Jamaica
Adaptive Agriculture Program

AQUAPONICS HANDBOOK

Guidance Manual for Aquaponic System Construction, Operation and Management
Preface

This handbook is designed as a training manual for practitioners of the aquaponics technology developed by INMED Partnerships for Children to address climate change and its effects on the sustainability and productivity of small-scale farmers in Jamaica. The manual provides a “how to” guide to implement aquaponics using an ebb and flow media bed system designed by INMED for the future aquaponics entrepreneur. It does not go into extensive detail into the science behind aquaponics, but rather, it outlines a practical approach to starting and maintaining one’s own system and managing, marketing and financing an aquaponics business.

INMED Partnerships for Children has been working in Jamaica since 2002 through its in-country operational group, INMED Caribbean, a registered non-profit organization. As part of INMED’s Adaptive Agriculture Program (AAP), INMED introduced and piloted aquaponics in Jamaica starting in 2011 to provide an innovative, alternative form of farming and empower small-scale farmers to generate income, produce food, and adapt to climate change impacts that disproportionately affect vulnerable populations. After the proven success of the technology, in which aquaponic systems were installed in 13 locations across Jamaica (and additional systems in South Africa and Peru), INMED is now developing an integrated access-to-financing program that will provide practitioners access to training and technical assistance, markets and sources of credit to start and operate a successful aquaponics business. The main objective of this program – and this guidance manual – is for aquaponics to become a more accessible and common form of agriculture for small-scale farmers and entrepreneurs, ultimately having positive impacts on economic conditions and climate resilience in Jamaica and beyond.

INMED is not advocating that aquaponics is the “be all or end all” answer to food security in a changing climate, but that it can play a major role in the survival of small-scale farmers in the coming years. We recognize that other new innovations and large-scale farming will be necessary if we are to avoid widespread famine across the globe, particularly with threats caused by increasing population, urbanization and environmental degradation. However, the support of small-scale farmers and businesses is a critical part of the strategy for food security and maintaining secure livelihoods, and aquaponics can play a key role in implementing this strategy.
Acknowledgements

INMED Partnerships for Children is an international humanitarian development organization that catalyzes multilateral partnerships to empower children and families to overcome poverty, disease, climate change and instability. Since 1986, INMED has built alliances with public- and private-sector partners in more than 100 countries. Through a broad range of agriculture, health, social, education, family support and community development programs, INMED works to create opportunities that inspire hope, build self-reliance and encourage community collaboration to sustain positive change. INMED has been working as an international NGO in Jamaica since 2002, and its in-country operational group, INMED Caribbean, is a registered non-profit organization.

INMED would like to express our gratitude to several key partners who have made this program possible, including: the U.S. Agency for International Development (USAID), which helped establish and pilot the initial AAP design and proof of concept for INMED’s aquaponics technology in Jamaica; the U.N. Environment Programme/Danish Technical University (UNEP/DTU) Partnership, which helped develop the business case for aquaponics in Jamaica, document best practices and financial returns, and mobilize value chain stakeholders; the Jamaican Ministry of Industry, Commerce, Agriculture and Fisheries (MICAF) and its Rural Agricultural Development Authority (RADA) and the Ministry of Economic Growth and Job Creation (MEGJC) and its Climate Change Division for their endorsement of INMED’s aquaponics program; the Development Bank of Jamaica (DBJ) for providing loan guarantees to future aquaponics entrepreneurs; and the various local cooperative, academic and social institutions that are continuing to operate their aquaponics systems to benefit farmers, women, youth and school children in Jamaica.

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Acronyms and Abbreviations

°C             Degrees Celsius
°F             Degrees Fahrenheit
AAP            Adaptive Agriculture Program
cm             centimetres
DWC            deep water culture
FAO            Food and Agriculture Organization
INMED         INMED Partnerships for Children
kg             kilograms
lbs            pounds
mm             millimetres
NFT            nutrient film technique
SMART         specific, measurable, attainable, realistic, and time-scaled
SWOT          strengths, weaknesses, opportunities and threats
1. Introduction and Overview

About 795 million people (or one in nine) in the world today are hungry. At the same time, climate change further threatens the food security and livelihoods of small-scale farmers and communities across the globe. According to the Food and Agriculture Organization (FAO), the world currently produces enough food for everyone, but the challenge is overcoming inequities caused by lack of access, poor agricultural management practices, dwindling water resources, changing weather patterns and a lack of knowledge about potential adaptive measures—all of which create food insecurity and loss of livelihoods among the most vulnerable populations.

Through its Adaptive Agriculture Program (AAP), INMED Partnerships for Children (INMED) is dedicated to establishing sustainable food programs that improve food security, conserve natural resources, promote strategies for adaptation to climate change, provide opportunities for income generation, and inspire this and successive generations of small-scale farmers and entrepreneurs. The cornerstone of INMED’s adaptive agriculture strategy—now operating in Jamaica, South Africa and Peru—is aquaponics.

The technology of aquaponics addresses many of the resource issues that small-scale farmers face when they try to expand food production. Issues such as lack of land, little to no capital for infrastructure or inputs such as fertilizers and insecticides, lack of suitable/high quality land and limited water resources have all plagued the small-scale farmers for centuries. If the farmer is trained in business planning and how to construct and properly implement aquaponics, most of these resource limitations can be addressed. Our goal is to provide the entrepreneurial farmer with the knowledge and technology to grow as much food as possible, in the most effective and sustainable way, and with the least amount of capital expenditure.

1.1 What is Aquaponics?

Aquaponics is a symbiotic ecosystem that combines two established technologies, aquaculture and hydroponics. Aquaculture is the growing and cultivation of aquatic life, including fish, crayfish, snails, shrimp, oysters and so on for food, and hydroponics is growing plants in sand, gravel, liquid or other media, but without soil. Combining both systems is not a new concept. Early settlers of what is now known as Mexico City built rafts and planted vegetables on the rafts and set them adrift to float on the local lake to soak up the nutrient-rich water that was produced by fish and other organisms. This was an early form of aquaponics.

The fundamental principles of aquaponics have been practiced for hundreds of years, with variations employed by the Aztecs in Mexico and in China and Southeast Asia. The development of modern aquaponics started in the USA, along with various institutions worldwide; the University of the Virgin Islands in the Caribbean, in particular, has done significant research and development on large-scale aquaponic systems. INMED’s concern for adequate childhood nutrition led to the development of our low-cost, simplified form of aquaponics. Because these systems do not require physically demanding labour, they can be used by mothers near their homes or used by disabled farmers. Larger systems can also provide a sustainable source of income generation.
INMED did not invent aquaponics, but we did develop a low-cost system that is suitable for low-resource settings, utilizing locally available materials. INMED’s design is modular so that the system can be expanded incrementally as additional income allows. The hallmark of our design is that it can be adapted depending upon available geographic and financial resources. For example, systems can be configured in a single module that produces enough fish and vegetables to feed a family of four with surplus for sale at the local market. Or the units can be configured in multi-module systems that are at least eight times the size of the individual units and are capable of substantial production to generate income.

There is increasing pressure on small-scale farmers to identify cost-effective, energy- and water-efficient agricultural methods that do not consume large amounts of inputs and other large capital expenditures, in order to make local agriculture competitive while preserving the environment and adapting to climate change. Aquaponics offers such a model and often becomes adopted outside of the communities in which it is initially established. Toward that end, INMED has intentionally designed the system to be highly scalable and replicable.

1.2 Why Aquaponics?

INMED has adapted the aquaponics technology to make it accessible to small-scale farmers and entrepreneurs in developing and emerging countries because aquaponic systems are much more productive than equivalently-sized plots that are traditionally cultivated, and protect both the quantity and quality of water resources by requiring no chemical fertilizers or pesticides and utilizing significantly less water than traditional irrigation techniques. The benefits of aquaponics include the following:

- Produces significantly more crops in the same amount of space as open field farming, creating much higher yields by comparison, and produces fish as a second product
- Uses significantly less water than traditional farming methods, extremely water efficient
- Consumes much less energy than mechanized agriculture, requiring low electrical usage and no tractors/machines to operate, thereby mitigating emissions
- Does not require mechanical or biological filters—the processes occur naturally, saving money and electricity, with fewer parts that can develop problems
- Does not use harmful chemical fertilizers, pesticides, herbicides or fungicides, so produce is organic and of a very high quality, and environmental conditions are not compromised by chemical production or waste
- Produces its own fertilizer from fish waste, reducing up-front capital
- Requires substantially less labour than required by most other food production methods
- Does not require soil, with fewer weeds to remove
- Has faster produce growth to market size due to optimal conditions being maintained
- Is vulnerable to fewer diseases (no soil-borne diseases) compared to traditional farming
- Remains in constant production throughout the year and can produce out-of-season crops if the system is in a greenhouse
- Promotes awareness of and strategies for mitigation and adaptation to climate change and natural resource conservation.
INMED experts have modified the aquaponics technique to use “off the shelf” local materials and a modular design, making it relatively inexpensive and therefore more accessible to low-resource individuals, families and communities. The basic module of our low-maintenance pond and grow-bed system occupies the space of two compact cars, and can meet the nutritional needs of a family of four plus provide additional fish and produce that can be sold to generate household income. The expandable modular design allows farmers to scale up as their income allows, incrementally increasing revenue potential. Larger aquaponics systems can also be established from the start and operated as a commercial enterprise.

Aquaponics can accommodate the production of many types of fish, including native river varieties. In many locations, however, tilapia is the fish of choice, as it is hardy, fast-growing and widely consumed. A wide variety of plant crops can grow successfully, both vegetative and fruit-bearing. Since small-scale farmers have very limited resources, the introduction of new technologies must be carefully considered. In most developing or emerging country situations, aquaponics, which is rapidly growing in popularity around the world, addresses all or most of the factors that are considered in starting a new agricultural business. Important factors that argue for aquaponics include:

- Affordable start-up costs, especially in relation to potential income generation
- High gross profit margins (very large commercial farmers can operate on lower margins)
- Relatively low maintenance costs
- Short-term and consistent cash flow
- Local niche markets where small-scale farmers can enter the market, make a profit and compete with large producers.

1.3 How it Works

There are three basic techniques (and several iterations of these techniques) used in aquaponic production: 1) an ebb and flow system, sometimes known as flood and drain, utilized by INMED, 2) a raft or float system, also called deep water culture (DWC), and 3) nutrient film technique (NFT). While the DWC and NFT systems are proven technologies, INMED employs the ebb and flow system specifically for the following reasons:

- Simplicity in design, construction, implementation and operation, ease for beginners
- Relatively low capital investment, using readily available local materials for construction
- Grow beds that act as filtration systems, simplifying both construction and maintenance
- No harmful fertilizers or chemical inputs
• Low energy inputs (the single pump runs for only 15 minutes out of every hour)
• Ecological footprint that is smaller than many other systems
• Resilient against extreme weather conditions (made of a concrete structure)
• Wider range of plants that can be grown without significant system modification

INMED’s aquaponics systems are made up of fish tanks, grow beds, water pipes and a pump, utilizing a simple ebb and flow system that eliminates the need for expensive and complex filters and oxygenation systems. The entire system is built on a project site using common building materials. In Jamaica, the primary building material is concrete with rebar, because concrete is plentiful and can withstand hurricanes. In other locations, such as South Africa, INMED has used plastic materials, shipping containers, and readily-available farm supplies like animal feeding or watering troughs to serve as grow beds in some systems. All internal plumbing components (such as pipes and pumps) are purchased from local suppliers. The figure below shows the pictorial representation of the water flow system of a single aquaponic module. For detailed plans and specifications for various sized models, see Appendix A.

Figure 1-1. INMED Aquaponic System – Single Module Side View

The construction of the systems can be designed to fit available space and meet production objectives—from individual family-sized units to commercial systems of various sizes. The systems include fish tanks (with water) and grow beds (with gravel), and a small submersible pump used to pump water from the tank(s) to the grow beds through a PVC pipe. A timer allows one water exchange per hour (approximate 15-minute flood periods with 45-minute drainage periods) to the gravel-filled grow beds. The water filters through the gravel, depositing fish waste onto the surface of the gravel (bacterial action converts the waste into nutrients that can be absorbed by the plants) and exits into troughs or pipes which return the filtered water to the fish tank(s). The systems can utilize solar and/or grid power and include a back-up battery system to protect against power outages.

1 In DWC and NFT systems, holes used to anchor plants have to be widened or spaced differently to accommodate different plants. Those systems need major modification for plant fruit-bearing crops like sweet peppers.
1.4 Using the Ebb and Flow System

The ebb and flow system has three primary components; fish tank, grow beds and pump. The fish tank, constructed with rebar and concrete and buried in the ground, can be of any size that fits the needs of the system and, as the name implies, holds the fish. The fish tank is the heart and soul of the system. The fish create nutrient-rich water, which contains all of the basic nutrients, trace minerals and oxygen that are required for plant growth.

The grow beds are constructed from concrete and rebar and are filled with small sized (1/4 to 1/2 inch or 6 to 12 mm) pebbles (alternative materials – but not soil – may also be used) which act as the growth media aerator as well as the filter for the system. Plants, or in some cases, seeds are embedded in the gravel, similar to planting in soil. Microorganisms naturally colonize the gravel and the walls of the fish tank and grow beds. One group of organisms converts fish waste into nitrites, and a second group of organisms converts the nitrites into nitrates, which are utilized by the plants for growth and metabolism. This naturally occurring microbiological system eliminates the need for routine fertilizers and chemicals normally used for crop production in traditional farming.

The pump transfers nutrient-rich water from the bottom of the fish tank up to the top of the grow beds. This water becomes aerated as it sprays out of the nozzles and breaks against the gravel surface in the grow beds. Water in the grow beds deposits nutrients for plants to uptake as it flows downward through the gravel from gravity. Through friction against the surface area of the gravel, the water again takes up oxygen, which is necessary for the fish, as it returns to the fish tank. It takes approximately 15 minutes to flood the beds, at which point the pump stops, and in approximately 45 minutes, the water drains back into the tank: hence the name ebb and flow. Water returning from the grow beds is clean and rich in oxygen. This closed system circulates on a continuous (24-hour) cycle.

Figure 1-2. Aquaponic System Nutrient Cycle
2. Before You Get Started

Before endeavouring to establish aquaponics system, care must be taken to determine the ultimate objective. For example, if the objective is food security for a family of four or five people, a single modular unit with a grow bed capacity of 192 square feet and a fish tank that can produce 600 to 800 fish a year is sufficient and can incorporate locally available components such as shipping containers, horse feed troughs or plastic water tanks. A system of this size will require minimal investment and land resources. On the other hand, if the objective is to establish a commercially viable aquaponics enterprise, multiple modules will be required. The beauty of INMED’s aquaponic design is the flexibility of its modular construction that allows for adjustments that will meet the needs for size and shape. The construction manuals for the durable individual family unit and a commercial system layout are provided in Appendix A.

