6. Plants in aquaponics

This chapter discusses the theory and practice needed for successful plant production in aquaponic systems. First, it highlights some of the major differences between ground-grown crop production and soil-less crop production. Following this, there is a discussion on some essential plant biology and plant nutrition concepts, focusing on the most important aspects for aquaponics. After, there is a brief section on recommendations for selecting vegetables to grow in aquaponic units. The final two sections cover plant health, methods to maintain plant health, and some advice on how to make the most of the plant growing space.

In many commercial aquaponic ventures, the vegetable production is more profitable than the fish. However, there are exceptions, and some farmers earn more from particularly valuable fish. Estimates from commercial aquaponic units predominantly in the West suggest that up to 90 percent of the financial gains can come from plant production. One reason is the fast turnover rate of vegetables compared with the fish.

Further information on aquaponic plant production is covered in Chapter 8 and in the appendixes. Chapter 8 discusses practices to manage plant production through the seasons, and discusses different approaches for each of the hydroponic methods (media bed, NFT and DWC). Appendix 1 is a technical description of 12 popular vegetables to grow in aquaponics; Appendix 2 contains descriptions and tables detailing several organic treatments of pests and diseases.

6.1 MAJOR DIFFERENCES BETWEEN SOIL AND SOIL-LESS CROP PRODUCTION

There are many similarities between in-ground soil-based agriculture and soil-less production, while the basic plant biology is always the same (Figures 6.1 and 6.2). However it is worth investigating major differences between soil and soil-less production (Table 6.1) in order to bridge the gap between traditional in-ground practices and newer soil-less techniques. Generally, the differences are between the use of fertilizer and consumption of water, the ability to use non-arable land, and overall productivity. In addition, soil-less agriculture is typically less labour-intensive. Finally, soil-less techniques support monocultures better than does in-ground agriculture.

FIGURE 6.1
Tomatoes (*Solanum* sp.) growing in soil

FIGURE 6.2
Swiss chard (*Beta* sp.) growing in an aquaponic system

6.1.1 Fertilizer

Soil chemistry, especially relating to the availability of nutrients and the dynamics of fertilizers, is a full discipline and fairly complex. Fertilizer addition is required for intensive in-ground cultivation. However, farmers cannot fully control the delivery of these nutrients to plants because of the complex processes occurring in the soil, including biotic and abiotic interactions. The sum of these interactions determines the availability of the nutrients to the plant roots. Conversely, in soil-less culture, the nutrients are dissolved in a solution that is delivered directly to the plants, and can be tailored specifically to plants' needs. Plants in soil-less culture grow in contained inert media. These media do not interfere with the delivery of nutrients, which can occur in soil. In addition, the media physically support the plants and keep the roots wet and aerated. Moreover, with in-ground agriculture, some of the fertilizer may be lost to weeds and runoff, which can decrease efficiency while causing environmental concerns. Fertilizer is expensive and can make up a large part of the budget for in-ground farming.

The tailored management of fertilizer in soil-less agriculture has two main advantages. First, minimal fertilizer is lost to chemical, biological or physical processes. These losses decrease efficiency and can add to the cost. Second, the nutrient concentrations can be precisely monitored and adjusted according to the requirements of the plants at particular growth stages. This increased control can improve productivity and enhance the quality of the products.

6.1.2 Water use

Water use in hydroponics and aquaponics is much lower than in soil production. Water is lost from in-ground agriculture through evaporation from the surface, transpiration through the leaves, percolation into the subsoil, runoff and weed growth. However, in soil-less culture, the only water use is through crop growth and transpiration through the leaves. The water used is the absolute minimum needed to grow the plants, and only a negligible amount of water is lost for evaporation from the soil-less media. Overall, aquaponics uses only about 10 percent of the water needed to grow the same plant in soil. Thus, soil-less cultivation has great potential to allow production where water is scarce or expensive.

6.1.3 Utilization of non-arable land

Owing to the fact that soil is not needed, soil-less culture methods can be used in areas with non-arable land. One common place for aquaponics is in urban and peri-urban areas that cannot support traditional soil agriculture. Aquaponics can be used on the ground floor, in basements (using grow lights) or on rooftops. Urban-based agriculture can also reduce the production footprint because transport needs are greatly reduced; urban agriculture is local agriculture and contributes to the local economy and local food security. Another important application for aquaponics is in other areas where traditional agriculture cannot be employed, such as in areas that are extremely dry (e.g. deserts and other arid climates), where the soil has high salinity (e.g. costal and estuarine areas or coral sand islands), where the soil quality has been degraded through over-use of fertilizers or lost because of erosion or mining, or in general where arable land is unavailable owing to tenure, purchase costs and land rights. Globally, the arable land suitable for farming is decreasing, and aquaponics is one method that allows people to intensively grow food where in-ground agriculture is difficult or impossible.

6.1.4 Productivity and yield

The most intensive hydroponic culture can achieve 20–25 percent higher yields than the most intensive soil-based culture, although rounded down data by hydroponic experts claim productivity 2–5 times higher. This is when hydroponic culture uses exhaustive greenhouse management, including expensive inputs to sterilize and fertilize the plants. Even without the expensive inputs, the aquaponic techniques described in this publication can equal hydroponic yields and be more productive than soil. The main reason is the fact that soil-less culture allows the farmer to monitor, maintain and adjust the growing conditions for the plants, ensuring optimal real-time nutrient balances, water delivery, pH and temperature. In addition, in soil-less culture, there is no competition with weeds and plant benefit from higher control of pests and diseases.

6.1.5 Reduced workload

Soil-less culture does not require ploughing, tilling, mulching or weeding. On large farms, this equates to lower reliance on agriculture machinery and fossil fuel usage. In small-scale agriculture, this equates to an easier, less labour-intensive exercise for the farmer, especially because most aquaponic units are raised off the ground, which avoids stooping. Harvesting is also a simple procedure compared with soil-based agriculture, and products do not need extensive cleaning to remove soil contamination. Aquaponics is suitable for any gender and many age classes and ability levels of people.

6.1.6 Sustainable monoculture

With soil-less culture, it is entirely possible to grow the same crops in monoculture, year after year. In-ground monocultures are more challenging because the soil becomes “tired”, loses fertility, and pests and diseases increase. In soil-less culture, there is simply no soil to lose fertility or show tiredness, and all the biotic and abiotic factors that prevent monoculture are controlled. However, all monocultures require a higher degree of attention to control epidemics compared with polyculture.

6.1.7 Increased complication and high initial investment

The labour required for the initial set-up and installation, as well as the cost, can discourage farmers from adopting soil-less culture. Aquaponics is also more expensive than hydroponics because the plant production units need to be supported by aquaculture installations. Aquaponics is a fairly complex system and requires daily management of three groups of organisms. If any one part of the system fails, the entire system can collapse. In addition, aquaponics requires reliable electricity. Overall, aquaponics is far more complicated than soil-based gardening. Once people are familiar with the process, aquaponics becomes very simple and the daily management becomes easier. There is a learning curve, as with many new technologies, and any new aquaponic farmer needs to be dedicated to learn. Aquaponics is not appropriate for every situation, and the benefits should be weighed against the costs before embarking on any new venture.

