small year-round daily harvests from different species that supply household food needs, both for carbohydrates and for minerals and vitamins. As another example, this time in Amazonia, Schmidt (2003) recorded on average from 7 to 17 useful species in seasonally flooded gardens to 19–28 in drier uplands (only a few metres above river level). The cultivation areas for each garden spanned a tenfold range, from 250 to 2500 m^2. Fruit and beverage species (42 of the total useful species) comprised the largest group within the total of *c*.200 species recorded; vegetables accounted for only 8% of the species, both groups supplementing the diet based upon cassava and banana. In a survey of the traditional home gardens, or ‘conucos’ of western Cuba, besides there being 15 fruit and 12 vegetable and spice taxa, 20 ornamental taxa were also reported across a sample of six ‘conucos’ surveyed (Esquivel and Hammer, 1992). In non-commercially orientated home gardens in Spain, a positive correlation was found between levels of agrobiodiversity, measured as numbers of species in a garden, and computed gross financial benefits accruing to the households (Reyes-García *et al*., 2013). Protective conservation of home garden systems would therefore align with the objectives of Biodiversity Conservation and the International Treaty on Crop Genetic Resources, with home gardens acting as in situ germplasm repositories (Galluzi *et al*., 2010).

Where there is a history of home gardens – they probably represent one of the oldest forms of managed land-use systems – they contribute to well over three-quarters of fruit and vegetable consumption. For example, in the island of Java in Indonesia they are estimated to occupy 20% of the arable land (Jensen, 1992 in Kumar and Nair, 2004). They reportedly contribute from 3 to 44% of total calorie and 4 to 32% of protein intake by families practising home gardening, and they supply significant amounts of minerals and nutrients. On average in Indonesia, home gardening (where practised) supplies *c*.20% of total household income. Up to 60% of home garden produce ends up being sold in Indonesia, and about one-half of this in South Africa, but the contribution to diets and incomes will depend upon the local conditions of garden size, species composition and alternative income sources. Nicaraguan home gardens established for at least 50 years in the Masaya Department, 31 km from the capital Managua, contribute on average 35% of total household income. It is of interest that ornamentals for sale were the predominant species in the smaller gardens, grown in association with some herbaceous crops, fruit, bananas and firewood species, illustrating the diversity of demands on home gardens (Marsh and Hernández, 1996). Where the garden is the only source of food, a dominance of staple foods will predominate for food security. In regions with adequate rainfall to support year-round growth, such as those found close to the equator and evidenced in the Af and Aw climate groups of Koppen (see Peel *et al*., 2007), multi-tiered canopy structure allows for vertical gradients of solar irradiance and saturation VPD and therefore provides niches that favour distinct groups of plant species; shade tolerant at the base and sun-loving species at the top of the canopy structure. Superimposed on this quite objective feature defining species choice are others that are conditioned by socio-economic and cultural considerations. In the biophysical respect, home gardens structurally and functionally parallel a functioning ecosystem characteristic of natural forests; this is the basis for a strong argument (albeit not scientifically validated) that agroforestry-based home gardens represent sustainable production systems (Kumar and Nair, 2004). It is probably no accident that the areas that most commonly depend extensively upon home garden food production are located close to the hot and wet equatorial rainforests.

Most traditional home gardens (those predating aid development interventions) are tree-based (Soemarwoto and Soemarwoto, 1982) and in Asia, more specifically in Java, are referred to as '*pekarangan*'. Geographic extension of such systems, if incentives were in place, could contribute significantly to the carbon (C) sequestration potential on otherwise poor degraded and underutilized land (Roshetko *et al*., 2002). A recent study by Kumar (2011) of 840 home gardens in Kerala, India, recorded 208 tree species with girth at breast height >20 cm among a total of 473 species, with above ground standing stocks of carbon in trees ranging from 16 to 36 t ha^{-1}. Smaller (<0.4 ha) gardens housed significantly higher per unit area stocks (*c*.27 t ha^{-1}) than medium (>0.4 < 1.2 ha) or larger gardens (*c*.22 t ha^{-1} if >1.2 ha). Similar proportions of perennial species in home gardens have been reported for other parts of India. Such data are important in revealing the extent of diversity and potential for C sequestration that may be accessed by households with home gardens. Nevertheless, more detailed understanding of the ecological and economic 'nuances' through hypothesis formulation and testing rather than through descriptive studies is called for to underpin development of sustainable commercial agroforestry systems modelled on tropical home gardens.

Much remains to be researched on the interspecific complementarities between species – vegetable, medicinal, ornamental, woody and others – providing direct products to their cultivators and ecosystem services to the rest of society. Overall competition between species for resources is reduced due to temporally and spatially different water and nutrient requirements and to differences in sensitivities in environment-determined growth and development. The number of permutations and experimental treatment combinations increase exponentially with the number of species that comprise home garden systems. Some of these are discussed further in the section on intercropping in Chapter 4. The complexity associated with multiple species mixtures managed differentially over time has tested the resilience of both horticulturalists and biometricians alike. Nevertheless, examples of successful and sustainable home gardens, with or without the perenniality of trees, are well known and continue to contribute to food and nutritional security of the tropical rural and urban poor.

To the likes of the reader from high-latitude temperate climates, the term 'home garden' may conjure up images of neatly spaced single-species plots of vegetables (Fig. 1.1), and perhaps some annual and perennial bush and tree fruits. Such gardens do not embody the ecological benefits attributable to multistrata ecosystems; but they do, where promoted through development agencies, provide an avenue for improved health and income of the rural poor. They are often promoted on the strength of tackling vitamin A deficiencies in rural communities, a strategy superior to the provision of vitamin A tablets. Home garden projects that capitalize upon locally adapted species (both to climatic and biotic stress), that propose to address a few rather than a multitude of development issues, and that provide options for change as needs evolve, tend to be the most successful (Midmore *et al*., 1991). Social and political considerations are equally as important as production success in ensuring effectiveness of interventions via promotion of home gardens for the rural poor (Table 3.2). A timely publication (Wiggins and Keats, 2013) traces the positive links between smallholder (including home garden) agricultural development, food security and nutrition. However, the report highlights the fact that investment alone in smallholder (often garden) production will have no favourable impact upon food security and nutrition unless backed up by parallel investment in public good infrastructure (primarily health care, clean water and sanitation) and female empowerment. Mimicking multistrata systems with annual crops, while ecologically desirable, is demanding of management input (especially knowledge-based inputs) and is unlikely to be adopted by new entrants to home garden projects. Simple crop mixtures that capitalize upon pest suppression and complementarities of resource use (see Chapter 4) should be all that is sought in the first instance, graduating to the adoption of perennial species when management skills so merit.

Examples of successful home garden interventions as development aid are numerous in Asia. For example, AVRDC and Helen Keller International took a 16 m^2 design and, allowing for adaptation with local species variants, it supplied nutrient-rich vegetables over most of the year to adopting rural-poor households in Bangladesh. Close to 1 million north-west Bangladeshi households were involved in the programme by the end of the 1990s, extending to Nepal and Cambodia thereafter (Talukder *et al*., 2010).

The very diversity of home garden species imparts much of the functional sustainability of home gardens. Efficient nutrient cycling by mixtures of species with

Table 3.2. Lessons learned from experience with home garden development projects. (From Midmore *et al.*, 1991.)

1. Build upon user needs and interests
2. Use appraisal techniques to assess limiting constraints
3. Assess traditional gardening activities
4. Formulate clear and achievable objectives
5. Evaluate social benefits
6. Use potential solutions that are already available

complementary root morphologies that minimize soil erosion, and contributions of species mixtures to productivity levels unobtainable in single-species plantings, the temporal spread of harvestable food products and the array of non-market products and species (e.g. shade for livestock, and for humans, wood for fuel) are all strong reasons why home gardens remain an important adjunct to the food and nutritional security of millions in the developing world. Balanced against these advantages, however, is the demand on family time and labour to tend and nurture home gardens, and the food energy input required to sustain the effort involved which may be from 2 to 3 h a week to a couple of hours a day, with each hour requiring about 150 calories (Keatinge *et al*., 2012). Given the investment in labour to manage home gardens, research towards less labour-demanding practices is called for.

Because of the tendency (and probably the desirability from a development perspective) towards closer integration of practitioners of home gardens into market economies, it might be asked whether home gardens will in the future continue to play a role in the supply of vegetables, and particularly of fruits, for the rural poor in the tropics. While the rate of market integration remains slow, the role for home gardens will remain strong, and the favourable internal benefits and externalities will remain in place. Indeed, with green consumerism, the shift back to organics and the demands for so-called 'chemical-free' produce, it would appear that home gardens will continue to have a role to play in tropical horticultural production, albeit continually adapting to optimize the socio-economic and biophysical benefits. The support of 'lead firms' (i.e. those that facilitate the integration of smallholders, particularly those evolving from home garden systems, into value chains by way of motivating them and other value chain participants forward) by development agencies will play an important role in improving and sustaining relationships and collaboration between all the actors in the value chain (USAID, 2008).

In these first two types of horticultural production systems, subsistence and home gardens, little differentiation has been made between vegetable, fruit or cut flower crops. Some distinction will be made between the fruit and vegetable commodity groups when produced in the semi-intensive mixed and highly intensive commercial systems. Flower productions systems are not dissimilar to vegetable production systems and are therefore not addressed separately. In the two production systems that follow the produce is primarily destined for sale to consumers who may be close to, or distant from, the production locale.

3.3.3 Semi-intensive mixed farming annual vegetable production systems

In contrast to the subsistence and home garden systems, semi-intensive mixed farming systems are almost entirely commercial. In reality, all the four systems described form a continuum with respect to their major determining characteristics, but for convenience they are discussed as if they were stand-alone and independent systems. Semi-intensive mixed farming systems, particularly in the tropics of South-east and South Asia, are cereal based, with vegetables grown in rotation most commonly with paddy rice, and located some distance away from major consumption centres (Midmore and Poudel, 1996). In Africa, vegetables in this type of system are rotated with upland rice, as seen for example around Morogoro in central Tanzania, and onions and tomato with lowland rice in the Senegal River Valley (Takahashi, 2011), but in Latin America there is no standard typology of the semi-intensive system.