2.1 Site Selection

Site location is often determined by circumstance: school grounds, cooperative community land, home garden space, farm land, etc. Whatever the geographic setting, INMED’s flexible modular design will usually fit the situation. However, there are basic factors that must be considered before choosing the site for locating the aquaponics system:

- The site should receive at least 6 to 8 hours per day of direct sunlight; ambient temperature is not so important except in climates with colder and freezing temperatures, which may require tank insulation or partial burial of the fish tanks and/or enclosed greenhouse for fish and plants (not applicable for the Jamaica context)
- Collected rain water and/or municipal water should be readily available; pond and stream water should be avoided, if possible (due to potential water quality issues or disease introduction)
- Electrical grid power or solar power (AC or DC voltage), or a combination, should be available to power the pump
- Ease of access to the system for construction and ongoing maintenance and harvesting
- Security necessary to protect the system from theft, vandalism, etc.

In addition to the factors listed above, the site should be levelled for ease of construction and operation (this is the simplest method). Designs can be adapted, however, for a tiered landscape. Care should also be taken to minimize the impact of the environmental footprint on the surrounding area (i.e., do not remove critical habitat, fill wetlands, etc.). Care should be taken in selecting the geographic setting for aquaponics, especially if the addition of a greenhouse is being considered, with special attention to the following factors:

- Orientation to the sun and alignment to prevailing wind direction
- Surroundings that obstruct light
- Readily available sources of power and water
- Other structures that can cause damage (or be damaged)
- Security against animal interference, vandalism or theft
2.2 Essential Components

INMED’s aquaponics system is generally made of sturdy, hurricane resistant, easily accessible (in Jamaica) concrete. However, other material options include plastic (cheaper, but less durable or long-lasting) and fiberglass (more durable, but more expensive). The essential components of INMED’s aquaponic system include the following (see Appendix A for construction details and list of necessary supplies and materials):

- Framing (wood or metal according to specifications) for site delineation and supporting construction of fish tanks and plant grow beds
- Structural materials, including concrete blocks, cement, sand, gravel and steel rebar
- Water system materials, including PCV pipes and fittings
- Submersible water pump and timer
- Tractor or other equipment for land grading and preparation, as necessary

2.3 Complementary Components

Complementary components, which are not vital to aquaponic system operation, but which enhance its resource efficiency and improve long-term earnings potential, include a greenhouse or greenhouse-type covering, solar power system, water harvesting system, and seedling nursery. Other components that can enhance production include the addition of an aerator and modifications to establish fish breeding/fingerling production. It is also useful to have a sorting and packaging site.

2.3.1 Greenhouse or Cover

The question regarding the need for a greenhouse often arises. In areas where the temperature of the water in the fish tanks can fall below the requirements to maintain fish health, a greenhouse is required for temperature control. In tropical and sub-tropical areas such as Jamaica, aquaponics systems do not require enclosed greenhouses for temperature control to be successful. However, in regions of heavy rainfall, a basic open greenhouse structure with plastic cover is highly recommended (at least, if not a full greenhouse) as an aid to protect crops from disease and physical harm brought on by too much rainfall. In this case, the solar film used for cold-weather greenhouses may be replaced with a greenhouse-grade plastic on top of a wooden or metal structure, which also provides a good surface for rainwater harvesting. In addition, insect barrier fabric may hang on the sides (depending on the proximity of dense foliage) to provide partial protection against neighbouring sources of insects and plant diseases.
2.3.2 Solar Power System
The inclusion of solar power has many practical benefits despite the additional up-front cost. In many areas of the world, including Jamaica, the electrical grid is unreliable and expensive on an ongoing basis. Even in areas where electricity is reasonably reliable and available at a modest cost, the aquaponic system will require a solar powered back-up system. It takes very little time for a power outage to halt the pump and water flow, impacting fish and overall system health. Remember the old adage, “if something can go wrong, it will.” A simple solar battery system can provide a reliable source of back-up energy for the aquaponic system, or if used as the primary power source, will save resources in the long-term.

2.3.3 Water Harvesting System
The water-circulating closed-system aquaponics design conserves precious water resources. In addition, INMED’s design also includes the installation of a low-cost rainwater harvesting system, the water from which can be used to fill the tanks when water evaporates or needs to be changed. These simple gutter and pipe systems, installed on rooftops, funnel rainwater into plastic water barrels or cement cisterns equipped with filters, hand pumps and hoses, and then into the tanks as needed. Rainwater is generally free of contaminants that are often common in surface or groundwater and with a neutral pH, is optimal for filling and replenishing the aquaponic system. The water harvesting systems also help to safeguard farmers from water shortages during periods of drought by storing the remaining water for drinking and home use (when treated) or for traditional agriculture.

2.3.4 Seedling Nursery
A separate seedling nursery is recommended to ensure good germination of seeds and better control of transplants for the aquaponic system. To operate a system optimally, a consistent supply of transplants will be necessary for replenishing crops that are harvested on a regular basis. Purchased plant stock can be unreliable, expensive and of poor quality. Planting small seeds directly into the system may be wasteful, since most seeds, other than large varieties such as beans, will wash away into the drain system.

A nursery is composed of a simple structure and a shade covering to protect germinated seeds from direct sunlight. It is important that the growth medium for seeds is NOT soil. Media such as peat, perlite, vermiculite and even small gravel may be used. Water from the aquaponics system is ideal for watering seedlings in the nursery. When seedlings are mature enough for transplanting, the healthiest ones should be selected and carefully removed from the growth medium. The roots should be carefully rinsed before transplanting to system’s gravel. See Appendix B for additional details related to sweet pepper seedling growth and transplant.
3. Water Quality

What is the most important factor for a successful aquaponics system? The answer is water quality. The production of fish and plants—and consequently the entire system—are greatly influenced by the quality of the water in the fish tank. Below are some of the most common factors that affect the quality of the water and in turn the health and viability of plants and fish. Various water quality testing kits are available commercially.

3.1 Water Source

The ideal source of water for the fish tank is rainwater. The reasons for this choice is that rain has a pH of around 7.0, which is neutral, and under normal circumstances is free of pathogens or diseases. If there is not a ready source of rainwater, the second choice is piped water. If the piped water is chlorinated, it must be left to stand in the tank (or other container) for 48 hours until the chlorine has dissipated before adding it to the system, since fish are very sensitive to chlorine. The piped water must also be tested for pH and adjusted accordingly (see below). The last choice is stream or pond water. The principal disadvantage of the last choice is the possibility of introducing disease into your system. If pond or stream water is the only source, it should be treated with chlorine, if possible, prior to its use in the system and then left to stand for the chlorine to dissipate. Another less common option is groundwater (e.g., via borehole); however, that is generally not an option in low-lying areas of Jamaica due to saltwater intrusion affecting groundwater quality. Highly saline water will adversely affect plants.

3.2 Temperature and pH

The aquaponics system is composed of three types of organisms: fish, plants and microorganisms (bacteria). Each of these organisms has an optimal range of pH and temperatures to thrive; pH is often referred to as the master variable because it controls many other water quality variables. For example, nutrient absorption for plants occurs most efficiently at a pH of 6.5. However, nitrification (bacterial action, see below) is more efficient at a pH of 7.5 or greater. Therefore, a compromise has to be made that can satisfy the needs of all of the organisms in the aquaponics system.

For water in INMED's ebb and flow design, a pH of 6.5 to 7.8 and a temperature of 21°C to 31°C (or 70°F to 88°F) are optimal. It is therefore important to regularly check the pH and temperature of the water in the fish tank to ensure that the values are within these ranges.

If you are not familiar with the term pH, the following is a chemistry definition: pH stands for the power of hydrogen, and pH is the measurement of the amount of hydrogen ions in water. The pH scale runs from 0.0 to 14.0. Values less than 7.0 are acidic, 7.0 is neutral, and greater than 7.0 is basic; pH is very important in many chemical reactions and in the case of aquaponics, is of special concern in the nitrification cycle (see below). Additional information about pH, for interested readers, is provided with the operational guidelines in Appendix B.
3.3 Nitrification Cycle

Nitrification is a natural biochemical cycle that is instrumental in allowing us to combine two technologies, aquaculture and hydroponics, to produce aquaponics. The majority of waste products from fish are in the form of ammonia, which is secreted through the gills and urine. The remainder of the waste is excreted in the form of faecal matter. Excessive amounts of ammonia are toxic to fish and plants. To overcome this toxicity, one type of bacteria (*Nitrosomonas*) converts ammonia to nitrite and another type of bacteria (*Nitrobacter*) converts nitrite to nitrate. Plants in the grow beds take up the nitrate as a plant nutrient. Thus the plants reduce the toxicity of the water that flows back to the fish tank. This process is called the nitrification cycle. This important cycle allows us to grow plants and fish within a closed aquaponic system.

It is important to establish the naturally occurring nitrification cycle before you plant your vegetables in the grow beds. Shortly after introducing fish into the tanks, bacteria generally present in the gravel will naturally begin to populate the fish tank and the grow beds. The process can be accelerated, however, by purchasing bacteria from an aquarium shop or by introducing water from a stream, but as mentioned above, stream water should be avoided if possible as it may introduce diseases to the system. The ebb and flow system does not require a biological filter as the grow beds filled with gravel serve as the filter.

3.4 Oxygenation or Aeration

The fish, plants and bacteria in the aquaponics system all require adequate amounts of dissolved oxygen for maximum growth and development. However, since we are using an ebb and flow system, where water is regularly moving, creating friction and absorbing oxygen, lack of dissolved oxygen in the water should not be a problem. The aquaponics system involves water being sprinkled onto the gravel beds, passing through the gravel to the return pipes, and exiting in a water fall into the fish tank. This continuous movement through gravel should provide sufficient amounts of dissolved oxygen for the aquaponics system, thus eliminating the need for air pumps (and filters). However, if oxygen levels become continuously low (e.g., as observed through foul smell), an air pump can be used to add oxygen to the water.

3.5 Algae Growth

The fish tank should be protected from direct sunlight at all times. This will prevent excessive growth of algae, which can plug up the system and reduce dissolved oxygen. Tilapia is a species of fish that can and does consume algae. However, with direct sunlight and a nutrient medium, rapid algae growth will occur that exceeds the consumption capacity of the fish and reduces the amount of oxygen in the water. Algae is a “double-edged sword”; in the day time it produces oxygen but at night it consumes the oxygen and produces carbon dioxide, often utilizing more oxygen than it produces during the day. Therefore, keep the fish tanks covered at all times—if not directly with a piece of wood or other tank cover, then indirectly with a shade structure.
4. Fish Tank

The fish tank is the “heart and soul” of the aquaponic system. The feeding of the fish starts the nutritional cycle for the system: fish eat the food, the food is metabolized, metabolites are excreted by the fish in the form of faeces and ammonia, bacterial nitrification converts the waste to nitrates, and plants then take up the nitrates for growth and development. It is this cycle that is key to system function, and it all starts in the fish tank.

4.1 Selecting Fish Breeds

Fish are the powerhouse of an aquaponic system. They provide the nutrients for the plants, and if you are growing edible fish, then they also provide protein. Keeping fish may be a little daunting to some, especially those without prior experience, but do not be discouraged. Keeping fish in an aquaponic system is as simple as keeping aquarium fish, so long as you follow simple guidelines and monitor them daily.

For the novice aquaponics farmer, only three species of fish should be considered: tilapia, catfish and carp species. Tilapia is by far the easiest species to grow and should be the species of choice. In some countries, there is legal restriction on the use of non-native tilapia. In Jamaica, however, this is not an issue as tilapia is the most common agriculturally farmed fish. If an alternate fish species is preferred or required, catfish or carp species are suggested for the novice. Ornamental fish can also be used if, for example, there is a market for them. The three primary recommended species are described below.

4.1.1. Tilapia

Origin: Africa  
Size: Harvest at 0.45 – 0.90 kg (1 – 2 lbs)  
\pH: 6.0 – 8.0  
Temperature: 17.7 – 32.2 °C (64 – 90 °F)

Tilapia, a member of the cichlid family, is the most widely cultured fish in tropical and sub-tropical regions of the world because it is easily bred, survives in a wide range of water conditions and densities, and gains weight rapidly on a low-protein diet. For these reasons, tilapia are considered the best fish to breed in an aquaponic system.

It is advised that you only change your breed for legal reasons. Tilapia is grown in aquaponic systems in which the tank population is very dense. Maintaining this level of density is not harmful to the fish, and in fact serves a practical purpose. At a low stocking density, the fish are likely to begin reproducing, and once the females reproduce, they will become stunted and will not grow to optimal size.
4.1.2. Catfish

Origin: North America
Size: Harvest at 0.45 – 2.27 kg (1 – 5 lbs)
pH: 6.0 – 8.0
Temperature: 21.1 – 32.2 °C (70 – 90 °F)

If for any reason you are not allowed to grow tilapia in your location, catfish is a good alternative. Breeds of catfish that are compatible with aquaponic culture include channel catfish, white catfish, black bullhead, brown bullhead and flathead catfish. Catfish are popular in fish farming due to their fast growth and marketability.

4.1.3. Common Carp

Origin: Asia
Size: Harvest at 0.6 – 1 kg (1.3 – 2.2 lbs)
pH: 6.5 – 9.0
Temperature: 23.0 – 30.0 °C (73 – 86 °F)

Carp are found all over the world. They are very hardy and able to tolerate low oxygen concentrations and cold temperatures. Carp are mainly bottom dwellers, but search for food in the middle and upper layers of the water body.

The fish can survive cold winter periods, but ideal growth temperature is 23 – 30°C. Carp are omnivorous, with a high tendency toward the consumption of animal food, such as water insects, insect larvae, worms, molluscs, and zooplankton. Carp also consume the stalks, leaves and seeds of aquatic and terrestrial plants, decayed aquatic plants, etc. Pond farming of carp is based on the ability of the species to accept and utilize cereals supplied by farmers.

4.2 Stocking Fingerlings (Tilapia)

An added convenience to consider before stocking the tanks is to line the fish tanks with fish netting in order ultimately to make the harvesting of fish easier. When ready to harvest, the net liner is simply lifted from the tank and the fish sorted. Good health and well-being of the fish is crucial to the functioning of the system. Once the fish tanks are full of clean water and the water has been tested for the proper pH etc., it is time to introduce fingerling fish (40 to 50 grams or about 0.1 lbs each) to the system. The easiest way to transfer fingerlings from the fish farm is to place the fish in plastic bags that contain additional oxygen gas, which will help to reduce stress on the fish during transport. The following sequence is used for the start-up and stocking of fish:
1. Start the pump and adjust the timer so that the pump is activated for 15 minutes out of every hour for 24 hours per day.

2. Run the system for 48 to 72 hours to check for leaks and to determine if the system is distributing water throughout the grow beds. In addition to checking the system, this period will provide time to distribute beneficial bacteria that are found in the gravel bed throughout the system. At the end of the 48 to 72 hours, you may add purchased inoculant bacteria directly into the fish tank to speed up the process of bacterial colonization.