TABLE 6.1
Summary table comparing soil-based and soil-less plant production

Category		Soil-based	Soil-less
Production	Yield	Variable, depending on soil characteristics and management.	Very high with dense crop production.
	Production quality	Dependent on soil characteristics and management. Products can be of lower quality due to inadequate fertilization/ treatments.	Full control over delivery of appropriate nutrients at different plant growth stages. Removal of environmental, biotic and abiotic factors that impair plant growth in soil (soil structure, soil chemistry, pathogens, pests).
	Sanitation	Risk of contamination due to use of low quality water and/or use of contaminated organic matter as fertilizer.	Minimal risk of contamination for human health.
Nutrition	Nutrient delivery	High variability depending on the soil characteristics and structure. Difficult to control the levels of nutrients at the root zone.	Real time control of nutrients and pH to plants at the root zone. Homogeneous and accurate supply of nutrients according to plants’ growth stages. Needs monitoring and expertise.
	Nutrient use efficiency	Fertilizers widely distributed with minimum control of nutrients according to growth stage. Potentially high nutrient loss due to leaching and runoff.	Minimal amount used. Uniform distribution and real time adjustable flow of nutrients. No leaching.

TABLE 6.1 (CONTINUED)

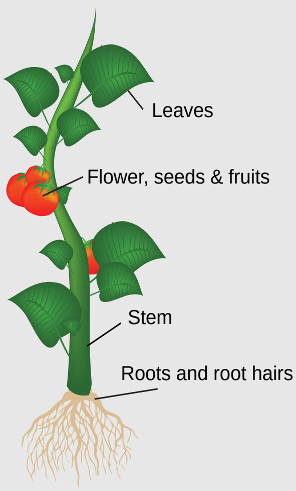
Category		Soil-based	Soil-less
Water use	System efficiency	Very sensitive to soil characteristics, possible water stress in plants, high dispersal of nutrients.	Maximized, all water loss can be avoided. Supply of water can be fully controlled by sensors. No labour costs for watering, but higher investment.
	Salinity	Susceptible to salt build up, depending on soil and water characteristics. Flushing salt out uses large amounts of water.	Depends on soil and water characteristics. Can use saline water, but needs salt flush-out that requires higher volumes of water.
Management	Labour and equipment	Standard, but machines are needed for soil treatment (ploughing) and harvesting which rely on fossil fuels. More manpower needed for operations.	Expertise and daily monitoring using relatively costly equipment are both essential. High initial set-up costs. Simpler handling operations for harvest.

6.2 BASIC PLANT BIOLOGY

This section comments briefly on the major parts of the plant and then discusses plant nutrition (Figure 6.3). Further discussion is outside the scope of this publication, but more information can be found in the section on Further Reading.

6.2.1 Basic plant anatomy and function

FIGURE 6.3
Illustration of the basic plant structures



Roots

Roots absorb water and minerals from the soil. Tiny root hairs stick out of the root, helping the absorption process. Roots help to anchor the plant in the soil, preventing it from falling over. Roots also store extra food for future use. Roots in soil-less culture show interesting differences from standard in-ground plants. In soil-less culture, water and nutrients are constantly supplied to the plants, which are facilitated in their nutrient search and can grow faster. Root growth in hydroponics can be significant for the intense uptake and the optimal delivery of phosphorus that stimulates their growth. It is worth noting that roots retain almost 90 percent of the metals absorbed by the plants, which include iron, zinc and other useful micronutrients.

Stems

Stems are the main support structure of the plant. They also act as the plant's plumbing system, conducting water and nutrients from the roots to other parts of the plant, while also transporting food from the leaves to other areas. Stems can be herbaceous, like the bendable stem of a daisy, or woody, like the trunk of an oak tree.

Leaves

Most of the food in a plant is produced in the leaves. Leaves are designed to capture sunlight, which the plant then uses to make food through a process called photosynthesis. Leaves are also important for the transpiration of water.

Flowers

Flowers are the reproductive part of most plants. Flowers contain pollen and tiny eggs called ovules. After pollination of the flower and fertilization of the ovule, the ovule develops into a fruit. In soil-less techniques, the prompt delivery of potassium before flowering can help plants to have better fruit settings.

Fruit/seeds

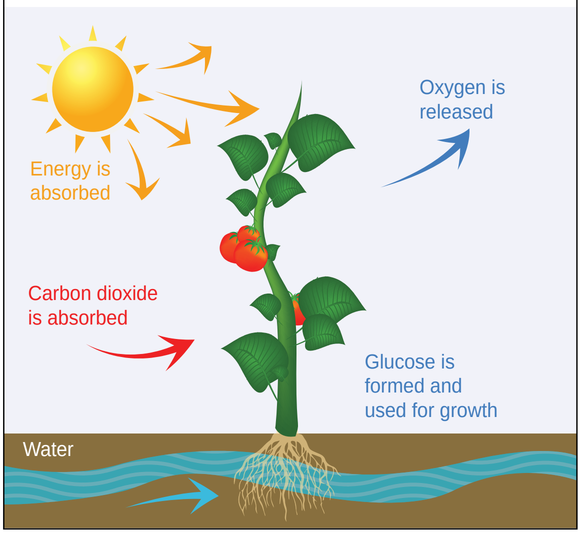
Fruits are developed parts of flower ovaries that contain seeds. Fruits include apples, lemons, and pomegranates, but also include tomatoes, eggplants, corn kernels and cucumbers. The latter are considered fruits in a botanical sense because they contain seeds, though in a culinary definition they are often referred to as vegetables. Seeds are the reproductive structures of plants, and fruits serve to help disseminate these seeds. Fruiting plants have different nutrient requirements than leafy green vegetables, especially requiring more potassium and phosphorous.

6.2.2 Photosynthesis

All green plants are designed to generate their own food using the process of photosynthesis (Figure 6.4). Photosynthesis requires oxygen, carbon dioxide, water and light. Within the plant are small organelles called chloroplasts that contain chlorophyll, an enzyme that uses the energy from sunlight to break apart atmospheric carbon dioxide (CO_2) and create high-energy sugar molecules such as glucose. Essential to this process is water (H_2O). This process releases oxygen (O_2), and is historically responsible for all of the oxygen in the atmosphere. Once created, the sugar molecules are transported throughout the plant and used later for all of the physiological processes such as growth, reproduction and metabolism. At night, plants use these same sugars, as well as oxygen, to generate the energy needed for growth. This process is called respiration.

It is vital to locate an aquaponic unit in a place where each plant will have access to sunlight. This ensures adequate energy for photosynthesis. Water should always be available to the roots through the system. Carbon dioxide is freely available from the atmosphere, although in very intensive indoor culture it is possible that plants use all of the carbon dioxide in the enclosed area and require ventilation.

FIGURE 6.4
The photosynthesis process



6.2.3 Nutrient requirements

In addition to these basic requirements for photosynthesis, plants need a number of nutrients, also referred to as inorganic salts. These nutrients are required for the enzymes that facilitate photosynthesis, for growth and reproduction. These nutrients can be sourced from the soil. However, in the absence of soil, these nutrients need to be supplied another way. In aquaponics, all of these essential nutrients come from the fish waste.