Species grown in this system tend to be of the Groups 2 and 3 types; distance from markets in many cases and the tortuous marketing channels tend to preclude Group1 types became of their high perishability. Another reason that Group 2 and 3 types are predominant is that labour requirements for cultivation of these are less than for Group 1 types; semi-intensive systems tend to be less land constrained and more labour constrained in their overall productivity than the very intensive systems. The latter, as will be seen later, favour Group 1, although not to the exclusion of Groups 2 species (Table 3.3). Notwithstanding this, some of the Group 2 species, such as tomato and peppers, require much labour for their long harvesting season, and development of varieties that allow a once- or twice-over harvest is needed and is under way.

In the tropical lowlands of Asia, the annual vegetable (and fruit if annual) crops in the semi-intensive systems are predominantly grown during the cooler, dry, winter season. Rice is the most common rotation species, grown during the hot, wet, rainy season, and frequently (where water permits) as two successive crops, for it is grown both for home consumption and as a cash crop. Double-cropping of shortened season rice cultivars, products of intensive rice breeding and selection, opened the opportunity to cultivate longer season, or even double-cropped winter fruit, vegetable or pulse species. Declining rice prices (with the caveat of the price hikes of 2007–2008) have been driving the expansion of vegetable production, even to the extent of replacing rice with vegetables (as in the very intensive production systems). In this system, access to irrigation during the dry winter is an imperative. Access to reliable

Table 3.3. Characteristics of semi-intensive and intensive vegetable production systems. (From Ali, 2002.)

Characteristic	Semi-intensive system	Very intensive system
Type of crops	Groups 2 and 3	Group 1 and some Group 2
MCI[1] and input use intensity	Moderately high	High
Disease and insect pressure	Moderately high	High
Soil degradation and excessive input use	Moderate	Serious
Dependence on agribusiness services such as credit, commercial seedlings	Low	High
Farm size	Relatively large	Relatively small
Proportion of hired labour	Higher than in cereal crops, but lower than in very intensive system	High
Structure for crop protection such as shade, rain shelter, raised bed	Simple	Sophisticated, possibly permanent
Diversity in vegetable production	Low	High
Contact with consumers	Less personal	More personal
Mechanization	Moderate/high	Low
Managerial skill of farmers	Higher than for cereal crops, but lower than very intensive vegetable system	High

[1] MCI, Multiple Cropping Index – see text for definition.

and well-maintained transport and communication systems is also essential for its production and marketing success. Responding to the opportunity to adopt a new crop, or range of crops, requires that farmers be supported with a bundle of services; for example, with credit, extension and marketing. This transition to growing high-value crops, from a rice-based production mindset, has best been favoured through interplay between the private and government sectors. This is illustrated in Thailand with the introduction of processing tomato, and vegetable and flower seed industries, and in the past in Taiwan with the asparagus and mushroom industries (Benziger, 1996). The major constraint, if the earlier-mentioned requirements are satisfied, is in the price penalties associated with the concentration of production to a reasonably short defined period of the year. This causes gluts and price slumps, although for the consumer lower prices lead to greater per capita consumption, as seen for example in Pakistan where urban per capita consumption is three times higher in the winter than in summer (Chaudhry and Ahmad, 2000). These gluts are caused largely by the timely need to harvest over a short time period and to prepare land for the staple cereal crop. Other constraints include the transport costs to urban markets (both financial, and loss of product quality during transport), and the management skills needed to fit into a cereal, or other staple-based annual production system. The relative difference between price in summer and winter is illustrated for tomato in Taiwan (Chapter 1, Fig. 1.9), and similar differentials are noted for most temperate vegetable species in lowland tropical regions, as illustrated for Asia by Ali (2000). The differential in price between summer and winter tomato in Taiwan has been reduced with time (as it has for other species and in other countries where research has focused on summer vegetable production), but the cause has been a reduction in summer prices rather than an increase in winter prices. Clearly, as discussed in Chapter 4, practices to extend production to the hotter summer months have somewhat evened out the annual supply of vegetables in tropical countries, but they do little to ease the problem of over-production in the winter season.

If the staple cropping is rice-based, there is a need for a period for the drying of soil following the rice harvest before land can be prepared for vegetables (although some crops such as soybean and mungbean are undersown into the rice crop before it matures for harvest). Sustainable irrigation infrastructure and an assured availability of labour to manage the crops are also important requirements to be satisfied. Indeed, horticultural crops require on average 3–5 and up to 7 times more man-days per cultivated crop than does rice (Table 3.4). The predominance in South-east and South Asia of a production system that involves rotating vegetable crops with irrigated rice is in part due to its advantage in that vegetable pests and particularly diseases are suppressed by such a rotation. Race 1 of bacterial wilt (*Ralstonia solanacearum*) is suppressed through flooding of fields during rice cultivation (Michel *et al*., 1996) reducing wilt among representatives of the *Solanaceae* (potato, tomato peppers), the *Musaceae* (banana) and the *Zingiberaceae* (ginger). The benefit for the rice is a solution to yield decline associated with continuous production of rice and rice–wheat season after season. The physiological basis for the yield decline is still unknown, although based upon long-term experiments a depletion of soil K has been implicated (Ladha *et al*., 2003), as has a steady decline in soil OM. The recent introduction of both aerobic rice and the so-called system of rice intensification (SRI), both of which rely much less on flooding of soils, will negate the otherwise rotational benefit of managing disease in vegetable crops when grown after flooded rice.

Diversification from production of rice or other cereals to that of fruits and vegetables has been promoted by development agencies such as the Asian Development Bank on the basis that it creates greater income per unit of land and labour (Table 3.4) and per unit of water (Table 3.5), and creates more employment opportunities for family labour and the landless than does cereal production. Investment costs are high: collection, transport and postharvest facilities and good market communication systems are necessary requirements for success, as is training in management operations and their timeliness in aligning with market potential. Although the volume of international trade in horticultural products is not great compared to that of cereals, due largely to the perishability of the former, it does take place when there is a strong market demand (such as the counter-season export from the south to north temperate countries) and between neighbour countries, as seen in the North-west Crop Diversification Project of Bangladesh. This raised incomes by 21–56% for 4 million households in Bangladesh, increased cropping intensity in the

Table 3.4. Comparisons of labour input and net returns (US$) to farm labour, land and management for peri-urban vegetables (Groups 1 and 2) and rice in Vietnam and Nepal (data for early 1990s). (From Ali and Abedullah, 2002; Jansen *et al*.,1996a,b.)

	Group 1	Group 2	Rice
Vietnam			
Profitability ha^{-1} yr^{-1}	700–3235	90–4495	455
Man-days $crop^{-1}$	230–550		100
Inorganic fertilizer kg $crop^{-1}$	534		197
Organic manure t $crop^{-1}$	7.6		1.8
Nepal			
Profitability ha^{-1} $crop^{-1}$	1210–4040		240–365
Man-days $crop^{-1}$	600		300[1]

[1] Labour-intensive spring rice.

Table 3.5. Comparisons of water productivity and economic efficiency between cereal and staple crops and some vegetable crops in Taiwan. ET, evapotranspiration. (From Ali, 2002.)

Crop (type of harvested yield)	Basic water ET requirements (mm growing $period^{-1}$)	Water productivity (kg of output m^{-3})	Farm price in Taiwan (US\$ kg^{-1})	Economic efficiency in Taiwan (US\$ m^{-3})
Vegetables				
Onion (bulb)	350–550	8.0–10.0	0.256	2.05–2.56
Tomato (fresh fruit)	400–600	10.0–12.0	0.688	6.88–8.25
Cabbage (head)	380–500	12.0–20.0	0.39	4.68–7.79
Pepper (fresh fruit)	600–900	1.5–3.0	0.679	1.02–2.04
Other crops				
Rice (paddy)	350–700	0.7–1.1	0.655	0.46–0.72
Peanut (unshelled nut)	500–700	0.6–0.8	1.587	0.95–1.27
Corn (grain)	500–800	0.8–1.6	0.556	0.44–0.89

project region by 28%, reduced horticultural imports of products, and diversified and increased exports to India. But promoting this is not without its risks; price volatility reflecting short-term shifts in supply impact upon price. The demand side, in contrast, is quite stable, and tending over time to increase in a manner not seen with cereals. Diversification from rice to horticultural crops is considered a development panacea to the afflictions of the rural poor, for whom the decline in real price of cereals has been felt most. Agricultural diversification has undoubtedly been responsible for the economic liberation of much of the rural poor in some countries. The earlier-mentioned examples of Taiwan notably with prowess in the past in asparagus and mushroom production, and in parts of Thailand where tropical fruit and cut flowers have flourished together with newly introduced production of vegetable and flower seed industries illustrate this (Benziger, 1996). But besides price volatility, other constraints such as high prices of inputs (fertilizers and other agrochemicals); high investment costs for infrastructure; and unfavourable topography, soil type and drainage are responsible for the notable differences between regions within countries in the proportion of arable land devoted to vegetables. More recently, the hike in global grain prices fuelled by declining investment in agricultural production research, by low reserve stocks, and by competitive use of land and crops for biofuels, has made cereal production more lucrative to farmers. This has forced a rethink of the benefits of shifting towards a greater research emphasis on vegetables and fruits in order to promote and underpin economic growth and development.

A number of factors, therefore, militate against diversification away from cereal crops into annual horticultural species. These include the high investment costs, the need to access and employ quality labour experienced with management-intensive fruit and vegetable crops, and above all the availability of labour to undertake the production-intensive practices associated with vegetable production. Comparison between the labour input requirements for rice, for example, and vegetable crops grown on the same farm in Nepal illustrates this point (Table 3.4), as does the wide range of gross returns to tomato production. On average a fivefold range was recorded by Jansen *et al.* (1996b) emphasizing the importance of good market intelligence and/or pre-harvest sales to marketing agents who may even forward-finance to cover the costs of production. Linking production decisions to market potential is a key skill to be learned as growers move from staple rice to semi-intensive vegetable production.