3. Place the plastic bag containing the fingerlings into the tanks. Do not open the bags until the temperature of the water in the bag is the same as the temperature in the tanks, which usually takes about an hour. Once the water in the bag has adjusted to the temperature of the water in the fish tank, open the bag to release the fingerlings. Plan carefully the travel time from the hatchery to the aquaponic system in order to reduce stress on the fingerlings. See Appendix B for guidelines on transporting fingerlings.

4. Do not feed the fish for 48 hours and then only very small amounts; no more than what can be consumed in 30 minutes. It is important that you do not overfeed the fish. (For further information, see the section below on feeding fish).

5. Do not start plant production for 14 days after the fish-stocked system has been in operation.

Stock the fish tanks utilizing a staggered system. When starting a new system, initially all tanks are stocked with 40 to 50 gram fingerlings. The following is an example of a four-tank system:

- After 24 to 26 weeks (about 6 months) from the date of stocking, fish from the first tank are harvested and the tank is restocked with 50 gram fingerlings.
- Six weeks later, the second tank is harvested and replenished with 50 gram fingerlings.
- Continue to tanks three, four, etc. at six-week intervals.

Using this schedule, each tank will produce two full crops per year, one every 24 to 26 weeks. The staggered system means that you never have more than one tank to deal with at a time and with sequentially smaller fish in each tank, there is never a system capacity overload, and there is a steady supply of nutrients for the plants. The initial stocking should not overload the system since the system is starting with zero nutrients.

There are other benefits of the staggered system, which include better nutrition and less stress for the fish. It is important that the fish are eating the right size pellets for the stage of fish growth, which is difficult to monitor with a mixed-size population. If each tank has a mixed-size population, all of the fish will be stressed when it is time to harvest the big ones. The staggered system also has the advantage of providing continuous cash flow (or food) throughout the year.

The fish density for the ebb and flow system is one fish per gallon. For an 800 gallon tank, approximately 820 fingerlings, using a 20% loss factor, would be stocked. With a four-tank system, approximately 3,280 fish would reside in the system at any given time. While this may seem to be a very high density of fish, in reality, given the staggered size of the fish and the fact that we use a 500 gallon-plus sump tank, the density is much less than it appears.
4.3 Feeding and Care

Several techniques can be used to feed fish. The simplest technique is: observe, observe and observe some more. The importance of daily observation of the fish (and plants) cannot be overemphasized. The most common cause of fish mortality is over-feeding—providing more fish food than can be consumed. Refer to Appendix B for more precise details on calculating the amount of fish feed necessary according to individual and total fish weight in the tank. In general, follow these procedures for fish feeding:

For newly introduced fish:
- In a new system, before adding the fish, allow the unit to operate for 48 hours, checking to ensure that there are no leaks and that the timer and pump are operating properly. Transfer the fingerlings to the fish tank as described above.
- Do not disturb the fish for 48 to 72 hours. This is important to allow the fish stress levels to subside and to become adjusted to their new environment.
- At the end of this period, add a small amount of powdered fingerling feed to the fish tank. Observe the activity of the fingerlings: Are they active? Are they eating? Are they rising to the surface? Observe whether they consume all of the feed within 30 minutes. In the event that the fish are not active and/or are not eating, wait 24 hours and try again. Do not feed more than can be consumed in 30 minutes.

For growing fish:
- Once it has been observed that the fish are active and feeding, begin increasing the amount of feed. Increase the feeding time from once a day to twice a day, and then ultimately to four times a day. Keep in mind that the amount of food at each feeding should not exceed what can be consumed in 30 minutes.
- Continue to feed the fish four times a day until the fish reach a weight of about 100 grams (0.2 lbs) or about 10 centimetres (4 inches).
- Fish weighing 100 grams and above can be switched to a feeding schedule of 2 or 3 times a day. Each feeding should still be no more than what can be consumed in 30 minutes.
- The last feeding of the day should occur by 5:00 pm. Feeding should occur at the same times each day as much as possible.
- As the fish continue to grow, it will be necessary to increase the amount of feed per feeding. Be sure that the amount of feed does not exceed the amount that can be consumed in 30 minutes. If food accumulates on the floor of the tank, stop feeding for 24 to 48 hours to allow the fish to clean up the residue.
• In the event that the fish have received more food than they can consume over a period of days, you will shortly notice that there is an odour coming from the tank. When this occurs, immediately isolate the tank (i.e., close connecting value), drain 1/4 to 1/3 of the water from the tank and replace with fresh water. Monitor pH, nitrites and nitrates; if these indicators remain outside of the safe range, drain another 25% of the water.

Some days, for reasons known only to fish, they will decide not to eat at one of the feedings. This happens quite often on cloudy days or the onset of pH issues. When this happens, skip a feeding or reduce the amount of food at the next feeding and check pH and water level. Some farmers only feed five days per week once their fish reach 100 grams to reduce the possibility of overfeeding. Feeding is as much an art as it is a science; constant observation is critical.

It is important to purchase the best quality of fish food available in the area. Some manufacturers offer special feed for fingerlings, which is in the form of a very fine powder. If this product is not available, grind the available pellets that are used to feed larger fish and use the powder to feed the fingerlings. Manufacturers often offer various sizes of pellets and formulations depending on the size of the fish. Care should be taken to provide a pellet size that is not too large for the fish to eat.

The observation approach to feeding fish should be used by all beginning aquaponic farmers. However there may be a time when a more exact approach may be useful, for example, if you want to compare the growth rate of two different strains of fish or test a new formulation of fish food. Detailed feeding calculations are included in Appendix B.

### 4.4 Managing Diseased Fish

As fish are living beings, they are susceptible to illnesses, injuries, stress, toxins and parasites, like all others. Although an ebb and flow aquaponic system is a closed system, this does not mean your fish will not experience issues that can cause harm or death. A few dead fish is not necessarily a cause for alarm, especially if it is within 48 hours of delivery. However, when large numbers die over a longer period of time, it is necessary to investigate and determine the cause. Remember that almost anything that is introduced to heal the fish will affect the plants and the system. Fish may die from a various number of factors such as:

- Oxygen depletion
- Bodily injury
- Stress
- Water pollution/toxins
- Diseases/illnesses
- Parasites
- Severe weather
The first line of defence is to make sure that the source of fingerlings is free of overt disease. Immediately remove any fish that are exhibiting strange behaviour or show signs of infection. If the death rate is excessive, isolate the fish tank, remove the fish, discharge all of the water, clean the tank with hypochlorite (10% bleach), rinse with clean water, wait 48 hours and refill with clean water. Restock with fingerlings at a higher than normal rate in order to rapidly increase the rate of nutrients.

4.5 Harvesting Fish

When fish are ready to be harvested, they should be placed into a separate tank of fresh clean water of the same temperature as the fish tank. The tank needs its own aeration system to provide adequate oxygenation. The live harvested fish should remain in the separate tank for 24 to 36 hours so that the digestive system of the fish is clean. This process will remove any objectionable taste or odours.

Do not feed the fish during this 24- to 36-hour period. Remove the fish from the cleaning tank and place them in an ice bath (crushed ice with a small amount of water). The ice bath will lower the body temperature of the fish and the fish will simply go to sleep. The fish should remain in the bath until sold to a customer. For the beginner farmer, fish should be sold as fresh whole fish product. Processing has certain sanitation requirements and equipment that only complicates issues for the beginner.

4.6 Fish Breeding

While fingerlings can be purchased (e.g., from the Ministry of Agriculture), fingerling production can also be an added component of an aquaponics system. INMED’s design, in particular, may be easily modified to accommodate fish breeding and fingerling production. This is done by using the centre grow bed as a breeding tank to hold brood stock, as a fry holding area and provide fingerling growth area. Procedures for fish breeding and fingerling production are described in Appendix C.
5. Plant Grow Beds

Crops grown in a well-maintained, optimally managed aquaponic system can produce substantial quantities of vegetables and fruits. Grow beds should be prepared, seeds planted/seedlings transplanted, plants monitored, diseases and pests managed, and produce harvested and sorted with an aim to obtain the highest quantity and quality of crop.

5.1 Preparing Grow Beds

The basic aquaponics grow bed is generally 4 feet (1.2 meters) wide by 12 feet (3.65 meters) long and 10 to 12 inches (25-30 cm) deep. The individual family food security system (single module) contains two basic grow beds (and one fish tank), and the medium-sized commercial system is eight to nine times the size with eight basic grow beds at 24 feet long (Appendix A). Each bed contains ¼ to ½ inch (6 to 12 cm) sized gravel to a depth of 6 to 8 inches (150-200 cm).

Prior to filling the beds, the gravel must be free from soil, sharp implements and other debris such as broken glass, nails etc., and rinsed numerous times with clean water to ensure there are no residual amounts of dirt or sand. Remember that this is a closed system and anything that enters the system stays in the system. The gravel must be rinsed until the rinse water is clear. Once the gravel is clean, it can be placed in the grow beds to a depth of 6 to 8 inches (150-200 cm). The clear water from the fish tank should be pumped to the beds and through the system for 48 to 72 hours.

During this period (before the fish have been introduced to the fish tank), the system is checked for leaks and the timer is adjusted so that the pump works for the correct amount of time. The correct amount of time is the time it takes for the water to rise in the bed until the water level reaches 1 inch (2.5 cm) from the surface of the gravel. In other words, do not flood the beds. This allows the gravel surface to remain relatively dry, reducing the possibility of infections and infestations of the plants. This period, the pump-on phase, usually takes 15 to 20 minutes; adjust the pump timer accordingly. Allow sufficient time, in the pump-off phase, for all of the water to drain back into the fish tank. The off phase usually lasts approximately 45 minutes.
5.2 Selecting Crops

Many different plants have been grown successfully in aquaponic systems. High-value crops such as herbs, lettuce, cucumbers, peppers and tomatoes have been produced most frequently for commercial use. Lettuce has been one of the more successful crops around the globe due to its short production cycle of 42-50 days. Lettuce also generally has low pest pressure, and income per unit area is high, depending on the market. Bush beans grow very fast in aquaponic systems, and several crops can be harvested during their growth cycle.

In Jamaica, sweet peppers and tomatoes are most lucrative. Basil, chives, cilantro and other herbs also are high-value, quick-production and high-demand crops, especially for the hotel and restaurant trade. Other successful crops include pak choy, callaloo, celery, okra, cabbage, cucumbers, strawberries and many other indigenous vegetables, fruits and herbs, although perhaps with greater competition from large traditional farms. The production of cut flowers can also be successful. Ultimately, you as the grower will select the crop combination for your aquaponic system, which you will determine during business planning.

5.3 Planting Seeds and Transplanting Seedlings

Before the seeds or seedlings are planted, the following things must be in place:

1. Water quality has been tested (Section 3).
2. The fish have arrived and are settled in over a period of 14 days (Section 4).
3. Grow beds are filled with clean gravel (see above).
4. Pump and timer have been in operation for 14 days.
5. Nitrification cycle has been initiated (this should occur if the first four steps are in place).

Now it is time to start plant production! This is the first crop and a learning opportunity, so start with something easy. Lettuce is a fairly easy plant to grow and has growth characteristics similar to many other leafy plants, and the nutrient requirements are quite modest. This is important as we wait for the nutrients to accumulate in the fish water. However, any crop or combination of crops may be grown at any point in your aquaponic system.

There are two methods of germination that are used in the grow beds of an aquaponic system: seedling transplants and direct planting of seeds. Direct planting of seeds into the grow bed is the simplest method used in plant production. An example of a seed that works well using this method is bush beans, which is a large seed that will not easily wash away through the gravel and pipe system. In this example, the bean seed is pre-soaked and planted directly in the gravel bed. Beans are best planted in a predetermined grid to make maximum use of space (Figure 5-1). Broadcasting, or random distribution of seeds, is not recommended for maximum efficiency.
The other option is transplanting seedlings, which is recommended for smaller seeds. Seedling production requires a nursery system that produces young plants that can be transferred to the grow beds after about 14 days, depending on the plant. For this reason, seedlings should be started at the same time as the stocking of the fish tank. Some vegetable seeds may require a longer period of time to germinate, but any seedling may be transplanted once it emerges from the growth medium and leaves begin to appear. Below are general guidelines for seedling production and transplant:

- **Week 1**: Establish the nursery site. Plant the seeds in transplant trays containing compost or a growing mixture, but definitely **not soil**. Lightly spray the surface of the growing medium with water from the fish tank 3 to 5 times a day. Keep the mixture damp but do not saturate the seeds.
- **Week 2**: Continue spraying the surface with the fish tank water until seedlings appear (about 7 to 10 days). Discontinue spraying when the first leaves appear, but keep the growing mixture damp.
- **Weeks 3 to 6**: Transplant the seedlings to the grow beds using a grid that has been designed for proper spacing (see plant management section below). Gently rinse the root system to remove any and all growing material that may be present before you transplant the seedlings. Inspect your plants daily, looking for any signs of disease or pest infestation. This can be done at the time that the fish are being fed. Any plants that look stressed should be removed and destroyed. If pest insects appear (e.g., aphids), remove by hand. If pests appear in large numbers, begin spraying plants, using water from the fish tank, 4 or 5 times a day.
- **Weeks 7-8**: About 28 to 35 days after planting the seedlings in the grow beds, the crops should be ready to start harvesting. Fruit-bearing plants, such as peppers, will produce multiple harvests before the plant loses capacity to produce and needs to be replaced.

### 5.4 Plant Management and Care

When implemented correctly, the grow beds can sustain growth rates 10 times that of conventional gardening in the same amount of space. This production rate can be achieved by using close cropping techniques: for lettuce, for example, rows should be 2 inches (5 cm) apart and the plants within the row should be 1 inch (2.5 cm) apart; while peppers should be about 1 foot (30 cm) apart and (when taller) trellised. In INMED’s current systems in Jamaica, 5,000 lettuce seedlings have been planted in a single 4-foot (1.2 meter) x 24-foot (7.2 meter) grow bed. Details for sweet pepper production are provided in Appendix B (Table B-9). There are four production strategies that can be used for vegetables:

- **Staggered crop production** utilizes a **single type of plant in different stages of growth**. For example, Bibb lettuce production has an initial grow time of 0 to 14 days in the nursery to develop into seedlings, and 4 weeks developing in the grow beds before harvest. For staggered production, divide the grow space into six even sections and stagger the nursery seed planting and seedling transplanting one week apart so that once a week there is a fresh crop of lettuce for sale to local consumers (see Appendix B for seedling production). Red leaf lettuce and green leaf lettuce require a 7-week cycle.
• **Harvest and return system** is a modified form of the staggered strategy that does not necessarily involve sectioning the grow bed. For example, bush bean seeds are planted directly in the growth media of the grow bed. Plantings occur over several weeks so that the plants will not mature at the same time. Crops are harvested one day and a new crop will appear several days later that requires harvesting. Staggering the planting will allow viable plants to be present over several months.

• **Batch systems** are more appropriate for crops with longer growth cycles (> 3 months), such as tomatoes and cucumbers, where the entire bed is planted and generally harvested at the same time.