There are two major categories of nutrients: macronutrients and micronutrients. Both types of nutrient are essential for plants, but in differing amounts. Much larger quantities of the six macronutrients are needed compared with the micronutrients, which are only needed in trace amounts. Although all of these nutrients exist in solid fish waste, some nutrients may be limited in quantity in aquaponics and result in deficiencies, e.g. potassium, calcium and iron. A basic understanding of the function of each nutrient is important to appreciate how they affect plant growth. If nutrient deficiencies occur, it is important to identify which element is absent or lacking in the system and adjust the system accordingly by adding supplemental fertilizer or increasing mineralization.

Macronutrients

There are six nutrients that plants need in relatively large amounts. These nutrients are nitrogen, phosphorous, potassium, calcium, magnesium and sulphur. The following discussion outlines the function of these macronutrients within the plant. Symptoms of deficiencies are also listed in order to help identify problems.

Nitrogen (N) is the basis of all proteins. It is essential for building structures, photosynthesis, cell growth, metabolic processes and the production of chlorophyll. As such, nitrogen is the most common element in a plant after carbon and oxygen, both of which are obtained from the air. Nitrogen is therefore the key element in the aquaponic nutrient solution and serves as an easy-to-measure proxy indicator for other nutrients. Usually, dissolved nitrogen is in the form of nitrate, but plants can utilize moderate quantities of ammonia and even free amino acids to enable their growth. Nitrogen deficiencies are obvious, and include yellowing of older leaves, thin stems, and poor vigour (Figure 6.5a). Nitrogen can be reallocated within plant tissues and therefore is mobilized from older leaves and delivered to new growth, which is why deficiencies are seen in older growth. An overabundance of nitrogen can cause excess vegetative growth, resulting in lush, soft plants susceptible to disease and insect damage, as well as causing difficulties in flower and fruit set.

Phosphorus (P) is used by plants as the backbone of DNA (deoxyribonucleic acid), as a structural component of phospholipid membranes, and as adenosine triphosphate (the component to store energy in the cells). It is essential for photosynthesis, as well as the formation of oils and sugars. It encourages germination and root development in seedlings. Phosphorous deficiencies commonly cause poor root development because energy cannot be properly transported through the plant; older leaves appear dull green or even purplish brown, and leaf tips appear burnt.

Potassium (K) is used for cell signalling via controlled ion flow through membranes. Potassium also controls stomatic opening, and is involved in flower and fruit set. It is involved in the production and transportation of sugars, water uptake, disease resistance and the ripening of fruits. Potassium deficiency manifests as burned spots on older leaves and poor plant vigour and turgor (Figure 6.5b). Without potassium, flowers and fruits will not develop correctly. Interveinal chlorosis, or yellowing between the veins of the leaves, may be seen on the margins.

Calcium (Ca) is used as a structural component of both cell walls and cell membranes. It is involved in strengthening stems, and contributes to root development. Deficiencies are common in hydroponics and are always apparent in the newest growth because calcium is immobile within the plant. Tip burn of lettuces and blossom-end rot of tomatoes and zucchinis are examples of deficiency. Often, new leaves are distorted with hooked tips and irregular shapes. Calcium can only be transported through active xylem transpiration, so when conditions are too humid, calcium can be available but locked-out because the plants are not transpiring. Increasing air flow with vents or fans can prevent this problem. The addition of coral sand or calcium carbonate can be used to supplement calcium in aquaponics with the added benefit of buffering pH.

Magnesium (Mg) is the centre electron acceptor in chlorophyll molecules and is a key element in photosynthesis. Deficiencies can be seen as yellowing of leaves between the veins especially in older parts of the plant. Although the concentration of magnesium is sometimes low in aquaponics, it does not appear to be a limiting nutrient, and addition of magnesium to the system is generally unnecessary.

Sulphur (S) is essential to the production of some proteins, including chlorophyll and other photosynthetic enzymes. The amino acids methionine and cysteine both contain sulphur, which contributes to some proteins' tertiary structure. Deficiencies are rare, but include general yellowing of the entire foliage in new growth (Figure 6.5c). Leaves may become yellow, stiff and brittle, and fall off.

Micronutrients

Below is a list of nutrients that are only needed in trace amounts. Most micronutrient deficiencies involve yellowing of the leaves (such as iron, manganese, molybdenum and zinc). However, copper deficiencies cause leaves to darken their green colour.

Iron (Fe) is used in chloroplasts and the electron transport chain, and is critical for proper photosynthesis. Deficiencies are seen as intervenous yellowing, followed by the entire foliage turning pale yellow (chlorotic) and eventually white with necrotic patches and distorted leaf margins. As iron is a non-movable element, iron deficiencies (Figure 6.5d) are easily identified if new leaves appear chlorotic. Iron has to be added as chelated iron, otherwise known as sequestered iron or Fe*EDTA, because iron is apt to precipitate at pH greater than 7. The suggested addition is 5 millilitres per 1 m^2 of grow bed whenever deficiencies are suspected; a larger quantity does not harm the system, but can cause discolouration of tanks and pipes. It has been suggested that submerged magnetic-drive pumps can sequester iron and is the subject of current research.

Manganese (Mg) is used to catalyse the splitting of water during photosynthesis, and as such, manganese is important to the entire photosynthesis system. Deficiencies manifest as reduced growth rates, a dull grey appearance and intervenous yellowing between veins that remain green, followed by necrosis. Symptoms are similar to iron deficiencies and include chlorosis. Manganese uptake is very poor at pH greater than 8.

Boron (B) is used as a sort of molecular catalyst, especially involved in structural polysaccharides and glycoproteins, carbohydrate transport, and regulation of some metabolic pathways in plants. It is also involved in reproduction and water uptake by cells. Deficiencies may be seen as incomplete bud development and flower set, growth interruption and tip necrosis, and stem and root necrosis.

Zinc (Zn) is used by enzymes and also in chlorophyll, affecting overall plant size, growth and maturation. Deficiencies may be noticed as poor vigour, stunted growth with reduced inter-nodal length and leaf size, and intravenous chlorosis that may be confused with other deficiencies.

Copper (Cu) is used by some enzymes, especially in reproduction. It also helps strengthen stems. Deficiencies may include chlorosis and brown or orange leaf tips, reduced growth of fruits, and necrosis. Sometimes, copper deficiency shows as abnormally dark green growth.

Molybdenum (Mo) is used by plants to catalyse redox reactions with different forms of nitrogen. Without sufficient molybdenum, plants can show symptoms of nitrogen deficiency although nitrogen is present. Molybdenum is biologically unavailable at pH less than 5.

FIGURE 6.5
Nitrogen deficiency visible in the pale older leaves (a); potassium deficiency visible as brown spots on the leaf margin (b); sulphur deficiency visible in the curled leaves and yellowing (c); and iron deficiency visible in the overall pale green colour of the mint plant (d)

The availability of many of these nutrients depends on the pH (see Section 6.4 for pH-dependent availability), and although the nutrients may be present they may be unusable because of the water quality. For further details on nutrient deficiencies outside the scope of this publication, please refer to the section on Further Reading for illustrated identification guides.