A feature of the semi-intensive system is the frequent inclusion of livestock for traction, for direct meat consumption, or for dairy and avian products. While at best animals can be fed on the natural wastes associated with fruit and vegetable production (e.g. wrapping leaves of brassicas, damaged or blemished fruit), at worst they can be fed with crops for which markets have collapsed due to over-supply. Additionally the livestock return nutrients to the enterprise, helping to close nutrient cycles. Commonly referred to as farmyard manure, solid and liquid wastes, the former (if not used as a rural fuel source) are applied at rates reaching in the tens of tonnes per hectare when available. Availability depends to a large extent on the management practices for livestock; excrement from corralled or animals overnight penned is spatially concentrated and more easily sourced and gathered for field application, although transport for the bulky material may be cost-prohibitive. Alternatively, other sources of organic-based nutrients are accessed, as for example the euphemistically so-called ‘compost’ from landfill or even before it reaches landfill (Midmore and Jansen, 2003), and used on farm for similar purposes. Besides their role in supply of nutrients, organic amendments improve soil physical structure, soil biological activity and chemical properties such as a higher cation exchange capacity and better availability of P: benefits that carry over into the rotations with cereals or other non-horticultural crops.

A novel feature of some semi-intensive systems is the renting out of space between rows of plantation crops for annual vegetable production in the tropics. The space is rented to landless tenant farmers who gain income from their cultivation of vegetables (Govinden, 1990). Cultivation for the interplanted vegetable species reduces inter-row weed growth in the mainstay crop and represents a welcome gain for the landlord. For example, immediately after the planting of sugarcane (the first season of cane, established from setts – short two- or three-node stem segments) tubers of potato or seedlings of tomato are established as intercrops in the space between cane rows. This is feasible, for the slow-growing sugarcane canopy does not cover over the inter-row space until a further 3–4 months or even later after planting in cooler seasons. Even the inter-row space in the ratoon cane crop can support a short-season horticultural crop (Govinden, 1990). This practice is adopted in a number of traditionally cane-growing countries (e.g. Mauritius) and cane-growing regions (e.g. Maharastra State, India; Nankar, 1990).

3.3.4 Very intensive vegetable production systems

Very intensive vegetable production systems will have been established because of one or more specific advantages over semi-intensive systems. The advantage may be geographic in that a sizeable market is close at hand (and peri-urban horticulture is a good example of this), or that a feature of the tropical climate favours cultivation of vegetables in at least part of the year. It may also be the combination of low transport costs, easy access to credit and possible recycling of urban wastes as inputs. The climate factor most likely to come into play is that of temperature; cooler highlands in the tropics are able to supply vegetables and fruits if growers are well linked through communication and transport to the distant markets, and with quality and price competitive with those produced near cities. Freedom from damaging monsoons (or typhoons or hurricanes) is yet another climatic motivation for geographic intensifications of vegetable production, as evidenced (together with the cool weather) in the highlands of Mindanao in the Philippines. Reliable transport is an issue for growers distant from markets, since they themselves are not able to market their own produce, so dependency upon one or more middlemen is necessary. Temperate vegetable species from peri-urban production systems may be available seasonally (i.e. during the cooler ‘winter’), and in the off-season highland produce serves to fill a supply deficit for the temperature vegetable species, often at higher than average annual prices. This occurs for the marketing in Ho Chi Minh City in Vietnam (Jansen *et al.*, 1996a), with the concentration of vegetables in the winter coming from the peri-urban zone extending to 15 km for leafy vegetables and to 35 km from the city centre for the more resilient cabbage, cauliflower and radish. In the climatically unfavourable summer, temperate- type vegetables are sourced from the cooler highlands of Dalat at 1500–2000 masl, some 300 km from Ho Chi Minh City.

During the hot summer the spectrum of vegetables cultivated in peri-urban Ho Chi Minh City shifts to include those more tolerant to high temperature, such as kang kong and aubergine.

From a development point of view, very intensive vegetable-producing systems represent the peak in terms of maximizing opportunity costs of land and labour. It is known that higher human population densities induce more intensive agricultural production, as shown by greater investments in land and advances in mechanical technology and manuring systems in sub-Saharan Africa (Pingali *et al.*, 1987). Fortunately, with horticulture returns to financial investment are high and justified, especially near cities, where demand is also high and increasing. Following the argument in Chapter 1, demand for fruits and vegetables in expected to increase, especially in response to rising incomes within cities of the developing world. As incomes continue to rise rapidly in cities, demand for fruits and vegetables increases, inducing substantial shifts in food demand patterns. As an example, consumer demand for the bright-orange-fleshed '*gadung*' mango cultivar is influencing growers' planting decisions in Indonesia (Minot, 2010). Urban agriculture already provides close to 20% of the world's food (FAO, 2007) and highly perishable and delicate fruits and vegetables comprise a significant proportion of that figure. Particular advantages of urban and peri-urban horticultural systems revolve around the easy access to credit and other inputs, low costs for storage, easy transport of produce to markets and easy access to commercial quantities of wastes as recycled resources. Close market intelligence on consumer purchasing patterns and preferences is a notable advantage, too, doing away with the need for small-scale traders (unless needed for provision of credit); producers market for themselves. Some of these advantages in favour of peri-urban production disappear when transport infrastructure linking cities with more distant production zones and communication media are well developed. In Bangkok one-quarter of vegetable supply is from peri-urban systems which contrasts with Ho Chi Minh City where on an annual basis peri-urban production supplies three-quarters of marketed vegetables. Likewise, with the advent of the mobile phone, small farmers' practices are becoming transformed as they adapt production to demand with knowledge of price mechanisms and fluctuations. Another justifiable reason to focus development into peri-urban production of vegetables is to reduce the environmental pressure on the highlands where vegetables are often grown on fragile sloping lands with a high propensity to erode (Midmore *et al.*, 1996). Although urban agriculture offers many advantages for producer and consumer, unfortunately these are offset by associated risks with contamination by residues, primarily agrochemicals, heavy metals and human diseases, many through the reuse of waste water. Water is a resource necessary for urban agriculture and is in particularly short supply in many arid and semi-arid areas. Integrated planning for its efficient use by urban populations constitutes a decisive feature in the development of low-impact urban agricultural systems. As urban expansion takes place good-quality land is lost to housing for higher-income urban residents. The spread of the ring of peri-urban production embraces less well-educated and skilled farmers who traditionally are more dependent upon seasonally conditioned commodity mixes, and land that requires high organic input to sustain intensive vegetable production.

In the following sections we will first consider field based then glasshouse or protected practices, followed by hydroponics and organic systems.

3.3.4.1 Field based

The cultivated land of crop production systems that characterize very intensive production systems grows almost entirely vegetable and less notably fruit crop species, with perhaps small land areas grown to cereals if required for home consumption or to satisfy national quotas (as in Vietnam until 1989 when a land tax system replaced the obligation to sell a part of the rice production to the state at a low price). In Asia these systems have traditionally been at the small-scale, family-farm level; the proportion of land under cultivation at any one time is largely determined by availability of family labour. Managing multiple cropping practices, dealing with sophisticated marketing systems and ensuring contractual arrangements are fulfilled are skills that horticultural producers must have in order to manage their intensive production systems successfully. They must also learn the skills needed to meet consumer demands for freshness and quality. The same management skills underpin other service and manufacturing industries that appear around cities, with which successful farmers engage. These skills are seen as critical in the rural poor's evolution from horticulture to service and other industries.

Commodity focus may be on a few species such as seen in the peri-urban farms surrounding lowland tropical cities (e.g. a focus on short-season Group 1 leafy vegetables around Ho Chi Minh City, Shanghai, Manila, Dakar) to a wider range of species, including Group 2 but less so of Group 3 species. Use of purchased inputs such as nutrients is high compared to those for cereals (Table 3.4), as is productivity and the multiple cropping index (MCI). The MCI, sometimes called the crop intensity, is defined as the harvest area of crops for one year divided by the cultivated area supporting those crops for one year, where a value of 1 represents a single crop grown in the cultivated area per year, whereas a value of 3 represents three harvested crops per year, in sequence. The harvest may be for a single crop or for a combination of crops planted as multiple or mixed crops on the same piece of land (see Box 3.1). Normally, as the size of the farm increases, the MCI or crop intensity declines (Fig. 3.1), a reflection of the family labour constraints to vegetable cultivation. Inputs are purchased to make good those of the natural environment that are in short supply yet essential for vegetable production. For example, on the sandy granitic paleudults of the Cameron Highlands of Malaysia, imports of chicken manure of up to 80 t ha^{-1} $crop^{-1}$ are not uncommon (Aminuddin *et al*., 2005). The production systems there for vegetables, and more recently for flowers, are essentially analogous to hydroponics systems with an inherently infertile solid sandy medium, to which is added manure and water. One of the major constraints with highland tropical vegetable production is the ecologically fragile nature of the physical environment; the susceptibility of steep slopes to soil erosion is discussed in Chapter 4. Growers take a number of steps to avoid loss of nutrient-rich topsoil and manure, including the use of extensive rainshelters and of tillage and planting operations parallel to the contour with permanent natural vegetative strips planted between alleys of crop production, also planted on the contour, and agroforestry with tree species planted along contours, with spaces between rows of trees planted to vegetables (Midmore *et al*., 2005). Where organic inputs (e.g. compost; farmyard manure – FYM) are in short supply inorganic fertilizer is substituted; however, in China the use of night soil, a choice phrase for processed human sewage, was and continues to be extensively used in peri-urban vegetable systems (it is heavy to cart, and therefore used close to its city source). Its use has proportionately declined (although in absolute terms increased fourfold) over the past 60 years from 100% of supply to about 25% of total nutrient use in agriculture, and has been accompanied by a rise in use of lighter-to-carry inorganic fertilizers. Complex cropping systems have evolved, largely through farmer trial and error, and examples from China summarized by Plucknett and Beemer (1981) illustrate farmer ingenuity (See Box 3.1).

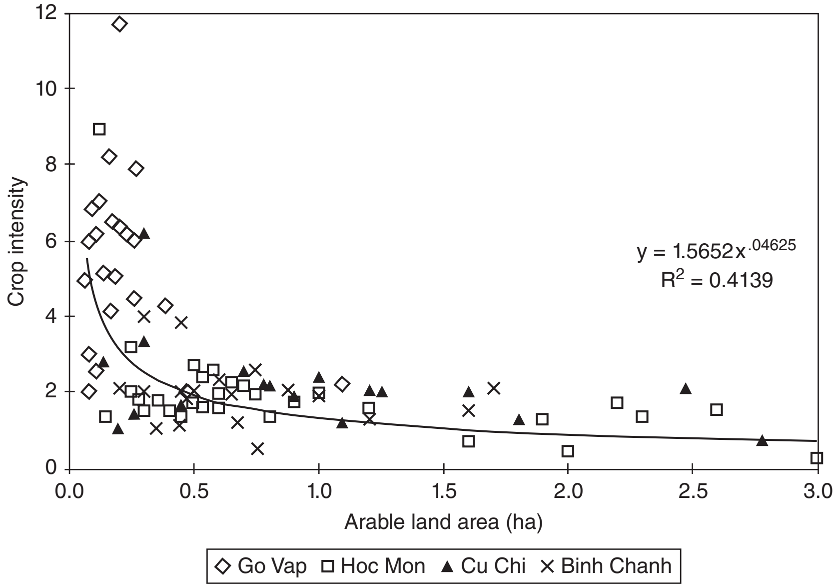

Fig. 3.1. Relationship between cropping intensity (= ratio on an annual basis of cultivated and arable land area) and arable land area, for surveyed farms in four districts supplying Ho Chi Minh City with vegetables, showing tendency for higher crop intensity with smaller farm size. (From Midmore and Jansen, 2003.)