• **Intercropping** can be used with a batch system. For example, bibb lettuce can be planted between the tomato or cucumber plants and harvested before the tomato plant canopy blocks the sunlight.

For commercial production, the staggered method is the most widely used system to allow for continuous harvesting. This method and the use of closely spaced plants provide maximum production and assure that the customer is always supplied with fresh produce.

### 5.5 Managing Pests and Diseased Plants

The greatest deterrent to plant disease is the “shadow of the farmer.” Daily inspection and a clean environment are the key to preventing outbreaks of pests and disease. It is essential that the farmer inspect the plants daily for stress and the presence of pests. The first line of defence is prevention. Plants that show signs of stress should be removed immediately and any insect pest should be removed by hand and destroyed. The surface of the grow beds must be kept free of debris or other materials where pest may hide or where disease microorganisms may flourish. At the first sign of infestation, spray plants with water from the fish tank 3 or 4 times a day. In many cases, this will control infection. Why this works is not entirely understood, but it is probably due to the presence of organic material and microorganisms that are antagonistic to plant pathogens.

**Harmful chemical pesticides cannot be used on plants**, as they will kill the fish. Do not use soap to treat plants, as soap will accumulate in the system and eventually kill the fish. Similarly, **chemicals and drugs used to treat fish for parasites and disease cannot be used**, as these agents will concentrate in and affect the health of the plants. The practice of adding common table salt (NaCl) to the fish tank to treat fish diseases or reduce nitrite toxicity, for example, is harmful to the plant crops. Therefore, only an integrated pest management system can be used in the aquaponics system. The integrated system is composed of the following:

• **Biological control** includes:
  - Planting crops that are genetically resistant to specific diseases
  - Planting barrier crops like lemongrass around the system
  - Introducing pest predators, for example, the wasp predator for whiteflies
  - Introducing pest pathogens, for example, the following bacteria and fungi:
• *Bacillus thuringiensis*, which can be sprayed onto plants to kill caterpillars without affecting fish or plants.
• *Bacillus subtilis* QST713, which is a broad-spectrum product that provides protection against a wide variety of the most common fungal and bacterial plant diseases.
• BotaniGard is a new product that contains the fungus *Beauveria bassiana* Strain GHA, which controls whitefly, aphids, thrips, psyllids, weevils and mealybugs (see Appendix B for additional information on pest control).

• **Temperature control** is important for crops where Pythium is a problem. Pythium attacks plant root systems, but can be controlled by keeping the water temperature below 27°C (81°F). Spider mites thrive in temperatures above 29°C (84°F) and dry environments.

• **Physical control** includes barriers, traps and physical manipulation of the environment. Keeping insects off of plants is a primary line of defence, and may include the following:
  o Floating row covers are one of the most effective methods of deterring insect infestations. Covers can be fitted directly over the grow beds and at the same time allow sufficient light for normal plant growth.
  o Diatomaceous earth (food grade quality) is effective in preventing ants, fleas, cockroaches, thrips and especially aphids. This product can be spread along the top walls of the grow bed to act as a barrier to the invading insects. If the diatomaceous earth absorbs water, it must be replaced.
  o Orange oil is used to prevent ants. This product kills on contact and disrupts the chemical trails that ants use to attack the system. **Orange oil should be used only on the ground** where the ant colony lives, and not in the aquaponics system, as orange oil will stick to fish gills and kill them.
  o **Spray affected plants three or four times a day with water from the fish tank.** Using a forceful stream of water will mechanically remove the pest and also provide some protection from the biological action of the fish water. This practice was mentioned above, but it cannot be overemphasized in its importance as a first line of defence.

Prevention is key to a healthy system. The first step is good hygiene: do not allow organic materials to accumulate around the system. All weeds and plant material must be cleared to a distance of 10 feet (3 meters) or more from the system to ensure that there are no hidden breeding sites for insects and disease organisms. Remember the general rule that if there are ants, there will be aphids. **Smoking should be prohibited on site,** and smokers should wash their hands before entering the system area. Tobacco is infected with a virus known as tobacco mosaic virus. This virus can cause disease in many species of plants, especially tomato plants. Restrictions on the use of pesticides are more challenging than the usual way of protecting traditional farming crops where pesticides are applied. However, these restrictions are critical to ensure that the crops are grown in an environmentally friendly way and that they are free of pesticide residues that might affect the fish (and human consumer). A major advantage of aquaponics production is that the crops are free from soil pathogens. As mentioned above, the use of nutrient-rich water from the fish tanks bestows some advantages that are not fully understood but very effective.
5.6 Harvesting and Sorting Plant Produce

The time has arrived to harvest the crops! The process described below is primarily for use in commercial operations, but a modified version can be used for home food security systems.

A designated area should be set aside to process all produce. There should be a clean source of running water and a sink with a large non-porous surface working area. The cleaning and processing site should be under cover for protection from the sun and rain. Wash hands thoroughly with soap and warm water. Wash all surface areas with a rag soaked in a 1-to-10 solution of bleach (hypochlorite) and water. This solution should be prepared in advance in a small plastic tray with enough room for a small cloth. Hypochlorite is one of the safest bactericidal agents available. Read the dilution instructions on the bottle.

After cleaning the processing surface with the diluted bleach solution, let the surface area dry before using. Clean cutting and other tools with the bleach solution. For most crops, harvesting should occur during the early morning hours. This will ensure that the plants are not stressed by heat, and this is the time when the plants contain the highest levels of plant sugars. Step-by-step processing procedures include the following:

- Wash hands thoroughly with soap and water. One of the greatest sources of food contamination is from dirty or improperly cleaned hands.
- Use hypochlorite-cleaned and very sharp cutting knives to reduce damage to produce. Place the harvested produce on the disinfected surface area. Do not allow produce to touch the ground; if this happens, discard the item. For produce where the whole plant is removed, immediately wash the roots and, where appropriate, remove the root system and discard them in a safe manner. Some customers require that the roots remain on the plants.
- Remove any bruised or discoloured produce or leaves that show signs of insect infestation. Remove any insects or worms that might be present.
- Inspect and rinse produce in cold water.
- After rinsing, immediately immerse the produce into a previously prepared ice bath. The ice bath is prepared with a half bucket of ice in a sink filled with water.
- Dry the produce by spinning or using an absorbent material.
- Store the produce in a container at a temperature of 35°F (1.7°C) and rush to market. An ice chest can be used where there is no refrigeration.
- For batch crops, such as beans or other “cut and return” crops such as basil, follow a similar pattern as described above.
6. Maintenance and Monitoring

Maintaining your aquaponic system is very important for long-term success, including routine monitoring and maintenance of the system and barrier area, record keeping to track care, feeding and other activities, setting up site security, and preparing for potential power outages.

6.1 General System Maintenance

The components of the system are varied and must be maintained regularly for proper performance. It is best to do major maintenance or repairs between crop and fish harvests, but it is essential to check each element daily. The main components/features to monitor include:

1. Tank water
2. Fish and fish tanks
3. Plants and grow beds/gravel
4. Water drain pipes
5. Spray pipes/nozzles
6. Wooden frames and netting
7. Surrounding environment

It is vital that each of these components be checked to ensure that all is working correctly and that there are no problems. Check these elements daily at time of feeding:

1. The surrounding environment is clean and clear of debris such as grass, leaves and weeds, as this can be a source of pest infestation.
2. Monitor the fish for signs of erratic swimming or stress and to be sure that they are eating sufficiently. Remove any dead fish from the tanks immediately.
3. Look for plants that might be infected or showing signs of stress. Remove immediately and destroy any plants with these signs. Check any trellising to ensure that it is stable, and prune any plants that need it.
4. Check that the tank water is clean, clear and has no debris. Check that the tank cover, if used, is in place and that there are no signs of algae bloom. Test the water temperature and pH and ensure that they are within the required range.
5. Check that all water pipes are connected and not leaking, and water is flowing freely.
6. Spray pipes and nozzles must be cleaned weekly or more often if needed. Ensure that water can flow out of the sprays and nozzles with little effort. Mould should not be allowed to build up on pipes and nozzles.
7. Grow beds and gravel must be checked to ensure that there are no structural issues and that the water is flowing freely through the gravel. If the water comes up too high and is above the top level of the gravel, moulds and fungi will grow on the gravel. If the water level is too low, the plants will not get the water and nutrients they need to grow. Adjust the pump timer to adjust water flow, if needed.
8. Fish tanks must be checked daily for leaks or structural damage. Ensure that the area around the tanks is clean.
9. Wooden frames and shade netting should be checked for tears or damage, and repaired as necessary.

Also, after a major harvest, grow beds should be isolated from the system and the gravel cleaned of roots and other debris and rinsed with clean water before replanting.

### 6.2 Record Keeping

It is important to document and keep records of the aquaponic system, implementation, maintenance and production. INMED has developed forms that capture this information. Record keeping will allow you to keep track of the harvest of fish and plants, fish mortality that might occur and problems that may arise. It also enables calculation of input costs, sales prices and ultimate profit. This information will be valuable in the future for expanding your business and for bank financing. Although record keeping can be a chore, it is essential to the success of the operation and business. Appendix D includes the following forms and templates:

- Aquaponics Input Cost Log
- Tilapia Feeding and Water Quality Data Log
- Crop Activity Log
- Production and Sales Record

### 6.3 Site Security

It is an unfortunate fact of life that we live in a world where security must be considered. If you have invested money in an aquaponic system, you do not want to discover that your fish, crops or solar power system have been stolen. This is an important factor in your considerations but also one of the more flexible factors, as there are many different ways to secure your system and ensure that your investment is safe.

Your first step should be to determine and understand the threat to your property. Ask yourself what needs to be protected then consider the 3 Ls: Lock, Light and Limit access. Don't make the mistake of installing a protection system and implementing security measures without identifying what is most at risk; doing so could prove costly, ineffective and/or inadequate. An effective physical protection system is based on 3 principles: **deterrence, detection and delay**.

Deterrents may include lighting, fencing, brush clearing and guard animals. Lighting may frighten off intruders, so motion sensor lights may be installed. Ensure that the lights are mounted up high so they cannot be tampered with or broken. This will also help in lighting a larger area. Gates and high fences or walls that limit access to the property will also deter the opportunistic thief. Ensure that gates can be locked when required and that walls/fences are high enough to control access. You are not only trying to limit vehicle entry but also foot access. Visibility is critical to see an intruder before reaching your system. Keep the surrounding area clear of bushes/shrubs to limit hiding places, and keep the grass short. Animals such as guard dogs may also be a deterrent, as their barking will notify you of and might scare off an intruder. Other animals should be kept away, however, such as cats that will steal fish if tanks are not secured, and goats who will eat the plants.
In addition to deterrence, detection and delay are important for security. The purpose of a detection system is to alert you when someone enters your property. Devices such as motion light sensors, cameras and alarms can be very effective. Effective delay tactics can be employed to allow enough time between detection and access. Locks on doors/gates/tanks help with delaying access of a thief to your system.

If you have a solar power system, it is vital that it be as secure as possible, as this is an item that is often stolen. Bolt the panels and weld the panel frames to the roof so they cannot be easily removed. A welded panel takes far longer to release from the roof than a bolted one.

**Figure 6-1. Battery Security Cage**

Batteries also need added security, as they are a very desirable item. Dig 4 to 6 inches (10 to 15 cm) down into the ground and pour a foundation of cement that is wider and longer than the batteries. Insert the battery cage into the wet cement. Ensure that it is well attached to the cement. Lock your cage with at least two, and preferably more, locks. If you have a secure building nearby, you can bolt the cage to the floor in one of the rooms (which should have a secure lockable door) and run the cable underground to the system’s water pump. The cable should be placed about 2 to 3 feet (50-100 cm) below ground, cemented in and then covered with soil. If possible, your sump tank should have a security structure placed over it that may be locked and lifted as required to protect your submersible solar pump.

### 6.4 Power Outages

The heartbeat of the aquaponic system is the water pump, which allows for the circulation of water. Like blood circulating in the human body, it brings oxygen to the fish. The pump comes on for roughly 15 minutes of every hour, and it is essential for the health of both the plants and the fish that it does not stop working. If it stops for more than three hours, the fish will start showing signs of stress; the longer the time it remains inoperative, the greater chance that the fish will die.

The plants will also show signs of stress if the water is not circulated on a regular basis. If it is a very hot day and no water flows through the system, plants will start to wither and may eventually die. Under these circumstances, hand irrigate with water from the fish tanks 3 or 4 times a day until the pump is restored.

If you live in an area where power outages are frequent, it is advisable to have a back-up power source. Backup battery systems kick into action the second the regular power supply is disrupted. When the regular power source returns, the battery cuts off, recharges itself and is ready for the next outage.
If budgets allow, solar power should be your main source of power. It is highly unlikely that you will suffer major issues of power outages with this type of system. Nevertheless, it is advisable to have a battery system with sufficient capacity to allow for down time. When there is a solar power outage, it is advisable that all non-essential systems be switched off for the duration to maintain power for the water pump. Electrical grid power may be used as back up.

6.5 Pump Failure

One other consideration that will critically affect your system is water pump failure. Without proper maintenance, this will happen in due course. The number one issue with good quality pumps is that the contact brushes inside the pumps will eventually wear. To avoid this, preventative maintenance is best; during the ebb period of the cycle, have an electrician examine the brushes and service your pump. It is essential to keep the pump’s user manual and buy spare brushes to keep at hand. This will save operations repair costs later. Another consideration is to securely store a back-up pump on site that could be activated in an emergency.
7. Troubleshooting

Some common problems that you will likely face during aquaponics operations include nutrient deficiencies, fish mortality, water quality imbalances, and system blockages and leaks. These issues, when identified through monitoring, can be addressed as described below.

7.1 Plant Nutrient Deficiencies

Leafy greens do very well in an aquaponics system. This is because the plants get ample supply of one of the three major nutrients they require, nitrogen, as well as the other two, phosphorus and potassium. However, all plants require 16 minerals to grow optimally. The three key plant nutrients, nitrogen, phosphorus and potassium, are considered major plant nutrients, without which plants simply cannot survive.

Crops, especially fruit-bearing crops like tomatoes and sweet peppers, require a well-balanced portion of all these 16 elements in the right quantities to bear optimally, which are supplied naturally in an aquaponic system by the fish waste and nitrification cycle. When there are deficiencies, however, plants will show these deficiencies in their appearance. Knowing these signs and correctly addressing them by providing supplementary nutrients in the form of additives can make a big difference for production. The details of identifying and addressing deficiencies are provided in Appendix B.

7.2 Fish Mortality

If you have ever had an aquarium, you will know that when it comes to raising fish, whatever can go wrong will go wrong. It’s a normal part of dealing with fish, so don’t panic. Fish will die. Apart from issues relating to transporting fingerlings and mortality related to their displacement, which is addressed in Appendix B, two factors are most commonly responsible for fish mortality: overfeeding and poor water quality. These issues are also addressed in Appendix B. However a quick solution to correcting the two causes is to:

1. Stop feeding the fish for a day or two
2. Remove all dead fish and bury them some distance away
3. Check water quality, reduce the water level by 1/4 to 1/3, then top up with clean water
4. Repeat steps 1-3 once more, check the pH and adjust accordingly. Do not change pH dramatically; a sudden change is far more harmful than the pH level itself.