6.2.4 Aquaponic sources of nutrients

Nitrogen is supplied to aquaponic plants mainly in the form of nitrate, converted from the ammonia of fish waste through bacterial nitrification. Some of the other nutrients are dissolved in the water from the fish waste, but most remain in a solid state that is unavailable to plants. The solid fish waste is broken down by heterotrophic bacteria; this action releases the essential nutrients into the water. The best way to ensure that plants do not suffer from deficiencies is to maintain the optimum water pH (6–7) and feed the fish a balanced and complete diet, and use the feed rate ratio to balance the amount of fish feed to plants. However, over time, even an aquaponic system that is perfectly balanced may become deficient in certain nutrients, most often iron potassium or calcium.

Deficiencies in these nutrients are a result of the composition of the fish feed. Fish feed pellets (discussed in Chapter 7) are a complete food for the fish, meaning they provide everything that a fish needs to grow, but not necessarily everything needed for plant growth. Fish simply do not need the same amounts of iron, potassium and calcium that plants require. As such, deficiencies in these nutrients may occur. This can be problematic for plant production, yet there are solutions available to ensure appropriate amounts of these three elements.

In general, iron is regularly added as chelated iron in the aquaponic system to reach concentrations of about 2 mg/litre. Calcium and potassium are added when buffering the water to the correct the pH, as nitrification is an acidifying process. These are added as calcium hydroxide or potassium hydroxide, or as calcium carbonate and potassium carbonate (see Chapter 3 for more details). The choice of the buffer can be chosen based on the plant type being cultivated, as leafy vegetables may need more calcium, and fruiting plants more potassium. In addition, Chapter 9 discusses how to produce simple organic fertilizers from compost to use as supplements to the fish waste, ensuring that the plants are always receiving the right amount of nutrients.

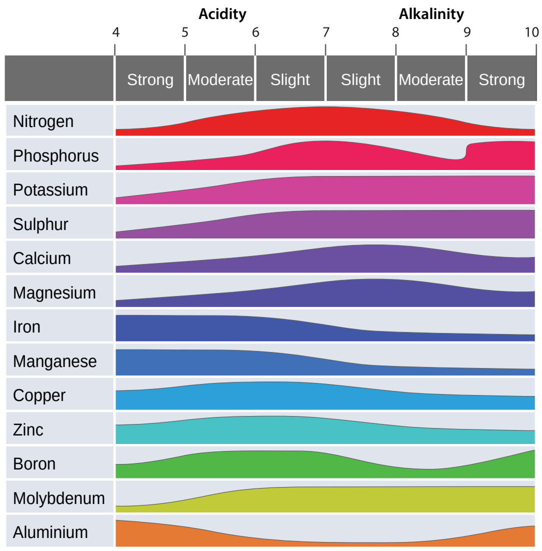
6.3 WATER QUALITY FOR PLANTS

Section 3.3 discussed water quality parameters for the aquaponic system as a whole. Here specific considerations for plants are considered and further expanded.

6.3.1 pH

The pH is the most important parameter for plants in an aquaponic system because it influences a plant's access to nutrients. In general, the tolerance range for most plants is 5.5–7.5. The lower range is below the tolerance for fish and bacteria, and most plants prefer mildly acidic conditions. If the pH goes outside of this range, plants experience nutrient lockout, which means that although the nutrients are present in the water the plants are unable to use them. This is especially true for iron, calcium and magnesium. Sometimes, apparent nutrient deficiencies in plants actually indicate that the pH of the system is outside the optimal range. Figure 6.6 describes the relationship between pH level and the ability for plants to take-up certain nutrients.

FIGURE 6.6
The impact of pH on nutrient availability for plants



However, there is evidence that nutrient lockout is less common in mature aquaponic systems than in hydroponics. Whereas hydroponics is a semi-sterile undertaking, aquaponics is an entire ecosystem. As such, there are biological interactions occurring between the plant roots, bacteria and fungi that may allow nutrient uptake even at higher pH levels than those shown in Figure 6.6. However, the best course of action is to attempt to maintain pH slightly acidic (6–7), but understand that higher pH (7–8) may function. This aspect is the subject of current research.

6.3.2 Dissolved oxygen

Most plants need high levels of DO (> 3 mg/litre) within the water. Plants use their stems and leaves to absorb oxygen during respiration, but the roots also need to have oxygen. Without oxygen, the plants can experience root-rot, a situation where the roots die and fungus grows. Some water plants, such as water chestnut, lotus or taro, do not need high levels of DO and can withstand low-oxygen waters such as those in stagnant ponds.

6.3.3 Temperature and season

The suitable temperature range for most vegetables is 18–30 °C. However, some vegetables are far more suited to growing in particular conditions. For the purposes of this publication, winter vegetables require temperatures of 8–20 °C, and summer vegetables require temperatures of 17–30 °C. For example, many leafy green vegetables grow best in cooler conditions (14–20 °C), especially at night. In higher temperatures of 26 °C and above, leafy greens bolt and begin to flower and seed, which makes them bitter and unmarketable. Generally, it is the water temperature that has the greatest effect on the plants rather than the air temperature. Nevertheless, care should be taken in the correct choice of plants and fish to meet their optimal water temperature ranges. Another aspect of seasonal planting is that some plants require a certain amount of daylight to produce flowers and fruit, which is called photoperiodism. Some, referred to as short-day plants, require a certain amount of darkness before flowering. This signal to the plant indicates that winter is approaching, and the plant puts its energy into reproduction instead of growth. Some commonly grown, short-day plants include varieties of peppers and certain medicinal flowers. On the other hand, long-day plants require a certain day length before producing flowers, although this is rarely a consideration in vegetables but may be so for some ornamentals. As such, it is important to follow the local seasonal planting practices for each vegetable grown or to choose varieties that are neutral to photoperiodism. Appendix 1 contains further details on individual vegetables.

6.3.4 Ammonia, nitrite and nitrate

As explained in Chapter 2, plants are able to take up all three forms of nitrogen, but nitrate is the most accessible. Ammonia and nitrite are very toxic to fish and should always be maintained below 1 mg/litre. In a functioning aquaponic unit, ammonia and nitrite are always 0–1 mg/litre and should not be a problem for the plants.

6.4 PLANT SELECTION

To date, more than 150 different vegetables, herbs, flowers and small trees have been grown successfully in aquaponic systems, including research, domestic and commercial units. Appendix 1 provides a technical summary of, and detailed growing instructions for, the 12 most popular herbs and vegetables. In general, leafy green plants do extremely well in aquaponics along with some of the most popular fruiting vegetables, including tomatoes, cucumbers and peppers. Fruiting vegetables have higher nutrient demands and are more appropriate for established systems with adequate fish stocks. However, some root crops and some sensitive plants do not grow well in aquaponics. Root crops require special attention, and they can only be grown successfully in deep media beds, or a version of wicking beds discussed in more detail in Section 9.3.