Box 3.1. Complex spatially adapted plantings within single fields

Albeit rather dated, the descriptions of intensive vegetable production systems in southern China (Plucknett and Beemer, 1981) where temperatures do not drop below 5°C (allowing year-round vegetable cropping) are revealing in terms of farmers' ingenuity as they optimize their use of temporally and spatially distributed resources. Based upon the construction of wide beds separated by deep ditches, trellised climbing vegetable species (such as yard-long bean, luffa) are planted near the edge of the beds and span alternate ditches. The beds allow for drainage during periods of heavy rainfall when soils are saturated. Interplanted on the beds is a sequence of species, often intercropped (e.g. small Chinese cabbage with aubergine) or relay-cropped (e.g. late summer tomato transplanted into a maturing summer squash crop) to capitalize upon space and on biological interplay for control of pests and diseases. Spatial arrangements for two such series are presented in Fig. 3.2.

Such systems allow for the growing of up to ten crops in the same land parcel each year. But one drawback of the intensive nature of the system is that it does not allow for

Continued

Box 3.1. Continued.

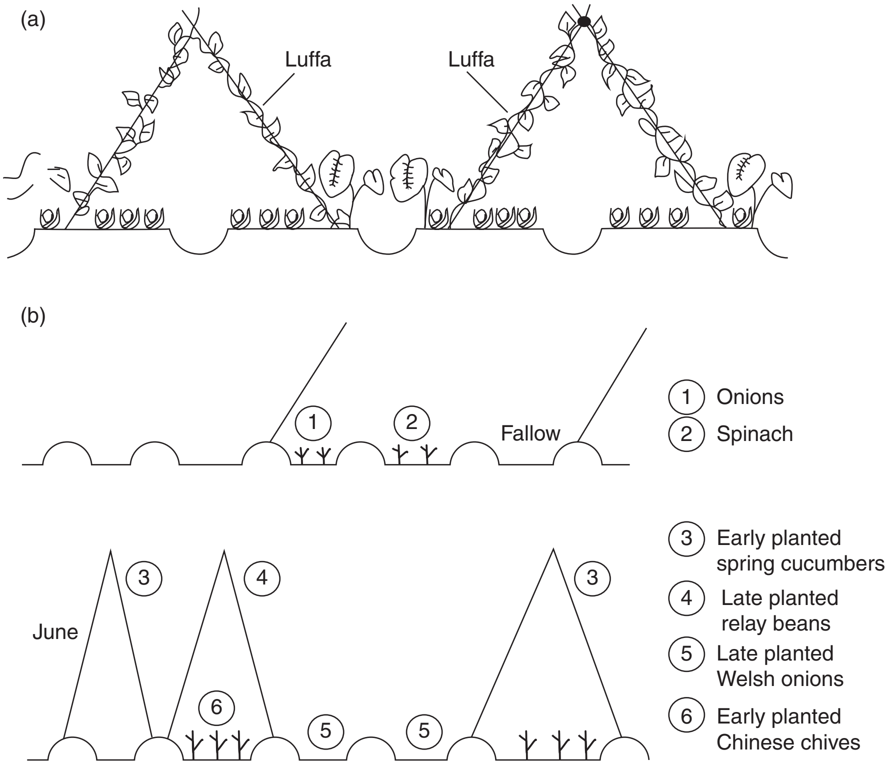

Fig. 3.2. Diagrammatic representation of some vegetable cropping sequences in China, (a) taro growing on edge of raised beds, short crop Chinese cabbage planted at same item as luffa with trellises of luffa spanning alternate ditches, (b) sequence from spring planting of onions, chives and spinach, and cucumber on trellises, followed by later plantings of relay beans and Welsh onions (From Plucknett and Beemer, 1981.)

annual land preparation. Instead, on a 3–5 year basis, land is levelled, a rotational crop of rice is planted to break diseases cycles and to destroy insect pests (as is done on a more frequent basis in many semi-intensive vegetable production systems) before de novo construction of beds and ditches.

The sorjan system of Indonesia is yet another farmer adaptation to inclement monsoon conditions. This time, and in the hotter tropics, raised and high permanent beds, up to 1.5 m above the surrounding flooded land, promote drainage and soil conditions favourable for ‘upland crops’ such as maize, tropical vegetables and soybean (Fig. 3.3). In the surrounding land rice is grown continuously or with break crops of legumes during the drier season. Again, the break of monoculture of rice with a legume, as for long-term cultivation of sugarcane, has been shown to be advantageous in terms of both crop nutrition and soil health, as discussed in Chapter 4. The break-crop is often soybean, or vegetable soybean, the latter being harvested when the pods are immature and the seeds prepared for consumption in the same manner as for peas.

Fig. 3.3. Integration of upland vegetable crop (vegetable soybean) and lowland aquatic crop (rice) in a permanent high bed agricultural system in southern Taiwan.

Various forms of intercropping are practised where land space is limited, or where returns to labour are to be increased. Objectively chosen intercrop mixtures are often adopted in very intensive production systems because they raise the land equivalent ratio (LER – the ratio of yield from unit area of an intercrop to the yield from the same area of land if planted to the component monocultures over the same time period). In an intercrop there is more efficient exploitation by the crop mixture than by the sole crops of resources such as light, water and nutrients. Intercropping reduces the need for land preparation, and weed and (at times) pest and disease control. The frequency of land preparation is also reduced, which can have benefits for the conservation of soil organic matter (and the reduction of CO_2 emissions). A detailed discussion of the practice of intercropping is presented in Chapter 4.

The very intensity of the highly intensive production systems underlies their role as causes of serious negative environmental and health impacts. Inefficiencies in the use of mineral fertilizers (through poor choice of formulation, quantity and timing) lead to their over-use, and through leaching contaminate ground water. Most Group 1 species are actively growing when harvested and require ready access to soluble nutrients. This ensures their visual attractiveness to the consumer. For simple crop sequences nutrient budgets clearly illustrate the impossibility for the crops to take up all applied nutrients. For example, a comparison between Group 1, 2 and 3 species, in terms of the application according to blanket recommendations and their nutrient uptake, highlights the increasing amounts of residual nutrients in the soil at harvests of sequentially planted crops (that remaining in the soil at week 18 in Fig. 3.4). To overcome this inefficient and potentially polluting increase in residual soil nutrients, two systems, one called the diagnosis and recommendation integrated system (DRIS) and the other Nmin, may be used to more objectively determine the necessary nutrient application rates. DRIS uses plant nutrient analyses (usually of the petiole) during the

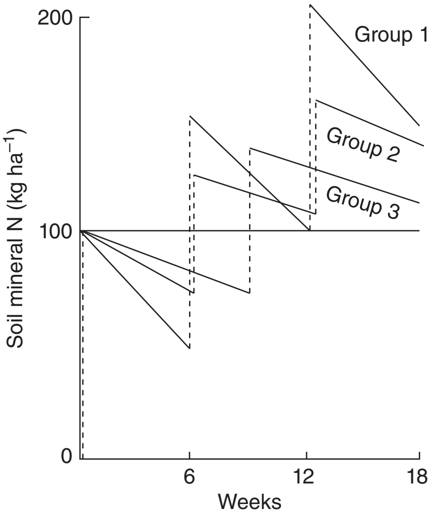

Fig. 3.4. Schematic for nitrogen application and content in the soil for Group 1 (leafy vegetable – three successive crops), Group 2 (tomato) and Group 3 (onion) vegetables in the absence of residual soil N pool and mineralization. Vertical dotted lines represent N applications (at plantings for Group 1, at planting plus two side-dressings for Group 2, and at planting plus one side-dressing for Group 3).

growth of the crop to determine deficiencies or excesses of soil nutrients, matching them against well-defined growth stage sufficiency ranges of a high-yielding reference population. Nmin uses soil analyses prior to planting the succeeding crop. It matches these with the calculated removal rate according to that needed for an estimated final total yield, to develop a fertilizer application strategy. Adopting this latter system can reduce total nutrient application, specifically nitrogen in a 29 month cropping sequence, for example, by up to 55% compared to arbitrary recommendation-based application rates. The traditional recommendations were made for low-bed cultivation, and only one crop on low-beds yielded significantly less with the Nmin fertilizer strategy than with the conventional fertilizer strategy (Table 3.6; see Chapter 4 for more detail).

Within an area-wide context, the geographical concentration of intensive fruit or vegetable production systems has both advantages and disadvantages. For example, it promotes a concentration of service and supply industries that evolves to support the industry; and of collection, processing, packaging and storage facilities necessary to extend shelf life of produce (see Chapter 6 for a full discussion on postharvest practices). However, the concentration of production of closely related vegetable species within specific locations, and the year-round planting and harvesting regime, is not without its own set of problems. One is that it guarantees a constant supply of hosts for both herbivorous insects and diseases. Pesticide use is consequently high as growers, struggling to manage the pests, are exposed to the persuasive promises of pesticide companies. With short-season vegetable crops in particular the minimal withholding period between the last application and harvest may often be exceeded, predisposing produce to unacceptable levels of residues. A decade ago in China 47%

Table 3.6. Marketable yield (kg ha^{-1}) of vegetables and N application rates as influenced by fertilizer strategy (Nmin-reduced rate total 460 kg ha^{-1}, traditional rate total 1070 kg ha^{-1}) and different bed heights (low bed 20 cm high, high bed 50 cm high). (From Kleinhenz *et al.*, 1997.)