7.3 Water Quality Issues

Prevention is always better than the cure. Here are some of the issues that one might encounter related to water quality:

- Dirty sedimentary water, usually caused at the start-up of a system by unclean gravel or soil entering the system. Ensure that gravel and roots of seedlings are thoroughly washed before entering the system.
• A foul smell from the system’s water, which is usually caused by overfeeding (excess feed sinking to the bottom and decomposing) and/or insufficient oxygen. Decomposition causes anaerobic conditions, limiting available oxygen. To address this issue, stop feeding the fish and physically remove excess feed at the bottom of the tanks using fine nets. Another method is to pump air to the bottom to discourage settling of the feed. In extreme cases, a complete water exchange may be necessary.

• A system that has over-diluted water, which is primary caused by too much water exchange, in other words too much fresh water going into the system either by rainfall or by topping up too frequently. While this is good for your fish, it’s not good for your plants, as they will become nutrient deficient. If you find that you are topping up too much, then you likely have a leak in the pipe system that must be fixed. The solution for too much rainfall is to cover the entire system with plastic using a greenhouse-type structure (described earlier).

7.4 Blockages, Overflows and Leaks

If you do not follow a strict routine in maintaining your system, blockages will likely result. The spray nozzles are the first to become blocked in the system. This is caused by the build-up of sediment, fish waste, algae and bacteria in the pipes and nozzles. The simple solution is to regularly pull off the nozzles and flush them out with clean water outside of the system.

The next part of the system to become blocked is the drain pipes embedded in the grow beds, which is caused by the same problem described above. You will notice this problem if the grow beds start flooding and there is no water draining back to the fish tanks. Use a >25-foot long ½-inch PVC pipe with a small enough brush or sponge attached to one end to flush out the drain pipe. The drain pipe has caps at the back end that should be removed so as to push the sediment blockage toward the end away from the fish tanks.

The drain holes may also be blocked or too small, causing the return to take longer than 45 minutes. Usually this problem is identified at the start-up of a system. To address this, the gravel along the drain pipe has to be removed and larger holes bored into the pipe. Remember, however, that the holes must be smaller than the gravel size so as not to flush the gravel out of the grow beds.

If the fish tanks overflow, the connecting tank pipes may be blocked or an isolated fish tank valve may be turned to the off position. Usually the tank with the overflow is the one with the blockage. The blockage is usually at the bottom of the affected tank where the pipe enters the tank. If the pipe is capped, simply remove it to solve the problem. If it is not capped, then unclog the blockage by entering the tank and inserting a flexible wire or tube to dislodge the blockage.
Overflows may also be caused by poor timing on the timer or a malfunctioning timer that fails to initiate the pump on schedule. You will notice this if the sump tank is below normal pumped levels. This situation requires urgent and immediate action. Disconnect the power supply and start topping up your system with water and until the timer is repaired; manual timing of the pump may be necessary.

The system will likely have some leaks, particularly where the pipe fittings are connected. This is because the pipe fittings are not cemented at the joints, specifically to accommodate cleaning and trouble-shooting. If the connection is too loose, however, leaking may become excessive. To address such leaking, a thin plastic material may be used to wrap the inserted end of the pipe carefully, so as not to block water flow, and reinsert into the receiving fitting. This should make the connections fit more tightly.

If there is a major leak in one of the tanks or grow beds, that tank or grow bed will have to undergo moderate masonry. To do the repairs, one should isolate the affect tank or grow bed prior to the repair. In this manner, your operations should not be severely affected. Once repaired, the isolated tank or grow bed can be re-joined with the system for continued operation.
8. Essential Business Plan

A business plan is a roadmap for your aquaponics business. It is both process and product. During the writing of an aquaponics business plan, you'll develop an overall vision and mission for your business. You will think about your short- and long-term goals. You'll define the steps needed to achieve those goals. Finally, you'll set the direction for your business to develop over the next three to five years. If you're already an established farming business, your new business plan will show where you're going next with aquaponics. A good business plan should be simple, realistic, specific and complete.

Writing a business plan is a big project, but don’t let that put you off. Your plan can be as simple as it needs to be for right now. Begin with your mission statement and goals. Do your homework by analysing markets and researching markets and trends. Have fun brainstorming alternative strategies and let them marinate a while. Take it one step at a time. Remember this is a work in progress, which will evolve over time. Plan as much as you can in advance, and be prepared to continually adapt along the way.

8.1 Mission Statement, Goals, Objectives and Background

Your mission statement is the overarching purpose for your aquaponics business. Why do you have or want to start an aquaponics business? What purpose does it/will it serve? Where is it headed? This may include, but is beyond, “make money.” This mission statement is based on your values and your core identity.

The goals in your business plan are the specific, measurable “things” you will achieve with your aquaponic system. Short-term goals are defined as those that you will complete within one year. Long-term goals are those that take longer than one year to complete. Although this is a business plan, if some of your goals are food security and/or educational objectives, list those as well. Action-oriented objectives can also be identified under each goal to help reach it. Goals and objectives should be “SMART” or:

- Specific
- Measurable
- Attainable
- Realistic
- Time-scaled

After establishing a mission statement and goals, your business plan should include a background section, including an inventory of what you have right now. Where are you located? How much space do you have? How does aquaponics fit with what you have been doing? How are you currently operating and for how long? What general practices do you use for such things as conservation, environmental impact and marketing?
8.2 Business Strategy, Implementation and Marketing Plans

The next section of your business plan is the strategy, where you take the opportunity to look forward and plan. You are going to formulate your aquaponics business strategy from now into the next three to five years or more.

1. Gather information and research markets. Make sure that your aquaponics plan fits into the general market in terms of supply and demand. Investigate and analyse industry trends, identify competitors, and define buyers.
2. Conduct a SWOT analysis. This is an analytical tool that can be used to help make decisions. SWOT stands for strengths, weaknesses, opportunities and threats. As a business, analyse your internal strengths and weaknesses. Then look externally at what opportunities and threats exist—for example, competitors, new markets, government regulations, economic conditions, and so forth.
3. Create alternative strategies. Looking at the information you’ve gleaned and the analysis you just did, think through options for your aquaponics strategy. Do not rely on price alone: economies of scale are challenging at the individual system level, but may be worth the initial investment, if feasible, to reach greater returns. Spend time fleshing out the specifics of your strategies and looking at their advantages and disadvantages. Try to find options that combine your internal strengths with opportunities in the external environment (e.g., consider consolidating with other producers in the region).
4. Look at all your strategies, then reread your mission statement. The ideal plan should fit within your mission.

Based on your overall strategy, write a more detailed implementation plan, identifying each step you will take to make your new aquaponics business strategy happen. Finally, complete your planning process by developing a marketing strategy for your products and services. This can build on the research you did in the previous step. For each product, include price, placement and promotion ideas. Consider how you will convey real and perceived value to your customers, and maintain your business relationship.

8.3 Business Management and Financial Analysis

The section of your business plan details your business’ structure. Everyone who is involved in the management of the business should be listed here. External resources are listed here as well. An organogram or other graphic may be developed to show relationships among multiple business partners, if appropriate.

Another section of your business plan will detail the financial information of your aquaponics farming business. List your current finances in detail, including all income and operating expenses. Referring to your new strategy, forecast what is needed for future growth and to meet the goals you have outlined in terms of capital. Also include what your future operating expenses will be. If you are an institution using some or all of the produce internally, include the cost savings from reduced purchasing costs, and include that as revenue against the operating costs of your aquaponic system. See Appendix E for a business and financial model.
Appendix A

Aquaponics System Construction Manual
AQUAPONICS SYSTEM CONSTRUCTION MANUAL
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1. Summary of Aquaponics Construction

This appendix provides photographs for a single system set-up and engineering drawings to accompany these instructions. It also includes photographs of a multi-modular system and an overview construction drawing. Generally, the detailed description provided below is not necessary for professional builders, who can refer to an engineering drawing to carry out the build. However, these step-by-step instructions may be used for added clarification.

This construction manual describes the steps for building a single-family aquaponics modular unit. This unit includes a single 650-gallon concrete fish tank, situated partially underground, and two 48 square-foot concrete grow beds, raised above ground, all of which are connected by a water pipe system. This single unit will support approximately 300 mid-sized fish and multiple crop plants, which is expected to feed a family of four with surplus for income.

The following steps are described in more detail in the instructions below:

1. Materials for single aquaponics unit
2. General layout and hole digging
3. Wire mesh, steel rebar, and concrete for fish tank and grow bed foundations
4. Wooden forms and concrete for fish tank walls
5. Wooden forms, wire mesh, and concrete for grow beds
6. Wooden form removal and water pipe placement

2. Materials for Single Aquaponics Modular Unit

The following materials are needed for a single aquaponics unit, which are available in major hardware stores:

- BRC fabric (wire) mesh (7' x 17'), 2 sheets
- Corrugated steel/rebar, 10 sticks
- Binding wire, 2 lbs
- Discs for grinder (4.5" diameter x 3/32" x 7/8" hole), 5 discs
- Grey cement (96 lb bag), 35 bags
- Rough sand, 4 yards
- Crushed stone (1/2"), 4 yards
- Building block (8"), 40 – only if not pouring concrete for grow bed footings
- 1/2" x 1' PVC pipe (cut from 20' length) for overflow pipe
- 2" PVC pipe (2" x 20'), 2
- 2" PVC end cap, 4
- 2" PVC elbow, 2
- 1" PVC pipe (1" x 20'), 3
- 1" PVC end cap, 26
- 1" PVC slip tee, 25
- 1" PVC 90-degree elbow, 2
- ¾" male pipe thread to ¾" slip fitting – depending on pump thread size
- 1" slip by ¾" slip reducer – depending on pump thread size
• ¾" PVC pipe 3" long – *depending on pump thread size*
• Water pump with ¾" female pipe thread output
• Aerator (air pump), air stones, and tubing
• Backup power (car battery) and inverter and trickle charger
• Shade (structure)
• Timer (for pump)
• Gravel/plastic bedding (estimated 24 cu. ft.)
• Duckweed vats – *only if cultivating separately as fish food*

The following materials are needed for constructing the wooden forms, which are reusable and guide the concrete pouring (nails that are ruined during form removal will need to be replaced for building the next aquaponics unit):
• Construction plywood (5/8", 15 mm), 22 sheets
• Lumber (2" x 4" x 14"), 22 pieces
• Galvanized wire nail (2.5"), 5 lb
• Concrete nail (3"), 5 lb

The following tools are used for building the aquaponics unit, including form construction and set up, and are reusable for building all aquaponics units:
• Hammer
• Carpenter square
• Levels (36" and/or 48")
• Measuring tape (min. 100')
• Hand saw
• Circular saw
• Grinder
• Drill and drill bit set
• Extension cords
• Plastic bucket (for concrete)
• Metal concrete float
• Trowel
• Wrecking bar (36")

### 3. General Layout and Hole Digging

In consultation with the recipient of the aquaponics unit, the location is identified and the general layout is marked for the future aquaponics unit, measuring the outside boundary of the entire unit to accommodate a single fish tank and two grow beds (see Plates 1 to 5). Within the layout, stakes are placed at each corner, spray paint is used to outline the holes, and holes are dug for the fish tank (one) and the grow bed foundations (six total) which support the footings for two grow beds (see Photograph 1). The dimensions for the layout and holes to dig are provided below:
• Outside boundary of entire unit: 11' 10" wide (to accommodate two grow beds at 4' 8" + 2' 6" space in between) by 19' 8" long (to accommodate 12' 8" grow bed + 7' fish tank).
• Outside fish tank dimensions: 7' by 6' (outside of concrete walls) by 24" deep below grade (plus 16" above grade).
• Outside grow bed dimensions (each): 12' 8" by 4' 8" (outside of concrete walls) with three footings supported by three 4' 8" by 16" by 8" deep (below grade) foundations; 3' 4" between the three footings (and 2' 6" between the two grow beds).

4. **Wire Mesh, Steel Rebar, Concrete for Tank and Foundations**
   After the holes have been dug, the wire mesh and steel rebar are placed and tied with binding wire in preparation for pouring the concrete floor of the fish tank and foundations of the grow bed footings (see Plates 6 and 7). The measurements for the wire mesh, rebar, and concrete for the fish tank (bottom and walls) and grow beds (foundations and footings) are provided below (see Photograph 2):
   - **BRC fabric (wire) mesh for fish tank:** 7' by 6' with 3" free ends all around that are bent up for a finish size of 5' 6" by 6' 6" with 3" bent up. From the factory-sized mesh (2 pieces at 17' by 7'), cut 13' 8" by 7' pieces from each (for future use) and take the remaining pieces (17' – 13'8" = 3' 4" by 7') and tie together with binding wire (overlapped 4" each way) for fish tank bottom.
   - **Vertical steel rebar for fish tank walls:** Twelve pieces at 3' 2" with 6" 90-degree bend on bottom.
   - **Horizontal steel rebar for fish tank walls:** Six pieces at 8' 6" with 24" 90-degree bend, and six pieces at 5' 6" with 15" 90-degree bend.
   - **Vertical steel rebar for grow bed foundations and footings:** Twelve pieces at 30" with 6" 90-degree bend at bottom.
   - **Horizontal steel rebar for grow bed foundations and footings:** Twelve pieces at 4' and eighteen pieces at 13", which provides two pieces at 4' and three pieces at 13" per foundation/footing for the two grow beds.
   - **Concrete blocks for grow bed footings are placed on top of cured concrete foundations (alternately, wooden forms and concrete can be poured):** approximately 40 total, which provides six blocks per footing (three footings per grow bed, two grow beds).
   - **Pour concrete:** Sand, gravel, and cement mixed in an equal ratio of 1:1:1 for fish tank bottom and grow bed foundations (and, if desired, footings).

5. **Wooden Forms and Concrete for Tank**
   After the bottom of the fish tank and the foundations/footings for the grow beds have been laid and cured, the removable wooden forms are set up to guide pouring concrete for the fish tank walls (see Photograph 3). The dimensions of the pre-made fish tank forms (inside and outside walls) are provided below, followed by instructions for placing the forms and pouring concrete.
Fish tank form walls (inside and outside) are pre-made with permanent pieces:

- Inside fish tank walls (plywood): Two pieces at 3' by 4' 10 ¾" (short walls) and two pieces at 3' by 6' (long walls).
- Inside fish tank wall permanent vertical posts (2x4s): Four posts total, one at each corner at 3' lengths mounted on short walls.
- Inside fish tank wall permanent horizontal beams (2x4s): Two beams at 4' lengths mounted on short walls 16 ½" from top, and two beams at 5' lengths mounted on long walls 18" from top.
- Outside (above grade) walls of fish tank (plywood): Two pieces at 16" by 7' (long walls) and two pieces at 16" by 6' 1 ¼" (short walls).
- Outside fish tank wall permanent horizontal beams/bracing (2x4s): Two beams at 7' 6" mounted to outside of long walls; top of beams are centered vertically and horizontally (8" from top). Two beams at 6' 6" mounted to outside of short walls; bottom of beams are centered vertically and horizontally (8" from bottom). Short wall beams sit on top of long wall beams at corners (labeled #1-4 where they overlap).
- An inside and an outside long wall have ½" holes that line up for overflow drain pipe.
- Outside fish tank wall permanent "top hat" fittings: Four pieces at 6 ½" placed at corners of short walls for "top hat" (to squeeze long walls together).