Vegetables vary regarding their overall nutrient demand. There are two general categories of aquaponic plants based on this demand. Low-nutrient-demand plants include the leafy greens and herbs, such as lettuce, chard, salad rocket, basil, mint, parsley, coriander, chives, pak choi and watercress. Many of the legumes such as peas and beans also have low-nutrient demands. At the other end of the spectrum are plants with high-nutrient demand, sometimes referred to as nutrient hungry. These include the botanical fruits, such as tomatoes, eggplants, cucumbers, zucchini, strawberries and peppers. Other plants with medium nutrient demands are: cabbages, such as kale, cauliflower, broccoli and kohlrab. Bulbing plants such as beets, taro, onions and carrots have medium to high requierements, while radish requires less nutrients.

The style of grow bed influences the choice of plants. In media bed units, it is common practice to grow a polyculture of leafy greens, herbs and fruiting vegetables at the same time (Figure 6.7). Provided media bed units are the right depth (at least 30 cm), it is possible to grow all the vegetables mentioned in the categories above. Polyculture on small surfaces can also take advantage of companion planting (see Appendix 2) and better space management, because shade-tolerant species can grow underneath taller plants. Monoculture practices are more prevalent in commercial NFT and DWC units because the grower is restricted by the number of holes in the pipes and rafts in which to plant vegetables. Using NFT units, it might be possible to grow the larger fruiting vegetables, such as tomatoes, but these plants need to have access to copious amounts of water to secure sufficient supply of nutrients and to avoid water stress. Wilting in fruiting plants can in fact occur almost immediately if the flow is disrupted, with devastating effects on the whole crop. Fruiting plants also need to be planted in larger grow pipes, ideally with flat bottoms, and be positioned over a larger distance than leafy vegetables. This is because fruiting plants grow larger and need more light to ripen their fruits and also because there is limited root space in the pipes. On the other hand, large bulb and/or root crops, such as kohlrabi, carrots and turnips, are more likely to be cultured in media beds because NFT and DWC units do not provide a good growing environment and adequate support to the plants

It is important to consider the effect of harvesting the plants on the entire ecosystem. If all of the plants were to be harvested at once, the result would be an unbalanced system

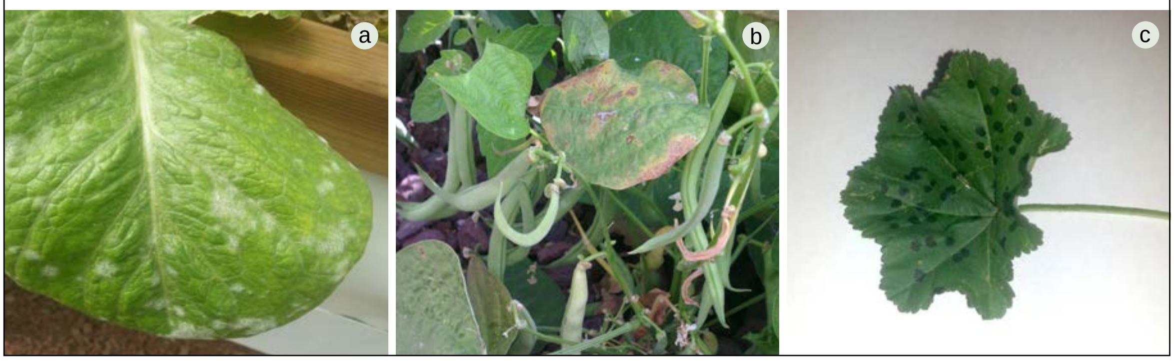
FIGURE 6.7
High nutrient demand vegetables growing in media beds, including eggplants (*Solanum* sp.) (a) and tomatoes (*Solanum* sp.) and cauliflower (*Brassica* sp.) (b)

without enough plants to clean the water, resulting in nutrient spikes. Some farmers use this technique, but it must correspond with a large fish harvest or a reduction of the feed ration. However, the recommendation here is to use a staggered harvesting and replanting cycle. The presence of too many plants growing synchronously would result in the systems being deficient in some nutrients towards the harvest period, when the uptake is at a maximum. By having plants at different life stages, i.e. some seedlings and some mature, the overall nutrient demand is always the same. This ensures more stable water chemistry, and also provides a more regular production both for the home table and the market. Staggered planting schemes are discussed in more detail in Chapter 8.

6.5 PLANT HEALTH, PEST AND DISEASE CONTROL

Plant health has a broad meaning that goes far beyond just the absence of illnesses; it is the overall status of well-being that allows a plant to achieve its full productive potential. Plant health, including disease prevention and pest deterrence and removal, is an extremely important aspect of aquaponic food production (Figure 6.8). Although the most important advances in plant health have been achieved through the management of pathogens and pests, optimal nutrition, intelligent planting techniques and proper environmental management are also fundamental to secure healthy plants. In addition, knowledge on the specific plants grown is fundamental to addressing various production issues. Although some basic concepts on plant nutrition have already been

FIGURE 6.8
Common diseases of plants include mildew caused by a fungus (a); canker/blight caused by bacteria (b); and leaf spots caused by bacteria or fungus (c)



described, this section aims to provide a far greater understanding on how to minimize the risks and to address plant diseases and pests in small-scale aquaponics.

For more information on beneficial insects, including insect characteristics and climatic needs, along with general information on pest identification, as well as integrated pest and disease management (including different products available for treatment), see Appendix 2 and the resources listed in the section on Further Reading.

6.5.1 Plant pests, integrated production and pest management

Insect pests are problematic for plant production because they carry diseases that plants can contract. Pests also extract liquids as they bore into plant tissues, leading to stunted growth. Controlled environments, such as greenhouses, can be particularly problematic for pests because the enclosed space provides favourable conditions for insects without rain or wind. Pest management for outdoor conditions also differs from that in protected cultivation (net houses, greenhouses), due to the physical separation of the plants from the surrounding area, which allows the use of beneficial insects indoor to kill/control the insect pests. Insect pest prevalence is also highly dependent on climate and environment. Pest management in temperate or arid zones is easier than in tropical regions, where higher incidence and competition among insects make pest control a far more difficult task.

As aquaponic units maintain an independent ecosystem, it is normal for a host of micro-organisms and small insects and spiders to exist within the media beds. However, other harmful insect pests, such as whiteflies, thrips, aphids, leaf miners, cabbage moths and spider mites feed upon and damage the plants. A common practice for dealing with problematic insect pests in soil vegetable production is to use chemical pesticides or insecticides, but this is **impossible** in aquaponics. Any strong chemical pesticide could be fatal for fish as well as the beneficial bacteria living in system. Therefore, commercial chemical pesticides must never be used. However, there are other effective physical, environmental and cultural controls to reduce the threat of pests from aquaponics. Insecticides and deterrents should be considered a last resort. Nevertheless, successful management integrates crop and environmental management with the use of organic and biological pest deterrents.

Integrated production and pest management (IPPM) is an ecosystem approach to soil-based and soil-less plant production and protection that combines different management strategies and practices to grow healthy plants and minimize pesticide use. It is a combination of mechanical, physical, chemical, biological and microbial controls along with host-plant resistance and cultural practices. Not all of these controls are applicable for aquaponics as some may be fatal for fish and bacteria (i.e. chemical and some organic pesticides) while others may not be economically justified for small-scale aquaponics (i.e. microbial control agents). Thus, this section concentrates on the most applicable strategies for small-scale aquaponics, including mechanical and physical control, host plant resistance and cultural techniques to prevent the threat of pests and diseases. Some brief comments are given on some aquaponic-safe biological controls (i.e. beneficial insects and microorganisms), and more details are included in Appendix 2. For further information on these methods, see the section on Further Reading.