Year	1993			1994			1995		
Vegetable	Chinese cabbage	Chilli	Carrot	Vegetable soybean	Chinese cabbage	Chilli	Carrot	Vegetable soybean	Chinese cabbage
Low bed									
Traditional rate	1.37^{a}[1]	0.220^{a}	1.29^{a}	1.26^{a}	0.75^{a}	0.172^{a}	3.06^{a}	0.89^{a}	2.43^{a}
Reduced Nmin rate	1.49^{a}	0.202^{a}	1.40^{a}	1.19^{a}	0.19^{a}	0.070^{a}	3.00^{a}	0.88^{a}	1.80^{b}
High bed									
Traditional rate	2.10^{a}	0.616^{a}	1.10^{a}	1.10^{a}	1.99^{a}	0.364^{a}	3.24^{a}	1.31^{a}	3.07^{a}
Reduced Nmin rate	2.14^{a}	0.533^{b}	1.16^{a}	1.05^{b}	1.32^{b}	0.292^{b}	2.99^{b}	1.28^{a}	2.32^{b}
Orthogonal contrast									
Flat bed versus high bed	<0.01	<0.01	0.13	<0.01	<0.01	<0.01	0.43	<0.01	<0.01
Traditional versus Nmin	0.31	0.04	0.39	0.06	<0.01	<0.01	<0.01	0.23	<0.01
Traditional rate of N kg ha^{-1}	120	200	120	60	120	150	120	60	120
Reduced Nmin rate of N kg ha^{-1}	60	170	0	0	20	70	50	20	70

[1] Means followed by the same letter within a bed type within a column are not significantly different at $P<0.05$.

of domestically produced vegetables contained pesticide residues in excess of government standards, and contaminated produce exported to Japan from China contained up to four times the limits agreed to by the two countries (Rerkasem, 2005). Introduction of hazard analysis and critical control points (HACCP) and other quality and health standards for food, especially on internationally traded products, is reducing the extent of this. For example, the most important hazard triggering the Food and Drug Administration (FDA) of the US to refuse vegetable imports is the presence of pesticide residuals. Studies in Vietnam (Hoi *et al*., 2009) show that there is still much room for improvement; the current poorly functioning safe vegetable system is due to poor involvement of state authorities in supporting market actors in safe vegetable governance, and there is still much consumer mistrust in safe vegetable production being able to provide safer produce than found with conventional vegetables.

A summary of the key features of semi-intensive and very intensive production systems is presented in Table 3.3. Management skills are at a premium in the very intensive systems as is the ability to invest heavily in infrastructure and pest and disease management.

3.3.4.2 Glasshouse/protected

Given the high degree of investment made by growers with intensive systems of fruit, vegetable and flower production in the tropics, compared to those for semi-intensive or cereal-based production systems (Table 3.3), it is not surprising that some invest heavily in technologies such as those that protect against heavy rain, reduce risk and synergistically raise productivity. A number of protected structures are available and one such is illustrated in Fig 3.5. High-cost glasshouses made with polycarbamates or

Fig. 3.5. Sophisticated cooling and vent systems, and water capture, in a South Korean greenhouse.

acrylic (with light-transmission qualities superior to glass), and with complete environmental control, allow for a degree of precision unimaginable half a century ago, but fuel costs preclude their adoption in the tropics for all but the most affluent societies. They are found, for example, in Taiwan, Singapore, Israel and oil-producing Middle Eastern countries. The agricultural land area in Singapore has decreased tenfold over the past 50 years, from 15,000 ha to 1500 ha – hence intensive production systems are an imperative when trying to ensure some own-grown supply of vegetables and flower products. As part of the 'awareness of food' programme, spare land at more than 60 schools in Singapore has been turned over to small-scale protected hydroponic units (Oh' Farms, n.d.). Financial investment in glasshouse and associated infrastructure is high (e.g. in Australia *c.*A$300–$350 m^{-2} for 1000 m^2 or A$200–$250 m^{-2} for 10,000 m^2), but returns to land and water are also much higher. For example, in temperate Victoria, Australia, compared to a field-based tomato production system returns were tenfold greater, water use efficiency was five times greater and gross market returns were twenty times greater. The disproportionate increase in market returns were due largely to increased yield and a greater proportion of higher-quality product. Such advantages have not missed the attention of development agencies and FAO has been advocating greenhouse technology for Caribbean countries, not only for increases in water use efficiency but also to avert the loss of vegetable crops during times of disaster, such as during the hurricane season, provided growers maintain hurricane preparedness. In areas of water shortage in Mexico the Federal Government and Canadian and US growers have invested heavily in greenhouse vegetable production (Cook and Calvin, 2005). The decision about whether to invest in a high-cost greenhouse for horticultural production is assisted by the use of dynamic simulation models. A number have been developed, e.g. KASPRO by de Zwart (1996), that simulate full-scale virtual greenhouse operations based upon choice of construction materials, ventilation openings, covering material properties, set points for inside and outside climate, energy consumption, water transpired, CO_2 introduced and crop dry matter production. In a recent application of KASPRO to the Taiwanese situation, for sites close to the Tropic of Cancer, Speetjens *et al.* (2012) compared low-tech, mid-tech and high-tech greenhouse types and highlighted the need for fogging in summer and heating in winter. The use of a diffuse (non-thermic) plastic film that reduces direct heating of leaves, but with a high transmission of the infrared spectrum to help reduce glasshouse temperatures in the summer, and the adoption of an open naturally ventilated system (as opposed to a more management-demanding closed greenhouse that is twice as expensive) were recommended. Representative data from the simulation are presented in Table 3.7 where it is evident that the mid-tech greenhouse is the most appropriate investment strategy, at much lower cost than the closed greenhouse, yet with a quicker payback period than for the low-tech greenhouses in current use.

Less sophisticated structures, covered with less robust plastic or PVCs, are more commonplace in developing countries for all but the most sophisticated export ventures. If designed to take advantage of natural ventilation, evaporative cooling and mechanical shading (in order of increasing costs) they have been shown to be economically viable. Yet simpler structures, such as 'rustic' rudimentary rain shelters, the plastic roofs of which are replaced every 2–4 years, provide considerable benefits to growers in tropical rainy seasons, preventing direct waterlogging and raindrop impact (Midmore *et al.*, 1997) and even UV damage to produce. When selling to more discriminating purchasers, a price premium can be added to damage-free or pesticide-free

Table 3.7. Characteristics of three greenhouse types (one also with CO_2 dosing) for use in subtropical Taiwan. (From Speetjens *et al.*, 2012.)

Main characteristics	Low tech	Mid tech	Mid tech, CO_2 dosing	Closed greenhouse
Ventilation capacity	Low	High	None	None
Cooling	None	Fogging and natural ventilation	Mechanical cooling	Mechanical cooling
CO_2 dosing	No	No	Up to 400 ppm	Always 1000 ppm
Cover	Plain plastic film	Non-thermic, UV blocking, diffuse plastic film	Diffuse glass	Diffuse glass
Heating	No	Yes	Yes	Yes
Production cherry tomato (kg m^{-2} $year^{-1}$)	8	29	33	80
Price tomato (TND[a] kg^{-1})	120	120	120	120
Total value crop (TND m^{-2} $year^{-1}$)	960	3480	3960	9600
Simple payback time (year)	2.2	1.0	1.0	0.8

[a] TND, New Taiwanese Dollars.

horticultural commodities produced under shelter, and this can offset and even reward the additional costs involved. Rain shelters in the tropical highlands, although creating an eyesore that detracts from the natural landscape such as in the Cameron Highlands of Malaysia (Aminuddin *et al.*, 2005), minimize damage to vegetables and flowers, reduce soil and water erosion, and, if combined with suitably placed water capture and storage structures throughout a watershed, can facilitate and support supplementary year-round irrigation. Protection from insect pests may also be afforded by glasshouses, or by net structures with suitably small-sized perforations. However, just as they are effective in excluding damaging insects, once inside them the pest populations multiply and special management measures (often adopting biological control) must be implemented rapidly. The largest concentration of glasshouses globally is in Almeria, in south Spain, where 25,000 ha of reflective glasshouses are believed to have cooled the region, compared to surrounding regions, with reflected light slowing the warming of the region's surface.

3.3.4.3 Hydroponics

Hydroponics represents the next step (and with current technology is the final step) towards the most intensive system of crop production, in particular for annual horticulture. It is considered an essential component of controlled environment agriculture, where every aspect of the crop environment is measured, analysed, and adjusted if necessary and possible. Obviating the use of soil, commercial hydroponics gained popularity in the last century in the glasshouse industry, although less sophisticated systems are known to have been adopted for centuries. An example is afforded by the 'chinampas', the floating gardens of Xochimilco in what is now Mexico City. Mud was placed on cane structures held in place by Ahuejote trees (*Salix bonplandiana*), which were anchored across large natural wetlands, and mud in the canals was dredged and spread periodically on the floating gardens (Torres-Lima *et al*., 1994). This system allowed fresh fruits, vegetables and flowers to be produced successfully year-round, even in the dry season. In this respect, the system is akin to those of some alluvial areas of the Red River Delta of Vietnam. It is being replicated in the wetlands of the Bay of Bengal in Bangladesh (Haq *et al*., 2004), using floating bamboo poles covered with aquatic weeds such as water hyacinth (*Eichornia crassipes*) and water lettuce (*Pistia stratiotes*). To these floating beds are added other organic wastes which decompose over 15–20 days to provide a growing medium. Beds remain on the soil surface during the dry season in seasonally flooded areas and provide for growth of vegetables on residual moisture. Floating beds increase the 'landholding' capacity of the poor and landless, involve both men and women (improving gender balance) and those who adopt them in Bangladesh are better off economically than those who do not (Saha, 2010).