The pre-made fish tank form walls are set up and secured with removable pieces:

- Inside fish tank free-floating horizontal cross bracing: Two free-floating horizontal braces at 5' 10 ¾" lengths placed parallel to long walls, and two at 4' 10 ¾" lengths placed parallel to short walls (placed on floor, unattached to walls).
- Inside fish tank wall removable horizontal cross bracing: Labeled #1 through #5 (penciled on 2x4 braces and corresponding walls, in order of assembly). Numbers 1 through 3 at 4' 10 ¾" placed parallel to short walls, and #4 and # 5 at 5' 10 ¾" placed parallel to long walls (midway on walls).
- Inside fish tank brace temporary pinning: 3" concrete nails placed in pre-drilled holes (3/16" drill bit) in horizontal bracing, part-way for easy removal and disassembly.
- Inside and outside removable "top hat" to hold walls in place: Two pieces at 7' 4 ½" for "top hat" bracing; numbers line up with those penciled on outside of fish tank walls.
- Beams/bracing permanently attached to walls, but held together as a box by removable pins: 3" concrete nails placed in pre-drilled holes (3/16" drill bit) in beams/bracing, part-way in for easy removal and disassembly.
- Place ½" PVC overflow drain pipe through inside and outside walls.
- Pour concrete: Sand, gravel, and cement mixed in an equal ratio of 1:1:1 for fish tank.

6. Wooden Forms, Wire Mesh, and Concrete for Beds

Either in conjunction with pouring the concrete fish tank walls or after the concrete has been poured and cured to complete the fish tank (and wood forms removed as much as possible), the removable grow bed forms (outside and inside) are set up (see Photograph 4). After forms are set up, wire mesh and 2" drain pipe are placed, and then concrete is poured.
The dimensions of the pre-made grow bed forms (bottom and walls) are provided below, followed by instructions for placing the forms and pouring concrete. Grow beds A and B are set up with their respective (labeled) pieces in relation to the fish tank (see Photograph 5).

Each grow bed form is pre-made with permanent pieces:

- Each footing (6 total, in lieu of concrete blocks): Two pieces at 15 3/8" by 4' pinned to two pieces at 8 5/8" by 15 3/8" with 2x4s permanently attached (for pinning).
- Outer grow bed bottom: Two pieces at 5' ¼" by 4', one piece at 1 ¾" by 5' ¾", and one piece at 1' 2" by 5' ¼".
- Outer grow bed sides: Two pieces at 12' 8" by 12" (wrapped in 2x4s, top and bottom).
- Outer grow bed ends: Two pieces at 4' 9 ¾" by 12" (wrapped in 2x4s, top and bottom).
- Inner grow bed structure (“ladder”): Nine pieces at 6 ½" by 3' 10 ¾" placed every 16".
- Inner grow bed sides: Two pieces at 8" by 11' 10 ¾".
- Inner grow bed ends: Two pieces at 8" by 4' with 1 ½" notches cut for drain pipe.

Each pre-made grow bed form is set up and secured with removable pieces:

- Outer grow bed removable pieces: Multiple scrap wood pieces nailed to the forms, overlapping the form bottom, sides, and ends to hold forms together.
- BRC fabric (wire) mesh for grow beds: Mesh cut at 13' 8" by 5' 8" (left over from fish tank), with edges bent up for finish size of 12' 4" by 4' 4" and placed inside grow bed.
- Drain pipe (2” PVC): Pipe placed in grow bed 18 ¼" from outside form side wall and 3" up from outside form bottom (closer to inside edge of grow bed).
- Inner grow bed form (removable): “Ladder” held together by two 2x4s (nailed in place) wired to internal braces; everything is justified to the top; drain pipe is wired up (see Photograph 6).
- Pour concrete: Sand, gravel, and cement mixed in an equal ratio of 1:1:1 for grow beds. Concrete should not be more than half of the bottom drain pipe.

7. Wood Form Removal and Water Pipe Placement

After the concrete is cured, the remaining fish tank forms and all grow bed forms are removed (carefully so as to be reused), and a finishing “mud” layer is applied to seal all concrete surfaces. Once the concrete unit is built (see Photograph 7), the water pipe system is put in place (see Photograph 8). The layout of the water pipe system, including perforations, is shown in Plate 8.

- Apply concrete “mud” layer: Sifted sand and cement mixed in an equal ratio of 1:1 to finish all concrete surfaces.
- Grow bed drain pipe (permanently placed within grow bed concrete): Pipe perforated with a 3/16" drill bit; holes in specified locations (Plate 8) for gravity drainage out of the grow beds into the fish tank.
- Above-grow bed (“rain”) piping: 1" PCV material constructed as follows:
  - Drill a 3/16"-diameter hole in 24 of the 1" caps (as close to center as possible), leaving two caps without a hole.
• Cut 24 pieces of 6"-length pipe and place a cap (with drilled hole) on one end of each piece.
• Cut 26 pieces of 11"-length pipe.
• On one 11"-length pipe, place a cap (with no hole) on one end and a tee on the other end. To this tee, place another 11"-length pipe to extend the length of the first pipe, adding another tee to the open end. The unplugged pieces of each tee will alternate, facing opposite directions.
• Continue this pattern with 13 of the 11"-length pipe pieces and 12 alternating tees.
• Place 12 of the 6"-length pipe pieces on the alternating (unplugged) tees.
• Place this assembled unit over the top of one grow bed running down the center – it should reach from one end of the grow bed to the other with a perpendicular 6"-length piece just inside each grow bed end. It will be necessary to place two pieces of wood across the grow bed to support the piping system.
• Repeat this process for the other grow bed.

• Connect grow bed “rain” pipe systems to allow water to be pumped from a single pipe from the fish tank: 1" PCV material constructed as follows:
  • Add a 90-degree elbow onto the end of each “rain” pipe, which hangs over the fish tank with the unplugged end facing towards center.
  • Cut a piece of pipe to join the unplugged elbows of the two rain pipe systems in the center of fish tank. Join the two pipes at center with a tee facing down into the tank.
  • Attach water pump with appropriate threaded adapter to 1" pipe at bottom of the fish tank directly under the tee.
  • Cut a piece of pipe to connect the water pump to the tee.

• Initiate testing of water pipe system as follows:
  • Clean fish tank of debris and fill with approximately 12" of water.
  • Connect the water pump to the power source, place timer, and test the unit. Water should be pumped from the fish tank up to the grow bed “rain” system, water the grow beds, and drain via gravity back into the fish tank.

Once the aquaponics unit is constructed, refer to handbook for stocking the system with fish, adding gravel and plants, and maintaining the system to produce healthy fish and plants within a closed water system.

8. Solar System Set-Up
A solar system is a great investment for your commercial size aquaponics system. This will ensure uninterrupted water circulation for the unit without electricity costs. The typical unit will require two 200-250 watt solar panels. These panels must be mounted in a location that is likely to get at least 8 hours of direct sunlight daily (and where they cannot be stolen).
You will need one 20 amp MPPT charge controller; two 200 amp/12 volt batteries (one as backup), a 12 volt 3800-4200 HP bilge pump, and one DC timer. You will also need ground rod, aluminum framing, surge protection, wires, and DC breaker (and consider transportation costs for these items as well). Your installer will need to measure the distance between the solar system location and the aquaponic system to know the quantity and type of wires needed.

It is very important to use a certified technician to install your solar system to ensure that the job is done properly. Remember to obtain a warranty on solar equipment and to ensure that you and your technician work out a maintenance schedule. Also ask about trouble-shooting for your solar system.

Security is paramount with a solar system. Ensure that the panels are installed where are secure from potential theft. The batteries are particularly attractive, so these should be securely installed and grilled with rebar, if possible.
Single-Module System

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Outlining and Digging Holes</td>
<td>Mesh, Rebar, and Concrete Floor</td>
<td>Fish Tank Forms and Grow Bed Footings</td>
<td>Fish Tank and Grow Bed Forms</td>
<td>Grow Bed Form Placement</td>
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</tr>
</tbody>
</table>

|----------|----------|----------|----------|----------|----------|----------|
Photograph 1. Outlining and Digging Holes

Photograph 2. Mesh, Rebar, and Concrete Floor
Photograph 3. Fish Tank Forms and Grow Bed Footings

Photograph 4. Fish Tank and Grow Bed Forms
Photograph 5. Grow Bed Form Placement

Photograph 6. Inside Grow Bed Form
Photograph 7. Concrete Fish Tank and Grow Beds

Photograph 8. Water Pipe System
<table>
<thead>
<tr>
<th>INMED Partnerships for children</th>
<th>Concrete aquaponics unit</th>
<th>DWG</th>
<th>Side view</th>
<th>JE</th>
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<td></td>
<td></td>
<td>Sheet Plate 3</td>
<td>5/16/11</td>
</tr>
</tbody>
</table>
Commercial Size Multi-Module System

Photograph Set 1. Line and mark out the areas for digging
Photograph Set 2. The tanks’ holes and troughs behind tanks
Photograph Set 3. Cut forms for tank
Photograph Set 4. Cut BRC wire to fit tank bottom and tie steel uprights
Photograph Set 5. Tie steel rebar to BRC fabric mesh – note how
Photograph Set 6. Mix concrete for tank bottom
Photograph Set 7. Put in tank forms for side wall – tie the steel around
Photograph Set 8. Put in 2” drain pipe and connect with valve and tie to drain pipe at the back
Photograph Set 9. Drain pipe must be protected from being covered
Photograph Set 10. Pour in cement at the side of the form
Photograph Set 11. Mark out footing for digging based on tank structure
Photograph Set 12. Dig footings based in the tank structure
Photograph Set 13. Frame BRC wire for grow bed (9 needed)
Photograph Set 14. Construct grow bed form on top of footings
Photograph Set 15. Place BRC reinforcement and pour concrete
Photograph Set 16. Remember the drain pipe
Photograph Set 17. Render and test for water leakages
Photograph Set 18. Fill system with gravel after each unit is constructed and washed
Photograph Set 19. Test and retest for leaks – run system for 1 week

Plate 1. Comercial size multi-module system top view

A standard commercial size aquaponics system has four fish tanks at 850 gallon each and eight grow beds at 768 sq. ft. total grow space. It has a 5th middle tank used as the sump tank where the pump is placed, and a 9th centre grow bed that can be used for fingerling production or growing duckweed or other supplemental fish feed. The commercial size system is modular, which means additional tanks and grow beds may be added, and the layout can be adjusted to fit available space. The system is built similar to the single unit but on a larger scale.
Photograph Set 1

Line and mark out the areas for digging

- Items Needed: spray paint, line, square, level, steel stakes, measuring tape, laths, pick, shovel, fork, nails.

Photograph Set 2

- the tanks holes and trough behind tanks
  - Needed: Backhoe, fork, shovel
Photograph Set 3

Cut Forms for Tank
Items Needed: Plywood, laths, 2x4x16, nails, wood saw and square.

Photograph Set 4

Cut BRC Wire to fit tank bottom and tie steel uprights
Items Needed: Grinder, cutting disc, hack saw and blades, rebar steel and binding wire, wire cutter and pliers, safety goggles, gloves.
Photograph Set 5

Tie steel rebar to BRC fabric mesh - note how
Items needed: BRC mesh, binding wire and steel rebar

Photograph Set 6

Mix concrete for tank bottom
Items needed: Concrete, cement, gravel, 5/8 stone
Photograph Set 7

Put in Tank forms for side wall - Tie the steel around
Remember to cut 2” hole for drain pipe to go to the trough piping at the bottom of the tank about ½ inch from tank bottom at the back-wall
Remember 1” drain hole about 4” from the tank top on the back-wall.

Photograph Set 8

Put in 2” drain Pipe and connect with valve and tee to drain pipe at the back.
Photograph Set 9

Drain pipe must be protected from being covered.

Photograph Set 10

Pour in cement at the side of the form.
Photograph Set 11

Mark out footing for digging based on tank structure. Tie steel work for matting.

Photograph Set 12

Dig footings based in the tank structure
Photograph Set 13

Frame BRC wire for grow bed (9 needed)

Photograph Set 14

Construct grow bed form on top of footings which is same height as the top of the tank.
Place BRC reinforcement and pour concrete

Note: No steel is used in the grow bed form only the BRC wire. Steel is used in the footings and bent over the BRC wire in the grow bed form.

Remember the Drain Pipe- Ensure that the tees are properly fitted and parallel to the wall side. This pipe may be centred in the grow bed. Remember the holes must be in the form to accommodate the drainpipe.
Photograph Set 17

Render and test for water leakages

Photograph Set 18

Fill system with gravel after all each unit is constructed and wash thoroughly
Photograph Set 19

Test and Retest for leaks - run system for 1 week
Operational Management Guidelines

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B.1 Water Quality: Maintaining pH

The technical information provided in this appendix is provided for scientific background; the most important information for effective aquaponics operation is provided in the main body of the text. Most water quality issues associated with pH can be solved simply by replacing some of the water in the system (1/4 to 1/3) and/or by stopping the feeding of fish for two days. This appendix is designed primarily for sites that have very poor water quality that require treatment. The most important note for the standard aquaponics operator is to continually monitor the water in the system and adjust the pH subtly, as necessary.

What is pH and why is it important?

pH refers to the acidity and alkalinity of a medium, usually water and soil or other plant media. Ranging from 0 to 14, a pH of 7 is neutral, below 7 is acidic, and above 7 is basic or alkaline. Knowing the pH of water is important to agriculture in general because additives, chemical solutions and minerals operate differently according to the acidity or alkalinity of the medium to which it they are applied. In aquaponic conditions, there are three main elements to having an optimally run system: nitrifying bacteria, fish or other aquatic animal life, and plants. These three components react and interact with each other in symbiotic, or co-benefiting, conditions. Their optimal functionality depends on the optimal pH of the water in which they live.

Each of these three elements will survive in a range of acid and alkali conditions. This, however, is not good enough to maximize effectiveness of an aquaponic system. Surviving within a range is like humans being able to live in extreme cold and extreme heat conditions. However, there is a relatively narrow band of temperature in which it is most comfortable for humans to thrive. While there are differences among scientists on what the most suitable pH ranges are for these three elements, these differences are small enough to be ignored. Nitrifying bacteria in an aquaponic system may survive in conditions from pH 5.0 to 9.0; however, the optimal pH range for nitrifying bacteria is between 6.0 and 7.0.