Physical, mechanical and cultural controls

For pest management in aquaponics, prevention is fundamental. Regular and thorough monitoring for pests is vital, and, ideally, minor infestations can be identified and managed before the insects damage the entire crop. Below is a list of simple inexpensive controls used in organic/conventional agriculture, which are also suitable for small-scale aquaponics, to avoid pest infestations. Physical exclusion refers to keeping the pests away. Mechanical removal is when the farmer actively takes the pests away from the plants. Cultural controls are the choices and management activities that the farmer can undertake to prevent pests. These controls should be used as a first line of defence against insect pests before other methods are considered.

Netting/screens
This method is common to prevent pest damage in tropical regions or wherever organic horticulture is practised or pesticides are not effective. Netting mesh size varies depending on the pest targeted; use nets with a mesh size of 0.15 mm to exclude thrips, 0.35 mm to exclude whitefly and aphids, and 0.8 mm to keep out leaf miners. Netting is particularly effective while the seedlings are very young and tender. Screens do not suppress or eradicate pests, they only exclude most of them; therefore, they must be installed prior to pest appearance and care should be taken not to let pests enter into the protected environment.

Physical barriers
Given the limited distances that insects can cover, it is possible to reduce pest prevalence by adding physical barriers between the vegetables and the surrounding vegetation such as paved surfaces or building stories. Rooftop aquaponic production benefits from the natural ventilation, given the higher altitude, and the large physical barrier (distance from the ground) creating ideal conditions for outdoor production relatively free from pests and diseases (Figure 6.9). Greenhouses often have a strong fan blowing out through the entrance way that can help to prevent insects from entering with the farmer.

FIGURE 6.9
Aquaponic units on a rooftop are isolated from some ground pests

Another useful technique is to create a barrier on the legs of the hydroponic containers. A ring of copper flashing can prevent snails and slugs from climbing up the legs, and a coating of petroleum jelly can prevent ants. Placing the bottom of the legs in a container of water can also prevent ants.

Hand inspection and removal
The removal, either by hand or using a high-pressured stream of water, of heavily infested leaves or plants helps to avoid and/or to delay the spread of insects to surrounding plants (Figure 6.10). Larger pests and larvae may also be used as supplementary food for the fish. Water sprayed from a hose directed at the underside of the leaves is an extremely effective management technique on many types of sucking insects. The stream can actually kill some insects, and the others are washed away. This is effective on sucking insects such as aphids and whiteflies. This is one of the most effective methods on small-scale systems, but it can be just a temporary remedy as the displaced pests can return to the plants. It can use significant volumes of water and become too labour-intensive with larger systems.

FIGURE 6.10
Manual removal of insect pests

Trapping
Sticky traps positioned slightly above the canopy of plants are effective in protected environments

FIGURE 6.11
Yellow sticky trap (a) installed in a greenhouse (b)

(e.g. net houses, greenhouses). Blue sticky cards trap adult stages of thrips while yellow sticky cards trap whiteflies and microlepidoptera (Figure 6.11). Sticky traps are less effective in outdoor conditions as new insects can easily come from the surrounding areas. The continuous monitoring of insects being captured by the traps can help a farmer to adopt specific measures to reduce the occurrence of certain pests. Another effective way of dealing with pests is to use pheromone-baited traps. These attract males of specific pests, thereby reducing the mating population in the area.

Environmental management
Maintain optimal light, temperature and humidity conditions, which can be easily changed in protected cultivation, to favour healthier plant growth and to build unfavourable conditions for pests. For example, spider mites do not tolerate wet and humid conditions, so timed misters directed on the plant leaves can deter infestations.

Plant choice
Some pests are more attracted to specific plant species than others. Similarly, different plant varieties from the same species have different resistance/tolerance to pests. This is one reason that polyculture can often prevent large infestations because some plants remain unaffected. Moreover, some plants attract and retain more beneficial insects to help manage pest populations (discussed in more detail below). Choose resistant varieties from local suppliers and agriculture extension agents to help reduce diseases and infestations.

Indicator plants and sacrificial/catch/trap crops
Some plants, such as cucumber and legumes, are more prone to aphids or red mite infestations and thus can be used to detect pest prevalence early. Often, indicator plants are planted along the exterior edge of larger gardens. Another strategy that can be adopted in aquaponics is the use of biological insecticides on sacrificial or "catch plants" planted near to, but not within, the aquaponic system. Catch plants (i.e. fava beans) attract pests. These plants can be grown in pots beside the aquaponic unit, attracting the pests away from the unit, which are then treated with insecticides (see below). This strategy would not affect the aquaponic ecosystem or beneficial insects present around the unit. Although not purely organic, catch plants can even be treated with commercial synthetic insecticides if large infestations are present. Fava beans and petunias (flowers) can be used to catch thrips, aphids and mites. Cucumbers are also used to catch aphids and hoppers while succulent lettuce seedlings are used to capture other leaf-eating insects.

Companion planting
Companion planting is the constructive use of plant relationships by growers. For example, all plants produce natural chemicals that they release from their leaves, flowers and roots. These chemicals may attract or repel certain insects and can enhance or limit the growth rate and yield of neighbouring plants. It is therefore important to be aware of which plants benefit from each other when planted together, and which plant combinations are best avoided. Appendix 2 provides a companion planting table to use when choosing crops. When using the companion table, concentrate on avoiding the bad companions rather than planning for good ones. Some plants release chemicals from their roots or leaves that either suppress or repel pests, which can serve to protect other neighbouring plants.

Fertilization
As mentioned above, excessive nitrogen makes plants more prone to pest attack because they have more succulent tissues. A correct balance of nutrients using the feed rate ratio (see Chapters 2 and 8) helps plants to grow stronger in order to withstand pest attacks. Some water should be exchanged when nitrate levels are greater than 120 mg/litre for this reason.

Spacing
High planting density and/or inadequate pruning increases competition for light, encouraging insect pests. This competition eventually makes plant tissue more succulent for pests to bore through or for pathogens to penetrate, and the cramped conditions offer shelter to the pests. Be sure that there is adequate ventilation and sunlight penetration through the canopy. As previously discussed, many plants have special needs for sunlight or a lack of it. By combining full-sun with shade-tolerant plants, it is possible to intensify the production without the risk of raising competition and weakening the plants. In this case shade-tolerant plants can grow under the canopy of sun-loving ones. In this way, the plants are healthier and more resistant to pests and disease.

Crop rotation
Although aquaponic units can be managed as monoculture without facing problems of soil tiredness (depletion of nutrients naturally present in soil), growing the same species continuously over multiple seasons can have a selective effect on the surrounding pests. Thus, a change in crop, even for a short period, may cause a drastic reduction of pests specifically targeting the monoculture crop.