The catalyst for adoption of hydroponics by the greenhouse industry was the substitution of hydroponic inert media and nutrient solution for conventional soil-based systems; systems that suffered from soil pests and diseases, surface salt accumulation and deteriorating soil structure and fertility. The nutrient solution contains dissolved elements essential for normal crop growth and development in close to optimal proportions. Oxygen may be supplied actively or passively to enhance root uptake of nutrients from the solution. Many commercial nutrient formulations are available, but most are quite similar, with main differences only in the ratio of nitrogen to potassium. The proportions of nutrients are approximately those of elemental composition of the leaves, stems and roots of all higher plants. Indeed, most formulations follow quite closely that of Hoagland and Arnon who evaluated earlier claims made in 1929 by Gericke of the University of California that plants could be grown on solution culture, and who later created the term hydroponics (Anon., 1937). All three are credited with the fatherhood of modern hydroponics. Under temperate conditions comparative yields of crops grown with hydroponics are claimed to be greater than those of soil-based cultivation, often by a factor of three to five (Resh, 2001) but the advantages of hydroponics are often confounded with the use of glasshouse technology. When all growth conditions other than the rooting media and supply of nutrients are similar the yield benefit of hydroponics is much smaller, but still present. In the tropics the yield advantage for hydroponics per se may not be so great. Comparison between soil-based and three different hydroponics systems in strawberry and bell pepper greenhouse production in Kuwait showed yield to be doubled in the soil-based method, although water use was 43–63% less with hydroponics. Primarily the reason is because of the high solution temperature. The concentration of dissolved oxygen in the solution is much reduced at higher temperature (Table 3.8) and the root system may well be temperature stressed, for the temperature of solution is consistently warmer than in the soil.

The soil, because of its capacity to dissipate heat and its lesser exposure to warm air, especially deeper in the soil profile, more effectively buffers roots from diurnal extremes than does hydroponics' media and/or films of solution. This is particularly so for daytime maxima. Efforts to dampen diurnal fluctuations in solution temperature, using insulation material around tanks and reflective piping, have been effective, particularly in reducing daytime temperature to within an acceptable range for roots (<30°C, Fig. 3.6), but raise costs for infrastructure. Of course, the use of white structure and pipes to reflect irradiance, or cladding with heavy-duty aluminium foil around a suitable insulator material (such as polystyrene) clearly help to keep the solution temperatures below 30°C (Kao, 1991). Other simple technologies have been developed to overcome high solution temperature; temperate vegetative species, most predominantly lettuce, can be produced year-round with hydroponics in the equatorial lowlands such as in Singapore. The solutions to the two major problems, high temperature and low oxygen solubility, can range from relying upon refrigeration of nutrient solution to cool the root medium (which is costly and energy demanding) to the more innovative design of the root support structure adopted for increased aeration and oxygen concentration of the solution. Named the Dynamic Root Floating (DRF) hydroponics (Kao, 1991), roots are subjected to short wetting and drying cycles, the wetting cycle designed to induce turbulence in the water so creating a

Table 3.8. Concentration of oxygen in water saturated with air at different temperatures and measured at sea level (ppm).

	Temp (°C)							
	0	5	10	15	20	25	30	35
Dissolved oxygen	14.5	12.7	11.2	10.1	9.1	8.3	7.5	6.8

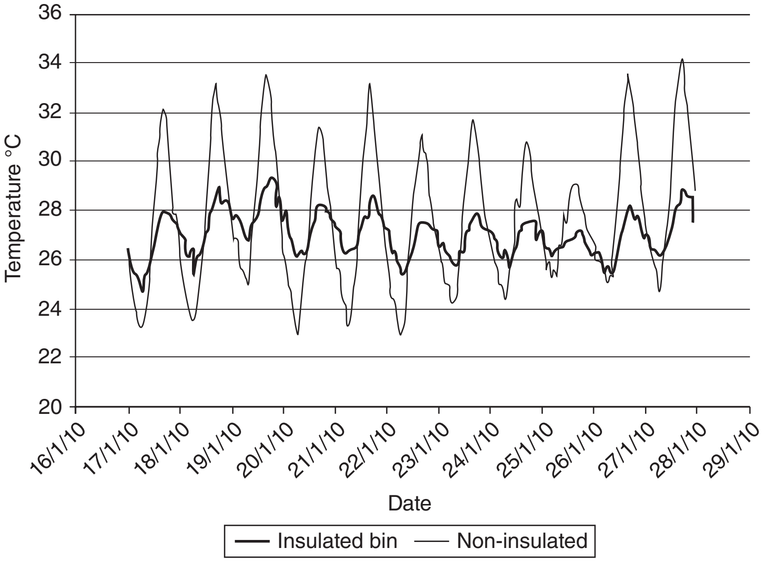

Fig. 3.6. Diurnal fluctuations of the temperature of nutrient solution as affected by increasing reflectivity of piping and insulation of the nutrient reservoir in the tropical summer of Rockhampton, Australia (Latitude 23.37 S). (From Midmore *et al.*, 2011.)

greater surface for aeration. Essentially DRF is a modified nutrient film technique (NFT) system (Cooper, 1979). The NFT system is one where roots are bare and bathed in a thin-film solution that flows under gravity through PVC channels along a gradient of 1:40–1:80, with some physical structure to provide support for the transplanted seedlings and aerial stems. The DRF also uses an aspirator to suck air into the solution and an air space is established between a panel supporting plants and the ridge culture bed. It is the development of 'aeroroots' in the air space that offsets the low dissolved oxygen in solution, and which allows for successful practical hydroponics in the hot tropics (Kao, 1991). Root activity (as measured by CO_2 release), dissolved oxygen and vegetable crop yields are significantly greater in DRF hydroponics than with NFT when ambient greenhouse temperature range from 30 to 38°C, but are the same as for NFT at 25–30°C.

Low-cost evaporative cooling systems have been developed and are used commercially to cool nutrient solutions in the tropics in Australia, and refrigerant cooling of nutrient solutions is practised in Singapore with aeroponics – the misting of root systems for 10 s every 1 min in heavy-duty polystyrene root chambers. For lettuce, the longer the plants are grown at 20°C root-zone temperature (versus 25–39°C in the Singaporean control) the higher is the production (Qin *et al*., 2002). Higher root zone temperature leads to a decrease in number of root tips, increases in root thickening and a reduction in total mineral accumulation. Higher root conductivity and increased stomatal conductance at the lower root temperature may also be responsible for the greater total mineral accumulation.

Further refinements of hydroponics have occurred since the initial research on commercial hydroponics, especially with the widespread availability of lightweight plastics and then that of NFT in the 1970s. Aggregate hydroponics systems, in which sand or other inert material such as perlite is contained in growing beds, provide somewhat more support for plants than does the NFT system. Bag culture and rock wool culture are drip fed with nutrient solutions in situ on glasshouse floors. More recently rock wool, an inert material manufactured as a spun melt from basaltic rock, has been combined with NFT channels. However, the two issues constraining success in the tropics, the high root temperature and low availability of dissolved oxygen for root respiration, still require research attention. One already mentioned approach, aeroponics (where micro-droplets of solutions are sprayed onto roots in enclosed lightproof spaces), also requires refrigeration of the solution to ensure sufficient dissolved oxygen is in the water. It also requires suitable aerodynamics within the root cavity, such as afforded by an A-frame beneath which roots have increased accessibility to dissolved oxygen in the root zone. However, high-pressure pumps required to pressurize water to deliver 50–500 µm mist or fog solution add to the ambient heat load. A new energy- and heat-efficient alternative is to use the venturi principle (employing Bernouli's Principle) to supply enclosed roots with larger but highly aerated droplets. Called air-dynaponics (by Gregory Chow of Singapore's Ngee Ann Polytechnic – Chow, 2004), air is pumped under low pressure through wider (4 mm) tubing to a narrower (2 mm) nozzle, creating suction in the nozzle, the orifice of which is placed just beneath the solution surface, which forces solution up to the aeroponics roots. Energy costs and heat output are one-tenth those of traditional aeroponics, and solution temperatures are 3–5°C cooler, both making the approach economically viable and technically feasible. Another approach is to introduce air into the irrigation system, again by way of a venturi valve, thus delivering air bubbles and, importantly, oxygen to roots in the hypoxic root environment found in the centre of rock wool (Bhattarai *et al*., 2008). This principle, highly relevant to drip irrigation, is discussed in more detail in Chapter 4. The use of a venturi sidesteps the need for external energy sources, for example for aspirators, in the DRF system.

The simplest hydroponic system, a non-circulating hydroponics based upon the original Gericke system, has also proven its worth in the tropics (Midmore and Wu, 1999). It requires timely management of water levels in enclosed insulated boxes to promote the development of aerial 'oxygen' roots which are found above the solution surface. In the presence of such aerial roots levels of dissolved oxygen can be so low as to be immeasurable, yet crop growth is still vigorous. The system does not require imposed aeration of the nutrient solution and has been adapted in a number of floating hydroponic systems not unlike DRF. Essentially modular in nature, the non-circulating hydroponic system is low cost (e.g. about one-quarter that for a fully automated system). This cost-effectiveness and flexibility in terms of tailoring the system to many vegetable species has led to the creation of small-scale enterprises in developing countries. For example, in urban Vietnam it is possible to purchase the simple box infrastructure, the nutrient solutions, and the seedlings established in returnable and replaceable box lids to satisfy both home production and consumption or for medium-scale commercial enterprise.

A recent extension of the hydroponics principle has been made with the development of aquaponics; that is, the culture not only of plants in nutrient solution but with in-line recirculation linkage with aquaculture too. Credited to the research by Zweig and McLarney at the New Alchemy Institute (Cape Cod, USA) in the 1970s, recent interest has highlighted the nascent commercial opportunities with aquaponics (International Aquaponics Society, 2013), notable in tropical island communities where growth of tilapia and lettuce complement each other. Nevertheless, Roe and Midmore (2008) outline the lack of a current sound scientific basis and the skills sets needed to manage both aquaculture and hydroponics side by side.

3.3.4.4 Organic systems

In both temperate and tropical horticultural production systems, organic practice is fast gaining ground, albeit from a low base. Sales values in the 1990s were seen to increase at annual rates ranging from 20 to 30%. In the first decade of the 2000s global sales of organic food and drink rose from US$23 bn in 2002 to US$38 bn in 2006 (Willer *et al*., 2008) and to $59 bn in 2010 (of which fruit and vegetables contributed 33%), with an annual compound interest growth rate of 10.9% between 2006 and 2010 (Willer and Kilcher, 2011). Significant amounts of organic tropical fruit are marketed from the 190,000 ha under production, with banana comprising the largest commodity group and together with avocado and mango accounting for more than 75% of the acreage. Organic vegetables and root crops are produced globally on 270,000 ha, with Mexico and Brazil contributing one-quarter of that area.