Tilapia, the fish of choice for many aquaponic systems, have a wide pH range for survival, from quite acidic at 3.7 to as high as 11.5. Their growth, reproductive system and mortality rates are affected by extremes and large, sudden swings in pH. The optimal pH range for tilapia is between 6.5 and 8.0. Yet do not be surprised if they thrive at a pH as high as 9.0.

Plants will quickly show effects of pH that is too high or too low. While most plants will survive in from 5.0 to 9.0, an ideal range depends largely on the crop variety. The safe pH range for most plants is between 5.5 and 7.5. It is important, however, to know the best pH for each crop, as nutrient deficiencies are often diagnosed based on problematic pH levels. Different minerals and nutrients are optimally available to crops at particular ranges. For instance, iron cannot be absorbed by plants unless the medium is in a neutral or near-neutral pH. Knowing the pH conditions is also important for disease control of plants; for instance, fungi thrive well in acidic pH while alkali conditions repel their growth.
In an aquaponic system, the ideal pH range is between 6.5 and 7.2. It is important not to panic, however, if this range is not continuously maintained. The process of nitrification, mineralization and adding buffers can maintain these levels quite easily with frequent monitoring and minor adjusting. Factors that affect maintaining the ideal pH range in an aquaponic system are: water source, growing medium, the nitrification process and fish feeding rate.

Ground water source will indicate the pH according to the general geographical conditions of an area. For instance, in Jamaica, the limestone geography tends to create slightly basic water with a pH of about 8. Mineralization also occurs in an aquaponic system, primarily due to the gravel medium used in the plant grow beds. Continuous mineralization tends to create water with a pH according to the type of rocks/gravel used; if the gravel is limestone-based, mineralization will create basic conditions. These tendencies towards alkaline conditions can act as a buffer in aquaponic systems, which naturally tend to convert to more acidic conditions due to the nitrification process. Fish excrete ammonia, which is alkaline. The nitrifying bacteria act on this ammonia, which causes more hydrogen ions to be released into the water, changing it to more acidic conditions.

Some pH swings may be temporary and do not need immediate action. This is the case when fish are overfed. Overfeeding may cause excessive excretion of ammonia at a faster rate than nitrification can take place, especially in conditions of low dissolved oxygen, which is necessary for nitrification. When this happens, the pH will swing quickly toward an alkaline condition. This is often followed by a foul water smell and cloudy water appearance. This is easily corrected by not feeding the fish for a day or two.

**Combatting pH swings by buffering**

As noted above, when a system is functioning perfectly, the tendency is for the pH to lower (become more acidic) due to nitrification. Adding a buffer routinely (in small quantities) to adjust the pH upward and compensate for the natural tendency will fix this nuance.

Also, as noted above, swings may occur in the opposite direction due to mineralization, particularly if the system’s gravel is limestone-based. Correcting this only takes patience, as the nitrification process will gradually readjust the pH. Swings may also be caused by the addition of water additives as nutrient levels (and water levels and temperature) change. Therefore, it is important to know the effect additives will have on pH. Nutrients such as sulphates are acidic, for example, and calcium is alkaline. Low water levels increase the concentrate of fish waste if the feeding rate is unchanged, and temperature changes can cause an increase or decrease in oxygen levels and activity of the bacteria available in the system.
Types of buffers to use and their impacts
A buffer is a solution/additive that may be acidic or alkali and is used to counteract the tendency of medium to swing along the pH range.

Commonly used acid buffers (to lower the pH of water) in aquaponic systems are nitric, malic and phosphoric acids. Commonly used bases (to raise the pH of water) are calcium carbonate or hydroxide and potassium carbonate/bicarbonate or hydroxide.

The buffer that is used is a matter of preference and dependent upon the crops growing in a system. For instance, calcium should not be used frequently in fruit-bearing systems, as calcium tends to block the uptake of potassium, which is needed for fruit bearing.

Myths about some acids and bases
In wanting to remain organic, persons have resorted to using acids and bases that may be harmful to their aquaponic system. These are some additives to generally avoid:

- Citric acids – these kill nitrifying bacteria
- Vinegar – the (acidic) pH is too weak to be effective
- Eggshells – the (basic) pH takes too long to become available and be effective

Table B-1 below lists common acids (pH < 7) and bases (pH > 7). Only those shown as bold and shaded should be used in an aquaponic system.

Table B-1. Common Additives to Adjust pH

<table>
<thead>
<tr>
<th>Acid</th>
<th>pH</th>
<th>Base</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>2.4</td>
<td>Ammonia</td>
<td>11.5</td>
</tr>
<tr>
<td>Alum</td>
<td>3.2</td>
<td>Barbital sodium</td>
<td>9.4</td>
</tr>
<tr>
<td>Arsenious acid</td>
<td>5.0</td>
<td>Borax</td>
<td>9.2</td>
</tr>
<tr>
<td>Benzoic acid</td>
<td>3.0</td>
<td>Calcium carbonate</td>
<td>9.4</td>
</tr>
<tr>
<td>Boric acid</td>
<td>5.2</td>
<td>Calcium hydroxide</td>
<td>12.4</td>
</tr>
<tr>
<td>Carbonic acid</td>
<td>3.8</td>
<td>Ferrous hydroxide</td>
<td>9.5</td>
</tr>
<tr>
<td>Citric acid</td>
<td>2.2</td>
<td>Magnesia</td>
<td>10.5</td>
</tr>
<tr>
<td>Formic acid</td>
<td>2.3</td>
<td>Lime</td>
<td>12.4</td>
</tr>
<tr>
<td>Hydrochloric acid</td>
<td>2.0</td>
<td>Potassium acetate</td>
<td>9.7</td>
</tr>
<tr>
<td>Hydrocyanic acid</td>
<td>5.1</td>
<td>Potassium carbonate</td>
<td>11.5</td>
</tr>
<tr>
<td>Lemon juice</td>
<td>2.0</td>
<td>Potassium cyanide</td>
<td>11.0</td>
</tr>
<tr>
<td>Malic acid</td>
<td><strong>2.2</strong></td>
<td>Potassium hydroxide</td>
<td><strong>12.0</strong></td>
</tr>
<tr>
<td>Nitric acid</td>
<td><strong>1.0</strong></td>
<td>Sodium acetate</td>
<td>8.9</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td><strong>1.5</strong></td>
<td>Sodium benzoate</td>
<td>8.0</td>
</tr>
<tr>
<td>Oxalic acid</td>
<td>1.3</td>
<td>Sodium bicarbonate</td>
<td>8.4</td>
</tr>
<tr>
<td>Salicylic acid</td>
<td>2.4</td>
<td>Sodium bicarbonate (baking soda)</td>
<td>8.4</td>
</tr>
<tr>
<td>Succinic acid</td>
<td>2.7</td>
<td>Sodium carbonate (washing or caustic soda)</td>
<td>11.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Trisodium phosphate</td>
<td>12.0</td>
</tr>
</tbody>
</table>
How much buffer to add
The best method to maintain optimal pH is to incrementally check/measure it without trying to adjust all at once. Large swings in either direction along the pH scale will negatively affect tilapia. Small additions of buffer reduce the risk of swinging too much in the opposite direction.

Always mix buffers in water before applying to the system. This will reduce sudden impact on nitrifying bacteria in the system. According to the University of the Virgin Islands, which operates large training aquaponic systems, a generally safe application rate to use is about 2 lb of buffer for every 30,000 gallons of water daily. Monitor your system over time to see the impact of the buffer on the pH before reapplying more buffers.

B.2 Transporting Fingerlings
Any fish, including young fingerlings, which are transported from one location to another, should be placed in transparent plastic bags that are filled with water and oxygen. Depending on the fish size and distance of travel, the number will vary from 10 to over 100 fish per bag. After the fish are placed in secure water-filled bags, the bags can be transported. If properly secured, they can even be transported on a car seat or in a trunk, but must be placed to avoid rolling or breaking of the bags. For large numbers of fish, a truck outfitted with an air pump and enclosed water-filled tank may be needed. Fish should not stay in the bags overnight; therefore, transportation and delivery must occur within one day. This limits the stress level of the fish, minimizing risk of death.

The pH of the water to which the fish are being introduced (e.g., aquaponic fish tank) should range from 6.5 to 7.8. The water temperature should be 70 to 86 degrees Fahrenheit and should be oxygenated. Avoid introducing the fish to extremes in water temperature. The fish tank should be filled to approximately 6 inches below the tank height (for ease of fish transfer and to avoid over-spill). When the fish arrive, they must be acclimatised to the conditions of the receiving tank. This is done by placing them (still in the bags) into the water-filled fish tank for one hour, then releasing them.

Depending on the period of transportation, the stress level of the fish may be very high; therefore, it is important to examine the fish for signs of erratic and stressed behaviour, including gasping and rapid frantic swimming. Overstressed fish may have to be released from the bags and introduced to the tank very quickly. When introduced to the tank, watch the fish carefully for stress or gasping. Gasping suggests lack of oxygen; an air pump can be used to introduce oxygen directly to the receiving tank. If a fish should die quickly, retrieve it from the tank and examine it for any irregular signs. After release, do not feed the fish for 1 to 2 days.

When transferring fish from tank to tank, buckets half-filled with water from the receiving tank should be used to dilute the bucket of water containing the fish from the transferring tank, then placed inside the receiving tank and tilted for the fish to swim free.
B.3 Daily Fish Feed Calculations

For new aquaponics producers, the best method for feeding fish is the observational technique, similar to monitoring water quality. Observe food consumption within 30 minutes of delivery (not lacking and no excess) and adjust accordingly, as described in the main body of the text. This appendix is used primarily for developing breeding stock or comparing strains of fish populations on weight gain (i.e., for optimal precision in food provision).

Whenever developing a feeding schedule for fish production, it is most important to **not overfeed the fish**. This is the major cause of fish mortality. When first introducing fish to the aquaponics system, do not feed them for 1-2 days, as the fish will be stressed and will not eat at a normal rate. Excess food in the system causes excessive build-up of nutrients, which depletes dissolved oxygen and affects water quality. Once you have a routine established, it is most important to monitor feeding rates and adjust as necessary.

### Table B-2. Fish Feeding Rate and Frequency by Size of Tilapia (at 28°C)

<table>
<thead>
<tr>
<th>Average individual fish weight</th>
<th>Feeding rate (percent of body weight) per day</th>
<th>Feeding frequency (number of times/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 5 g</td>
<td>8.0%</td>
<td>4</td>
</tr>
<tr>
<td>5 - 20 g</td>
<td>5.0%</td>
<td>4</td>
</tr>
<tr>
<td>20 - 100 g</td>
<td>3.5%</td>
<td>3</td>
</tr>
<tr>
<td>&gt; 100 g</td>
<td>2.5%</td>
<td>2</td>
</tr>
</tbody>
</table>

When the fish arrive at your tank, determine how much feed to provide to the fish each day using Table B-2 and the following formula:

\[
\text{Amount of feed per feeding} = \frac{W_t \times W\%}{F_f}
\]

*Where* $W_t$ *= total weight of fish in the tank (may be calculated by weighing several fish to obtain an average multiplied by the total number of fish)*

*W\%* *= Percent of body weight (determined by average individual fish weight in Table B-2)*

$F_f$ *= Feeding frequency (also determined by average individual fish weight in Table B-2)*

Here are two examples:

1. If each fish has an average weight of 1 g and there are 250 fish, the total weight is 1 g x 250 fish = 250 g of fish in the tank multiplied by the % feeding rate of 0.08 (8%) divided by feeding frequency of 4 times per day = 5 g per feeding. Therefore, deliver 5 g of food 4 times per day.

2. If each fish has an average weight of 30 g and there are 250 fish, the total weight is 30 g x 250 fish = 7,500 g of fish in the tank multiplied by the % feeding rate of 0.035 (3.5%) divided by the feeding frequency of 3 times per day = 87.5 g per feeding. Therefore, deliver 87.5 g of food 3 times per day.
The rate of growth of fish varies over time and by temperature, water quality, pH, quantity and quality of food and other factors. The following table displays the optimal growth rate of tilapia in a closed recycling water system under controlled conditions. Since fish will be growing, the amount of feed required should be evaluated about every two weeks using Tables B-2 and B-3.

### Table B-3. Growth Rates of Tilapia (at 28°C to 30°C)

<table>
<thead>
<tr>
<th>Fish size</th>
<th>Growth rate: weight (g/day)</th>
<th>Growth rate: length (mm/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 - 20 g</td>
<td>0.5</td>
<td>1.17</td>
</tr>
<tr>
<td>20 - 50 g</td>
<td>1.0</td>
<td>1.13</td>
</tr>
<tr>
<td>50 - 100 g</td>
<td>1.5</td>
<td>1.12</td>
</tr>
<tr>
<td>100 - 250 g</td>
<td>2.5</td>
<td>1.16</td>
</tr>
<tr>
<td>250 - 450 g</td>
<td>2.9</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Source: Rakocy, J.E. (1989) Tank culture of Tilapia. College Station, TX Southern Regional Aquaculture Center, Publication No. 282

Using the second example from Table B-2 above, a 30 g fish two weeks later should be 44 g (20-50g fish grow at a rate of 1 g/day growth per Table B-3) or a total of 11,000 g of fish in the fish tank (44 g x 250 fish). Again using Table B-2, for fish that are 20-100 g, use a feeding rate of 3.5%. Therefore, 11,000 g of fish x 0.035 feeding rate = 385 g of feed/day with a feeding frequency of 3 times per day = 128 g/feeding. So, on day 14 we will increase individual feedings from 87.5 g to 128 g of food 3 times per day.

Water temperature influences the metabolic rate, and this in turn effects feed consumption and growth. The optimal temperature range for the feeding of fish is 26°C – 32°C (78°F – 90°F). Table B-4 provides suggested feeding and frequency rates based on temperature.

### Table B-4. Tilapia Feeding Rates and Frequencies by Water Temperature

<table>
<thead>
<tr>
<th>Water temperature (°C)</th>
<th>Average body weight &lt; 100g</th>
<th>Average body weight &gt; 100g</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feeding rate (% of normal rate)</td>
<td>Feeding frequency (n/day)</td>
</tr>
<tr>
<td>26 - 32</td>
<td>100</td>
<td>4</td>
</tr>
<tr>
<td>24 - 26</td>
<td>90</td>
<td>3</td>
</tr>
<tr>
<td>22 - 24</td>
<td>70</td>
<td>2</td>
</tr>
<tr>
<td>20 - 22</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>18 - 20</td>
<td>30</td>
<td>1 - 2</td>
</tr>
<tr>
<td>16 - 18</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>&lt; 16</td>
<td>No feeding</td>
<td>No feeding</td>
</tr>
</tbody>
</table>

As an example: if you are feeding your fish 385 g/day (for 30 g fish from the example above and the temperature drops below 26°C, reduce the amount of feed to 90% (0.9) of the normal rate (385 g x 0.9 = 346.5 g). If feeding 3 times per day, divide by 3 or 115.5 g of feed 3 times per day. As an additional safeguard to overfeeding and maintaining good water quality, consider the following: when the fish reach an average size of 100 g, reduce the daily rate of feeding to 5 times per week (e.g., Monday to Friday). This should not affect the growth rate of the tilapia.
B.4 Plant Nutrient Deficiencies and Remedies

Below are charts for identifying plant nutrient deficiencies and for treating those deficiencies with appropriate remedies. In Table B-5 below, nutrient deficiencies are present according to observed symptom (left-hand column) and the out-of-balance nutrient causing the symptom (row header), with a description provided in the intersecting box of what type, age or part of a plant is affected. In Table B-6 below, common plant problems are listed with the suggested remedies, including application rates of the various additives into the system (water) or sprayed directly to the plants themselves.