Sanitation
The removal of all plant debris, including all roots, at the end of each harvest helps to reduce the incidence of pests and diseases. Dead leaves and diseased branches should be removed consistently. In outdoor conditions without nets, it is advisable to reduce the surrounding vegetation to a minimum in order to prevent pests spreading to the aquaponic unit. Diseased plants and compost piles should be kept far from the system to prevent contamination.

Chemical controls
If pests remain a problem after using the above physical, mechanical and cultural controls, it may be necessary to use chemical control. Synthetic pesticides and insecticides must never be used in aquaponics because they will kill the fish. Many biological controls are also deadly to fish. All chemicals controls are to be considered a last resort in aquaponic systems and only used sparingly. If possible, such as for DWC systems, it is better to remove and treat the plants away from the system and allow the

chemicals to dry completely. Appendix 2 contains a list of common insecticides and repellents, their indications and their relative toxicity to fish.

Biological controls
As for botanical pesticides, some extracts obtained from micro-organisms are safe for aquatic animals because they act specifically on insect structures and do not harm mammals or fish. Two organisms widely used in aquaponics and organic agriculture are *Bacillus thuringiensis* and *Beauveria bassiana.* The former is a toxin extract from a bacterium that damages the insect's digestive tract and kills it. It can be sprayed on leaves and specifically targets caterpillars, leaf rollers, moth or butterfly larvae without damaging other beneficial insects. *B. bassiana* is a fungus that germinates and penetrates the insect's skin (chitin), killing the pest through dehydration. The efficacy of the fungus depends on the number of spores sprayed and on the optimal humidity and temperature conditions, ideally a good agent for humid tropics.

Beneficial insects – pest predators
Finally, beneficial insects are another effective method to control pests, particularly in controlled environments such as greenhouses or nethouses. Beneficial or predator insects such as lacewings are introduced into the plant growing space in order to control any further infestation. Some of the advantages of using beneficial insects include: the absence of pesticide residue or pesticide-induced resistance in pests, economically feasible (in the long run for large-scale operations only), and ecologically sound. However, successful pest control using this method depends on detailed knowledge of each beneficial insect along with the constant monitoring of pests to time correctly the introduction of beneficial insects. Moreover, beneficial insects can be attracted naturally to outdoor systems. Many of these beneficial insects feed on nectar in their adult stages, so a selection of flowers near the aquaponic unit can maintain a population that can keep pests in balance.

It is important to underline that this method of control never fully eradicates the pests. Instead, pests are suppressed under a tight prey-predator relationship. This method has already been used with positive results for large-scale aquaponics, yet for small-scale aquaponics there may not be enough pests for the beneficial insects to predate, which may lead them to fly away. The choice of beneficial insects to use (see Appendix 2) should take into account the environmental conditions where they are going to operate.

6.5.2 Plant diseases and integrated disease management

Unlike hydroponics, which is mostly managed under sterile conditions, aquaponics takes advantage of a complex microscopic ecosystem that includes bacteria, fungi and other micro-organisms. The presence of these well adapted micro-organisms makes each system more resilient in the event of attack by pests or diseases. Nevertheless, successful plant production is the result of management strategies to avoid disease outbreaks that mainly focus on the environmental conditions, pest deterrence (pests such as whitefly may carry lethal viruses) on plant management as well as the use of organic remedies that help to prevent or to cure the plants. Similar to IPPM, integrated disease management relies on prevention, plant choice, and monitoring as a first line of defence against disease, and uses targeted treatment only when necessary.

Environmental controls
Temperature and humidity play an important role in the health management of plants. Each plant pathogen (i.e. bacteria, fungi or parasites; Figure 6.8) has optimal growth temperatures that can be different to those of plants. Thus, diseases occur in certain areas and periods during the year when conditions are more favourable to the pathogen than

to its host. Moreover, moisture plays a key role for the germination of fungal spores, which require a thin film of water covering the plant tissues. Similarly, the activation of some bacterial and fungal diseases is strictly correlated with the presence of surface water. Therefore, the control of relative humidity and moisture are essential in order to reduce the risks of disease outbreaks. Appendix 2 contains detailed environmental conditions that encourage several common fungal diseases.

Control of relative humidity, especially in greenhouse aquaponics, is particularly important. This can be achieved through dynamic or forced ventilation by means of windows and fans creating horizontal airflow helping to minimize temperature differentials and cold spots where condensation occurs. Moving air is continually mixed, which prevents the temperature dropping below the dew point; therefore, water does not condense on the vegetables.

Evaporation from fish tanks and/or aerated DWC canals housed in greenhouses should also be avoided by physically covering the water surfaces, as evaporated water can dramatically increase the indoor humidity. Pipes in NFT units are prone to high water temperatures in hot seasons because of the continuous exposure to the sun on the pipes. Media bed systems are an optimal compromise, given the right choice of medium, because the top surfaces of the beds are always kept dry (see Chapter 4). Finally, systems built on rooftops have the advantage of a drier microclimate and good ventilation compared with ground level, which facilitates environmental management of plants.

Control of water temperature plays a key role in avoiding fungal outbreaks. A very common disease in aquaponics is root rot caused by *Pythium* spp., a soil-borne pathogen that can be accidentally introduced into the system from contaminated materials (soil, peat, seedlings from nurseries). Unlike in hydroponics, in aquaponics this fungus does not cause damage below certain temperatures because of the competitive presence of other micro-organisms. The maintenance of temperatures below 28–30 °C is thus essential in order to avoid the exponential germination of spores that would eventually cause an outbreak.

Attention should also be given to planting densities. Very high densities reduce the internal ventilation and increase the humidity among the plants. The risk of diseases for densely planted crops is also enhanced as, under intense light competition, plants grow without consolidating their cells, leading to softer and more succulent tissues walls. Tender tissues are more prone to disease because of their limited resistance to pest and/or pathogen penetration.

Plant choice

Plant varieties have different levels of resistances to pathogens. In some cases, using known resistant cultivars is the most successful method of avoiding disease. Thus, it is vital to select plant varieties that are more adapted to grow in certain environments or have a higher degree of resistance against a particular pathogen. Moreover, many seed companies offer a wide selection of plants that have different responses against pathogens. The use of local varieties that are naturally selected for a specific environment can ensure healthy plant growth.

If it is not possible to control certain diseases with resistant varieties, it is wise to shift to other crops during the critical season. In the case of *Pythium* spp. if resistant varieties of lettuce and beneficial micro-organisms are not able to control the infestation, it is opportune to shift to other species, such as basil, that are more tolerant to the pathogen and to high water temperatures.

Seeds and/or seedlings must be bought from a reputable nursery that employs effective disease prevention strategies and can secure disease-free products. Moreover, avoid injury to plants, as broken branches, cracks, cuts and pest damage often lead to diseases breaking out in the same area.

Plant nutrition

Nutrition greatly affects a plant's susceptibility to disease. It also affects a plant's ability to respond against disease using different mechanisms, including antixenosis (processes to deter colonization by herbivores) or antibiosis (processes to kill or reduce herbivores after landing or during eating). A correct balance of nutrients not only provides optimal growth but also makes plants less susceptible to diseases. Although the description of nutritional disorders has been discussed above, Table 6.2 outlines how some nutrients can play a major role in disease occurrence.