Certified organic farming differs from other practices that claim to be sustainable in that the inputs for organic agriculture are proscribed. Two principles set organic farming aside from conventional farming: the prohibition of soluble mineral inputs and the rejection of agrochemicals for insect, disease and weed control. Nevertheless, the use of the term 'organic' on produce is more a claim as to the production process than the product itself. Organic farming avoids the use of synthetically produced fertilizers, pesticides, growth regulators and genetically modified organisms, and depends upon rotations, crop residues, animal manures, green manures and legumes to maintain soil productivity. To achieve integrated pest management the focus is on biological control and preventative methods to manage insects, weeds and diseases. Organic production systems do allow the use of irrigation and of farming machinery, but with limitations that they do not lead to damage of the environment. Organic systems attempt to integrate economic, environmental and social sustainability, and to deliver ecologically sound, fair and responsible outcomes for present and future generations. There is much debate as to the effectiveness of organic agriculture in underpinning the principles of sustainability, and even more questions are asked of it as a system that will be able to adequately feed and nourish the growing global population (Badgley *et al*., 2007). From a biological perspective, organic agriculture more closely mimics natural ecosystems, with promotion of soil biology for antagonism of soilborne insects and diseases and to make available nutrients for crop growth. Year-round presence of pests in the lowland tropics significantly challenges integrated pest management. Organic agriculture favours restoration of functional evenness in ecosystems among natural enemies, not just species richness, overcoming disrupted evenness that results from pesticide usage (Crowder *et al*., 2010). From a nutrient perspective, once produce is taken away from the farm and sold, nutrients so removed have to be replaced – and deficits are likely particularly for P and K if replacements are not brought back to the farm. Nutrient cycles are not tightly closed; hence nitrogen removed must be replaced by natural deposition, or through associative (e.g. with legumes) or non-associative nitrogen-fixing bacteria, largely in the soil. Natural deposition, depending upon biomass burning, livestock and fertilizer usage, may reach 7–10 kg N ha^{-1} yr^{-1}. Other restorative practices such as the introduction of short-season green manure crops, in particular *Crotalaria juncea* with strong taproots that forage deep in the soil to capture and bring to the surface leached nutrients, can improve the efficiency of nutrient recycling. However, with the exception of nitrogen (they can produce up to 140 kg N ha^{-1} in 9–12 weeks) and solubilizing of P, they do little to bring new nutrient sources to bear on the cropping system (Sanchez, 1999). Organic production systems are, therefore, not unlike shifting cultivation systems in that 'restorative' cropping allows for replenishment of soil nutrients. When external manures or certain allowable materials such as dolomitic limestone, wood ash, dried seaweed and natural rock phosphate are imported to the farm the duration of the restorative period can be reduced. A major drawback with dependency on organic nutrient sources is the unreliable release of nutrients through mineralization at rates that do not necessarily match crop demand (Tinker, 2001). This can led to leaching, particularly of nitrogen, at rates that even exceed those from conventional horticulture. This and other issues such as NH_3 volatilization from surface-applied bulky animal manures mean that it is difficult for organic systems to match nutrient use efficiency of conventional systems, although recently it has been shown that yields in organic systems may be similar to those in conventional agriculture. As an example, sweet pepper yields from a number of studies in temperate and tropical climates show consistency between conventional and organic systems (Table 3.9).

Year-round growing conditions in the lowland tropics lend themselves to organic production systems for annual crops, especially if in-crop rainfall, rather than irrigation, can be sourced to sustain crop growth. Indeed, during hot, wet summers a number of nitrogen-fixing species, such as *Sesbania sesban* and *Crotalaria juncea*,

Table 3.9. Marketable yields of bell pepper across three reported studies in warm to hot conditions comparing organic and conventional production.

	Delate *et al.*, 2008			Chellemi and Rosskopf, 2004	Juroszek and Tsai, 2009
Year	2001	2002	2003		
Conventional	25.6	15.7	11.0	35.8[1]	41.1[2]
Organic	26.9	15.6	18.8	37.0	42.1

[1] Statewide average yield.

[2] Different years, cultivar Andalus.

which are tolerant to monsoonal rains and their attendant waterlogging, are desirable species to rotate with cooler-season vegetable production (Lien, 1995). However, normally the mining of nutrients other than nitrogen requires replenishment, as mentioned earlier, through the application of permitted organic materials.

Where the use of pesticides and inorganic fertilizers in the tropics has ceased, often because of the absence of credit schemes and spiralling oil-associated costs, and the absence of supply (as in Africa), farmers are looking to organic production systems – through the premium prices paid for organic produce – as offering some recompense for any losses of yield. With acceptable certification schemes and well-organized production, marketing and transport ventures, small producers should be able to access markets in developed countries on favourable terms. Opportunities and experience with this are discussed further in Chapter 7.

Organic produce commands a premium in price compared to conventional produce, yet from a sensory perspective (i.e. evaluating visual quality, texture taste and odour) no differences have been found between conventional and organic produce (e.g. with tomato, Zhao *et al.*, 2007), or between organic, hydroponic and conventional (e.g. with lettuce, Murphy *et al.*, 2011). Earlier reviews (e.g. Woese *et al.*, 1997) summarizing many studies in both fruits and vegetables draw a similar conclusion to Zhao *et al.* and Murphy *et al.* This should be no surprise since the ionic form in which plants take up nutrients is identical whether the source is from mineral fertilizers (as in conventional or hydroponic production) or organic sources as in organics. As might be expected, though, nitrate levels are generally lower in organic leaf, root and tuber vegetables as a consequence of lower concentrations in the soil (Lester and Saftner, 2011). Oliveira *et al.* (2013) argue that because organic crops are subjected to a greater degree of mineral stress than conventional systems, fruit size (e.g. of tomato) is reduced and concentrations of vitamin C and phenolic compounds are higher. It is on this basis that organic fruits and vegetables are promoted; since they are not consumed for energy supply, any factor that improves gustative and micronutrient quality is of importance. Organic produce is also promoted on the grounds that it contains no or minimal contamination with pesticides; but nowadays (with the exceptions noted earlier) residue levels are low or mostly below detectable limits in conventional fruit and vegetable produce.

Intensive vegetable production systems, as illustrated earlier (and in Chapter 4) depend upon imports of organic materials, and crops are likely to suffer less from nutrient deficits than may broad-acre organic crops, when compared to their conventional counterparts. Rather than suffering from macronutrient deficiencies, intensive vegetable production (including organic production) may counter-intuitively lead to pollution through the over-use of organic inputs. There are many certification schemes worldwide, 576 in 2013, all loosely abiding by the Common Objectives and Requirements of Organic Standards (COROS) of the International Federation of Organic Agriculture Movements (IFOAM), and for certification purposes the organic inputs (e.g. manure) must in the main be sourced from organic farms. This may create an underlying problem for the expansion of organic vegetable production systems due to the scarcity of such an input. One solution would be to move from a polarized 'organic' versus 'conventional' input perspective of the production system to one that combines the most environmentally friendly practices from both.

3.4 Fruits

Fruit trees (e.g. macadamias), vines (e.g. grapes and strawberries) or simply herbaceous plants (e.g. pineapple) are more permanent fixtures than most vegetable crops, and plantations require meticulous long-term planning in terms of assured supply of natural and human resources. Unless planted at supra-high densities that are subsequently uprooted and thinned out, larger-statured species (particularly tree species) are characterized by inefficient use of land space during establishment years. Intercropping with annual crops in the form of agroforestry offsets this inefficient use of the land resources, and provides income during years of no or low income until a commercial-sized fruit crop is harvested (Awasthi *et al.*, 2009). Intercropping of annuals and perennials is discussed in more detail in Chapters 4 and 5, respectively. The most extreme form of intercropping has already been referred to – in the home garden context, where fruit species are found in the upper storey of the canopy, providing shade and protection to shorter-statured species, protective cover over the soil surface and of course harvestable fruit for home consumption or sale.

Where market demand justifies, fruit trees are planted along field edges, enjoying access to water and nutrients provided to the field crops and creating a favourable microclimate that often enhances water use efficiency of the field crop. In the semi-arid tropics of Africa, species such as jujube (*Ziziphus mauritiana*) and date (*Phoenix dactylifera*) are being trialled for this purpose, but all trees grown on field boundaries may compete for light with the crop close to the field edge.

In the developed world one of the major costs for commercial production of fruit, both temperate and tropical, is the high cost of labour. In some sectors it comprises up to 40% of production costs. Oppressive heat during harvest operations in the tropics reduces manual harvesting efficiency and deters the labour market from taking on such tasks. Mechanization offers a solution to the difficulties with sourcing and retention of staff, and adds benefit from the food-safety perspective (reduced human handling). When linked to sensing technologies that determine overall status of an orchard with respect to harvest readiness (e.g. by unmanned aerial vehicles capturing data across all visible and near-infrared (NIR) spectra), and to measurements of internal quality of individual fruit to suit mechanized harvesting, automated robotic harvesters become a reality. Their use will be accompanied by a concomitant reduction in staff numbers. It is then only a small step towards mechanized and automated pruning and other spatially demanding operations. These and other innovative practices designed to increase whole-of-chain production efficiently are discussed in Chapter 8.

3.5 Seed and Propagation Systems

The propagation of annual horticultural species is quite distinct from that of perennials. They differ in numbers involved, for population densities are generally higher for annuals than for perennials. Clearly, too, the frequency with which fields are planted is greater for annual cropping. Growers of annuals may save their own propagating materials (generally seed, but for some species vegetative propagules) or buy them in, whether as seed, seedlings or vegetative materials. Grower-saved seed tends to predominate in developing countries, in industries that are not geared towards export markets, whereas in developed countries the vast majority of seed is commercially produced and then purchased by growers. Climatic conditions in the warm tropics preclude the saving of seed for a number of temperate vegetable species. For example some species do not flower; the low-temperature vernalization requirement of most Cruciferae, to either initiate flowers or to make plants responsive to inductive photoperiods, is not satisfied due to supra-optimal temperatures, and therefore those species rarely flower. In temperate environments other biennials such as onion and carrot require an additional season after a vernalization of the parent plant in order to flower and for the production of seed. As for the Cruciferae, they too are not vernalized and therefore do not flower in the hot tropics. Seed production of such species is additionally complicated for growers, since these crops are grown for their vegetative product as leafy vegetables, heading vegetables, roots or bulbs, and they are not traditionally grown for seed. Approaches to the production of seed of Chinese cabbage are presented in Box 3.2.

Where seed production is undertaken in the tropics it is generally located in dry temperate environments that discourage disease and favour seed ripening. So too is that of some major vegetatively propagated crops in the tropics, such as the potato where cool, dry growing conditions for the production of seed tubers favour health and vigour of resulting crops (Midmore and Roca, 1992).