TABLE 6.2
Effect of nutrients on fungal disease prevention

Nutrient	Effect
Nitrogen	Overfertilization makes more succulent tissues that are more prone to fungal attack. Nitrogen starvation makes stunted plants more prone to attacks from opportunistic micro-organisms.
Potassium	Accelerates wound healing and reduces the effect of frost damage. Delays maturity and senescence of plants.
Phosphorus	Improves nutrient balances and accelerates the maturity of the plants.
Calcium	Reduces the severity of some root and stem fungal diseases. Affects the cell wall composition in plants that resists fungal penetration.
Silicon	Helps plants to produce specific defence reactions, including the release of phenolic compounds against pathogens.

Source: Agrios (2004).

Monitoring – inspection and exclusion

Early detection and intervention is the foundation of disease and pest management. Thus, plants should be inspected regularly for early signs of infection or pest presence that may result in infection. Whenever plants show signs of damage or initial stages of disease (wilt, blight or root rot), it is vital to remove the infected branches, leaves or the whole plant to avoid the disease spreading throughout the entire crop. Moreover, regarding exclusion, it is important to enforce the control of potential vectors (sources) of viruses, such as whiteflies, by growing plants in insect-proof structures (see Section 6.5.1). In addition, the avoidance of soil contamination as well as the use of disinfected tools (e.g. shears used for pruning/harvesting) would help to avoid the transmission of potential pathogens into the system. Finally, it is good practice to monitor and record all symptoms and the progression of each disease in order to determine the best prevention and treatment methods in the future.

Treatment – inorganic or chemical

As mentioned above, aquaponics is a complex ecosystem that is more resilient than hydroponics to soil-borne disease. However, some disease outbreaks may still occur in the case of unfavourable environmental conditions, such as higher relative humidity in greenhouses or in tropical climates, and need to be controlled. As aquaponics is an integrated system containing fish, plants and beneficial micro-organisms, it is not possible to use the standard disease treatments of conventional agriculture (i.e. chemical fungicides) as they are toxic to fish. However, common practices used for organic agriculture are possible, provided that they do not harm fish and/or the bacteria or do not accumulate in the system leading to higher than accepted thresholds. Appendix 2 indicates elements and methods of application used in organic agriculture that can also be used for aquaponics to fight and stave off different diseases. In general, successful treatment using the methods relies on the combination of a few strategies that can have synergic effect against specific pathogens.

Treatment – biological

Some biological control agents can be used for aquaponics such as *Thricoderma* spp., *Ampelomices* spp. and *Bacillus subtilis*, which are cultured micro-organisms used to fight against specific diseases. These biological agents can be applied either on leaves or at the root zone. They provide protection against the most common soil-borne diseases including downy mildew, powdery mildew and some bacteria. In particular, *Thricoderma* spp. have proved effective in controlling *Pythium* spp. and most of the soil-borne pathogens, while *Ampelomices* spp. could offset any need for inorganic or chemical treatments against powdery mildew. In the case of *Thricoderma* spp., the spores can be distributed on substrate when seeding, to let the beneficial fungus protect plants starting at their seedling stage. Product information, producers and distributors should be consulted before use in order to identify the best treatment methods for specific diseases.

For more detailed information on specific vegetable diseases including identification, susceptibility and prevalence, see recommended texts in the section on Further Reading.

6.6 PLANTING DESIGN

The layout of the grow beds helps to maximize plant production in the available space. Before planting, choose wisely which plants will be grown, bearing in mind the space needed for each plant and what the appropriate growing season is. A good practice for all garden design is to plan the layout of the grow beds on paper in order to have a better understanding of how everything will look. Important considerations are: plant diversity, companion plants and physical compatibility, nutrient demands, market demands, and ease of access. For example, taller crops (i.e. tomatoes) should be placed in the most accessible place within the media bed to make harvesting easier.

Encouraging plant diversity

In general, planting various crops and varieties provides a degree of security to the grower. All plants are susceptible to some kinds of disease or parasites. If only one crop is grown, the chance for a serious infestation or epidemic is higher. This can unbalance the system as a whole. As such, growers are encouraged to plant a diverse range of vegetables in small-scale units (Figure 6.12).

FIGURE 6.12
Example of two media beds growing multiple types of vegetables

Staggered planting

As mentioned previously, it is important to stagger planting. In this way there can be constant harvest and replanting, which helps to maintain a balanced level of nutrients in the unit. At the same time, it provides a steady supply of plants to the table or market. Keep in mind that some plants produce fruit or leaves that can be harvested continually throughout a season, such as salad leaf varieties, basil, coriander and tomatoes, whereas some other crops are harvested whole, such as kohlrabi, lettuce, carrots. To achieve staggered planting there should always be a ready supply of seedlings (the development of a plant nursery is discussed in Chapter 8).

Maximizing space in media beds

Not only should the surface area be planned out to maximize space, but also the vertical space and time should be considered. For example, in regard to time, plant vegetables with short grow-out periods (salad greens) between plants with longer-term crops (eggplant). The benefit of this practice is that the salad greens can be harvested first and provide more room as the eggplants mature. Continued replanting of tender vegetables such as lettuce in between large fruiting plants provides naturally shaded conditions.

Make sure that the shaded crops are not completely dominated as the large crops mature. Vegetables such as cucumbers are natural climbers that can be trained to grow up or down and away from the beds. Use wooden stakes and/or string to help support the climbing vegetables. This creates more space in the media bed (Figure 6.13). One of the benefits of aquaponics is that plants can be easily moved by gently freeing the roots from the growing media and placing the plant in a different spot.

FIGURE 6.13
Examples of maximizing space in media beds using vining crops (a) and staggered planting (b)

6.7 CHAPTER SUMMARY

- The major advantages of aquaponics over soil agriculture are: (i) no wasted fertilizer; (ii) lower water use; (iii) higher productivity/quality; (iv) ability to utilize non-arable land; and (v) offset of tillage, weeding and other traditional agricultural tasks.
- Plants require sunlight, air, water and nutrients to grow. Essential macronutrients include: nitrogen, phosphorus, potassium, calcium, magnesium and sulphur; Micronutrients include iron, zinc, boron, copper, manganese and molybdenum. Deficiencies need to be addressed by supplying the limiting nutrients with supplemental fertilizer or increasing mineralization.
- The most important water quality parameter for plants is pH because it affects the availability of essential nutrients.
- The suitable temperature range for most vegetables is 18–26 °C, although many vegetables are seasonal. Winter vegetables require temperatures of 8–20 °C, and summer vegetables require temperatures of 17–30 °C.
- Leafy green herbs and vegetables do extremely well in aquaponics. Large fruiting vegetables are also applicable, including tomatoes, peppers, eggplant, and cucumbers, peas and beans. Root crops and tubers are less commonly grown and require special attention.
- Integrated production and pest/disease management uses physical, mechanical and cultural practices to minimize pests/pathogens, and then uses fish-safe chemical and biological treatment in targeted applications, when necessary.
- Intelligent planting design can maximize space, encourage beneficial insects and improve production.
- Staggered planting provides continual harvest as well as a constant nutrient uptake and more consistent water quality.