It is fortunate for the harvest and reuse of seed by farmers that very few virus diseases are transmitted by seed (some notable exceptions exist, for example the potato spindle tuber viroid of true botanical seed of potato, and mosaic virus of lettuce), but the same is not so for vegetatively propagated species. The relative ease with which growers collect and store vegetatively propagated material (although even this may be problematic if an annual cycle of cropping is all that the climate permits – one crop per year) compared to that of seed (which requires harvesting, cleaning, treatment, packaging and storage) is offset by the predisposition of vegetative propagules to carry over debilitating diseases, not only viruses (e.g. Sweet potato feathery mottle virus) but also bacteria (e.g. *Erwinia carotovora* of potato) and fungi (e.g. *Alternaria solani*, also of potato). The need for disease-free vegetative planting propagules, stored if necessary under suitably cool yet reasonably humid conditions to minimize respiration and moisture loss, has led to intensive efforts in developing countries to establish centralized and usually government sponsored propagation systems in the tropics where they did not exist in the past. Examples are afforded by Bangladesh and India (Scott and Suarez, 2011), and are discussed in Chapter 6. Following government investment in infrastructure, and pending success of the venture, the private sector may then take over responsibility for the delivery of good-quality propagation materials in developing country seed industries. Indeed, good-quality seed is the building block upon which returns to other inputs such as irrigation, fertilizer and labour are optimized – starting with poor-quality

Box 3.2. Seed production in Chinese cabbage

Seed production of any species is favoured by adequate water and nutrients, low humidity and warm temperatures; these underpin production of good-quality, disease-free seed. However, other factors need to be satisfied for the production of seed: conditions suitable for induction and programmable development of flowers, minimal between-plant competition that might reduce resources being allocated to flowers and seeds, presence of pollinating agents and so on. Objective choice of location for seed production should satisfy these requirements.

Chinese cabbage, a species for which production is expanding in the lowland tropics, is a typical quantitative long-day plant; short daylengths in the lowland tropics normally prevent flowering, but cool temperatures (from 1 to 4 weeks with night time at 5–12°C, and ideally 5–8°C) soon after emergence in part replace the long-day (LD) photoperiodic requirement for flowering in temperate cultivars of this species. Such low temperatures are rarely found at altitudes below 800 m in the tropics, but artificial vernalization of seedlings (i.e. subjecting them to low vernalizing temperatures for between 1 and 3 weeks, and subsequent planting out) in the warm tropics will promote flowering, despite the growing environment temperature not dropping to 12°C. Tropical Chinese cabbage cultivars have a less critical low-temperature requirement, and even average temperatures of 17–20°C can effect the vernalization response and induce flowering. Devernalization, the prevention or delay of flower induction after being induced by a low-temperature stimulus (Wiebe, 1990), can occur when temperature, even during one day or night does not drop below 30°C. The warm and humid conditions of much of the lowland tropics favours proliferation of pests and diseases, and a good seed production system requires their adequate control, to which must be added the adoption of seed-drying and storage technologies to overcome the high ambient humidity. For these reasons, most seed of Chinese cabbage, whether tropical or temperate varieties, is produced in temperate environments, and sold between countries. Indeed, seed exports from countries endowed with ideal seed-producing conditions (e.g. the Chiang Mai Province of Thailand) are considerable. Success of attempts to commercially produce seeds of Chinese cabbage and other vegetable species in regions and countries less well-endowed with suitable environmental conditions for seed production would be subject to the forces of economics and to the availability or lack of foreign exchange for seed purchase from elsewhere.

seed constrains such returns. Even in developed countries such as Australia, government investment in the delivery of virus-free propagating materials such as the slips or vines of sweet potato has been shown to be necessary as the basis for a profitable and sustainable commodity industry, as exists in the USA (Ling *et al*., 2010).

The extent of government and private sector investment in the horticultural seed industry is linked to the government policy for agricultural development, whether nationally, regionally or even common to groups of countries such as the Asia and Pacific Seed Association. For example, regional companies such as the Known-You Seed Company and the East–West Seed Group span a number of South-east Asian countries engaged in seed production and trade. The policy may be to promote self-sufficiency in seed production, avoidance of costly import of seed and planting materials, and even establishment of a healthy seed export business, as has happened in Chile.

This was underpinned by international investment, given that Chile is a UPOV (International Union for the Protection of New Varieties of Plants; acronym in French) member providing plant breeding companies with the security that all their intellectual property (IP) rights are protected (Gutiérrez, 1991).

Just as a healthy seed industry is essential for a prosperous vegetable industry, so too is a vibrant seedling industry. Greenhouse and hydroponic vegetable and flower crops, small-seeded species and those for which gaps in crop establishment are not tolerated, are more likely to be established as seedlings rather than as direct-seeded crops. The seedlings are raised by entities that are specialized and often separate from the horticultural crop producer. Besides enhancing establishment, crop competition with weeds in the field is improved by the use of seedlings and the period for capture of solar radiation is lengthened compared to crops direct sown at the same time in the field, thereby improving potential yield.

As mentioned before, most of the perennial horticultural species are fruits. Some, such as the papaya, are normally grown directly from seed; others, indeed the majority, are scions taken from selected clones and grafted on to rootstocks of the same or related species. Rootstocks will have been selected for tolerance, usually to rootborne biotic or abiotic stresses, or (as in lime or lemon rootstocks for sweet orange) for their conditioning influence upon canopy size and earliness of cropping (Bitters, 1950). The rootstocks themselves have to be propagated and this normally is by way of direct sowing of seeds, as for mango and sapodilla (*Manilkara zapotilla*). Propagation by the rooting of stem cuttings may offer benefits in terms of genetic homogeneity among propagules. As experimentally trialled with papaya, yield benefits of 30% compared to seed-propagated crops accrue from using *in vitro* clonally propagated hermaphrodites (saving interplant competition and labour as up to five seedlings may be planted per hill and later thinned to one hermaphrodite – Fitch *et al*., 2005). However, seed propagation of papaya still remains a cheaper option than rooted cuttings or micropropagated plants, by a factor of four. Yet other species may be propagated through the layering of branches. Layering is the laying down of young wood, covered with soil, that allows root initiation and formation of roots from the cambium zone of the stem and is done in raspberry and blackberry. Marcotting is a variation of layering, sometimes called air-layering, where a receptacle filled with soil or sphagnum moss is retained around an aerial branch, as is done for figs. In both layering and marcotting the stem may be wounded prior to layering, and sugars and auxins concentrate above the wound and promote axillary bud formation. Layering does not offer some of the advantages afforded by choice of suitable seedling rootstocks, and is overall of lesser importance than grafting in commercial horticulture. *Passiflora edulis*, the passion fruit, is a species that can be readily propagated by all four methods: by seed, by stem cuttings, by air-layering and by grafting to rootstock selections. Hybrid passion fruit cultivars are often grafted on to rootstocks tolerant to *Fusarium* wilt. Mango is also easily propagated by all four practices. However, rootstocks from poly-embryonic seed are favoured over mono-embryonic cultivars because of their genetic uniformity (nucellar plantlets are derived from maternal tissue, i.e. they are asexual and are 'true to type', and are easily selected in nurseries due to their greater vigour than the zygotic plantlets – Cordeiro *et al*., 2006). Mono-embryonic cultivars, when used as rootstocks, can only be propagated vegetatively because rootstocks vary considerably. For avocado, cuttings and air-layering are not favoured;

rather, a double grafting method is employed starting with a large-seeded rootstock to which a scion of the cultivar is grafted to act as the rootstock. Adventitious roots are then induced on the scion which, once rooted, acts as the rootstock clone. Some applications for grafting technology in annual horticultural cropping, mainly vegetables, are presented in Chapter 4.

The range of perennial species for which tissue culture is employed in their propagation has expanded considerably over the past two decades. Because repeated soil-based propagation from cuttings, bulbs, corms or tubers leads to build-up of plant pathogens, aseptic tissue culture (whether on a solid or liquid medium) has been developed to obviate much of this contamination. Proliferation of shoots or buds from pathogen-free shoot tips under aseptic conditions, and subsequent manipulation of plant growth regulators to promote root development, form the basis of large-scale disease-free horticultural enterprises, among which are tropical banana plantations. One successful example is found in the highlands of Mindanao, the Philippines, where by using tissue culture a local university underpinned the expansion of local cultivar Saba from 75 ha in 1 year to nearly 500 in the following year. Two multinational companies, one certified by the New York-based Rainforest Alliance, expanded production from a negligible base to over 1000 ha in the space of 5 years. This practice is successful provided somaclonal variants, which are not true to type, are in low proportions and are screened out. In Taiwan, the 3% of banana variants that do escape detection until planting out in the field (Lee, 2003) are replaced with an additional 3% supply of propagules to growers. It is now possible to commercially source disease-free planting stock of species such as strawberry, citrus and pineapple. The practice of *in vitro* propagation is also favoured in the floriculture industry, where rates of propagation (e.g. 30–40 per parent plant per year for *Gerbera*) are well exceeded by tissue culture by up to 5000 times (Kanwar and Kumar, 2008), and it is routinely used in the micropropagation of orchids (e.g. *Dendrobium, Oncidium*) and roses.

Innovative micropropagation systems, for example with the aeroponic production of potato mini-tubers, have been researched to improve upon both resource use efficiency and phytosanitary health of the vegetative propagation materials. Chiipanthenga *et al.* (2012) have reviewed the procedures involved in aeroponic minituber production. Numbers produced in warm climates (such as in Malawi) reach 300–400 m^{-2} of 12–15 g mini-tubers, compared to close to double in cooler climates (e.g. *c.*800 m^{-2} in Germany – Abdullateef *et al.*, 2012). Other approaches use a combination of tissue culture-raised plants which provide for rooted cuttings, again in potato, as evidenced commercially in the Dalat region of Vietnam (Van Uyen and Vander Zaag, 1987).

This chapter has provided an overview of the diversity of tropical horticultural production systems, ranging from subsistence through home gardens to semi-intensive and very intensive systems, and has linked the production systems to the typologies of species according to their perishability. It is within this framework of production systems that the following chapter addresses management of the major inputs to, and constraints that govern, the production of vegetables within the tropics. This is followed by Chapter 5 with a similar analysis for tropical fruit and flower production.

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