B.5 Plant Pest and Disease Control

Below are charts for controlling pest diseases, including commercial pesticides and organic home remedies. In Table B-7 below, a list is provided of aquaponic-safe, approved pesticides that are available in Jamaica, including the product name, the pests that are controlled and the application instructions. Additional information on the status of pesticide registration in Jamaica can be found on the Pesticide Control Authority website: www.caribpesticides.net.

Important notes about pesticide application, which should always be done sparingly:

- Rotate chemicals with a different mode of action and do not use products with the same mode of action more than twice in a row to help prevent and/or delay development of pesticide resistance.
- When applying insecticides and/or fungicides, use 200-250 litres (44.5 – 55.6 gallons) of water per hectare, or 17.8 – 22.3 gallons of water per acre, to ensure good leaf coverage. When using a knapsack sprayer, use a hollow cone nozzle.

Finally, in Table B-8 below, a list is provided of homemade remedies that may control various insects and fungi.
### Table B-5. Identifying Nutrient Deficiencies

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>NITROGEN</th>
<th>PHOSPHORUS</th>
<th>POTASSIUM</th>
<th>MAGNESIUM</th>
<th>CALCIUM</th>
<th>IRON</th>
<th>SULFUR</th>
<th>MANGANESE</th>
<th>ZINC</th>
<th>BORON</th>
<th>COPPER</th>
<th>MOLYBDENUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHLOROSIS (YELLOWING) THROUGHOUT LEAVES</td>
<td>AFFECTS OLDER LEAVES STARTS AT TIPS</td>
<td></td>
<td></td>
<td></td>
<td>AFFECTS OLDER LEAVES STARTS AT LEAF EDGE</td>
<td>AFFECTS CITRUS LEAVES</td>
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<tr>
<td>INTERVEINAL CHLOROSIS LEAVES</td>
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<td>AFFECTS YOUNGER LEAVES</td>
<td>AFFECTS CITRUS LEAVES</td>
<td>AFFECTS LEGUMES LEAVES</td>
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<td>CHLOROSIS IN TINY SPOTS</td>
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<td>AFFECTS YOUNGER LEAVES</td>
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<tr>
<td>GRAY-GREEN SPOTS</td>
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<td></td>
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<td>AFFECTS YOUNGER LEAVES</td>
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<tr>
<td>BLEACHED LEAVES</td>
<td>AFFECTS OLDER LEAVES</td>
<td></td>
<td>AFFECTS YOUNGER LEAVES</td>
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<tr>
<td>DARK GREEN/PURPLE LEAF STEM</td>
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<td>AFFECTS OLDER LEAVES</td>
<td></td>
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<td>BRONZED LEAVES POSIBLE</td>
<td></td>
<td></td>
<td>AFFECTS OLDER LEAVES</td>
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<tr>
<td>MARGINAL LEAF TIP CHLOROSIS BURN</td>
<td>AFFECTS OLDER LEAVES STARTS AT TIPS</td>
<td></td>
<td>AFFECTS OLDER LEAVES STARTS AT LEAF EDGE</td>
<td></td>
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<table>
<thead>
<tr>
<th>Symptoms</th>
<th>NITROGEN</th>
<th>PHOSPHORUS</th>
<th>POTASSIUM</th>
<th>MAGNESIUM</th>
<th>CALCIUM</th>
<th>IRON</th>
<th>SULFUR</th>
<th>MANGANESE</th>
<th>ZINC</th>
<th>BORON</th>
<th>COPPER</th>
<th>MOLYBDENUM</th>
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<tbody>
<tr>
<td>NECROTIC SPOTS</td>
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<td></td>
<td>AFFECTS OLDER LEAVES</td>
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<tr>
<td>GROWING TIP DIES</td>
<td></td>
<td></td>
<td></td>
<td>AFFECTS YOUNGER LEAVES</td>
<td>AFFECTS YOUNGER LEAVES</td>
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<td>WILTING</td>
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<td></td>
<td>AFFECTS YOUNGER LEAVES</td>
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<td>LEAF DROP</td>
<td>AFFECTS OLDER LEAVES</td>
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<td>STRAPLIKE LEAVES</td>
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<td>AFFECTS YOUNGER LEAVES</td>
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<td>ROSETTING LEAVES</td>
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<td>AFFECTS YOUNGER LEAVES</td>
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<tr>
<td>DISTORTED LEAVES</td>
<td>AFFECTS OLDER LEAVES</td>
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<td>AFFECTS YOUNGER LEAVES</td>
<td>AFFECTS YOUNGER LEAVES</td>
<td>AFFECTS YOUNGER LEAVES</td>
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<tr>
<td>POOR FRUITING/FLOWERING</td>
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<td>PRESENT</td>
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<tr>
<td>WEAK, THIN STEMS</td>
<td>PRESENT</td>
<td>PRESENT</td>
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<tr>
<td>STunted GROWTH</td>
<td>PRESENT</td>
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<td>PRESENT</td>
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<tr>
<td>AbNORMAL ROOT GROWTH</td>
<td>PRESENT</td>
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<td>PRESENT</td>
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<td>PRESENT</td>
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</tbody>
</table>

**NOTE:** The nutrient imbalance occurring in a plant is noted as affecting older leaves, younger leaves, specific leaves, or simply causing the symptom noted (present).
<table>
<thead>
<tr>
<th>Problem</th>
<th>Possible Causes</th>
<th>Remedies</th>
<th>Application into System</th>
<th>Application Spray to Plant Under Leaves</th>
<th>Effect on pH</th>
<th>Notes</th>
</tr>
</thead>
</table>
| Seeds are not germinating within expected timeframe | • Poor seed quality  
    • Seeds planted too deep  
    • Ant damage  
    • Germination  
    • Temperature, lighting and moisture issues | Select and store seeds properly. Use within safe dates. | NA                       | NA                                      | Nil          | It is best to sow seeds in trays and grow them for a while outside of the system where they can be treated to prevent pest damage early, resulting in healthier seedlings. This will make them resist diseases and pests while in the system where it is more challenging to treat them. Newmectin and Cure are organically approved pesticides that can treat aphids, miners and mites. Phyton is an organically approved fungicide and bactericide. These can ONLY be used OUTSIDE of the system at least 3 days before transplanting seedlings. XenTari and DiPel may be used to treat cabbage worms. These are organic and may be applied directly to plant foliage in the system. |
<p>| Germination is weak                           | Insufficient nutrients                               | Spray with fish water             | NA                       | NA                                      | Lowers pH slightly |                                                                                                                                 |
|                                              |                                                      | Spray with magnesium sulphate     | NA                       | 5 ml/gal fish water                      |              |                                                                                                                                 |
| Seedlings are damping off (rotting at the stem) | Too much watering                                  | Reduce watering or use fungicide Biolife (uses natural citrus seed extract) | NA                       | 5 ml/gal fish water                      | Lowers pH     |                                                                                                                                 |
| Seedlings are shrivelled up                   | Insufficient watering                                | Add water consistently            | NA                       | NA                                      |              |                                                                                                                                 |
| Mature lower leaves are yellow. Remaining foliage is often light green. Stems may also yellow and may become wiry. Growth slows. | Nitrogen deficiency                                | Increase fish feeding rate safely  | Increase feed amounts slowly for fish to eat completely. Spend 20 minutes to feed fish slowly or until fish stop eating | Raises pH     | Do not overfeed because of feed rotting at the bottom of tank                                                                                                                                      |</p>
<table>
<thead>
<tr>
<th>Problem</th>
<th>Possible Causes</th>
<th>Remedies</th>
<th>Application into System</th>
<th>Application Spray to Plant Under Leaves</th>
<th>Effect on pH</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>New leaves are distorted or hooked. The growing tip may die. Causes blossom end rot in tomatoes, tip burn in cabbage and hollowing/black heart of broccoli and celery.</td>
<td>Calcium deficiency</td>
<td>Add crushed eggshells. Eggshells are 40% calcium carbonate.</td>
<td>Crush/powder 2 shells per grow bed and add to gravel in 1 location. This is a slow-release method taking action over weeks to months depending on the size of the crushed shells.</td>
<td>To get calcium quickly from eggshells, heat in the microwave for 2 minutes, crush into a powder and dissolve in vinegar at a rate of 1 tsp egg shells to 1 tsp white vinegar. This breaks down to calcium, water and CO₂. The result should be pH neutral. Add 1 tsp of this mix to 2 gallons of water and spray.</td>
<td>Raises pH</td>
<td>Check pH gradually as you add calcium carbonate. Do not apply within one week of adding magnesium and/or potassium or iron. It will inhibit uptake of these nutrients.</td>
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<tr>
<td>Old leaves may look scorched around the edges and/or wilted. Yellowing between the leaf veins develops.</td>
<td>Potassium deficiency</td>
<td>Add potassium bicarbonate</td>
<td>Mix 1/4 lb per 1000 gals of water in system and slowly add to sump tank</td>
<td>Mix 1/2 tsp per gal of fish water and spray</td>
<td>Raises pH</td>
<td>Potassium is inhibited by too much calcium and also inhibits calcium. Apply potassium sulphate and magnesium sulphate together. Magnesium helps to move potassium throughout the plant cells.</td>
</tr>
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<tr>
<td>Blossoms are not holding for fruit set.</td>
<td>Potassium and/or calcium deficiency</td>
<td>Add SOP and calcium (1 week apart)</td>
<td>Same as above for SOP and calcium</td>
<td></td>
<td>One neutralizes the other</td>
<td>More likely a potassium problem. Calcium deficiency is rare. Apply remedies 1 week apart.</td>
</tr>
<tr>
<td>Leaves have a reddish-purple tint. Leaf tips can look burnt and older leaves become almost black. Reduced fruit or seed production.</td>
<td>Phosphorus deficiency</td>
<td>Add bone meal Add crushed crab shells</td>
<td>Apply very small amounts and observe pH and fish appearance</td>
<td></td>
<td>pH range dependent</td>
<td>Monopotassium phosphate may be added to sump at ½ lb weekly until problem disappears. Do not apply within 1 week of applying sulphates.</td>
</tr>
<tr>
<td>Problem</td>
<td>Possible Causes</td>
<td>Remedies</td>
<td>Application into System</td>
<td>Application Spray to Plant Under Leaves</td>
<td>Effect on pH</td>
<td>Notes</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
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<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Slow growth and leaves turn pale yellow, sometimes just on the outer</td>
<td>Magnesium deficiency</td>
<td>Add magnesium sulphate (Epsom salt)</td>
<td>Mix 1/2 lb per 1000 gals of water in system and slowly add</td>
<td>Mix 1 tsp per gal of fish water and spray</td>
<td>Lowers pH</td>
<td>Check pH after application. Do not apply within one week of applying calcium. Magnesium sulphate will also help in healthier fish – helps with digestive problems.</td>
</tr>
<tr>
<td>edges. New growth may be yellow with dark spots.</td>
<td></td>
<td></td>
<td>to sump tank</td>
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<tr>
<td>New growth turns pale yellow, older growth stays green. Stunted growth.</td>
<td>Sulphur deficiency</td>
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<tr>
<td>Blanched/bleached leaves in younger leaves/yellowing of younger leaves</td>
<td>Iron deficiency</td>
<td>Add green banana peels</td>
<td>Add 2 green banana peels per grow bed and bury under gravel in two locations. Remove after plants show change or after 2 weeks. Repeat monthly.</td>
<td>Mix 1/2 tsp per gal of fish water and spray</td>
<td>Neutral</td>
<td>Iron is most effectively dissolved in lower pH ranges, around 6.5. May be added with sulphates. Do not add within one week of adding calcium. Too much iron will cause iron bacteria to bloom and cause other problems. Watch for reddish-brown colour of water.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Add chelated iron (11%)</td>
<td>Mix 1/4 lb per 2000 gals of water in system and slowly add to sump tank. Repeat monthly.</td>
<td>Mix 1/2 tsp per gal of fish water and spray every other week</td>
<td>Neutral</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Possibly fungus or bacteria or plant virus</td>
<td>Use <strong>Bio-Life</strong> (this is a natural product made from citrus seed extracts and may be applied on plants in the system – safe for fish). It is a systemic fungicide, bactericide and virucide.</td>
<td>NA</td>
<td>Mix 1 tsp per gal of fish water and spray every 5 days</td>
<td>Lowers pH slightly</td>
<td>Lower the pH of the mixing water to 4.5 to 5.5 for most effective results</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use potassium bicarbonate</td>
<td>Mix 1/2 lb per 1000 gals of water in system and slowly add to sump tank</td>
<td>Mix 1 tsp per gal of fish water and spray. Good for downy mildew.</td>
<td>Raises pH</td>
<td>Ensure pH in the system is in a safe range before using because it will raise the alkalinity.</td>
</tr>
</tbody>
</table>
Table B-7. Aquaponic Safe Pesticides in Jamaica

<table>
<thead>
<tr>
<th>Crops</th>
<th>Trade Name</th>
<th>Active Ingredient</th>
<th>Mode of Action</th>
<th>Chemical Group*</th>
<th>Toxicity Class</th>
<th>Pests Controlled</th>
<th>Pre-harvest Interval</th>
<th>Dose Rates</th>
<th>Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pak choy, Cabbage</td>
<td>DiPel</td>
<td><em>Bacillus thuringiensis</em></td>
<td>Contact</td>
<td>Bt microbials</td>
<td>IV</td>
<td>Lepidopterous pests such as armyworms, leaf rollers, cutworms, corn earworms,</td>
<td>0 days</td>
<td>0.5 - 3.0 tsp / gal of water</td>
<td>For control of worms, commencement of spraying should coincide with egg hatch and first instar larvae (very young worms) and before damage to the plant</td>
</tr>
<tr>
<td>Cucumber</td>
<td>XenTari</td>
<td><em>Bacillus thuringiensis</em></td>
<td></td>
<td></td>
<td>IV</td>
<td>Aphids, whiteflies, leafminers</td>
<td>0 days</td>
<td>0.5 - 3.0 tsp / gal of water</td>
<td></td>
</tr>
<tr>
<td>Herbs</td>
<td>Agree</td>
<td><em>Bacillus thuringiensis</em></td>
<td>Contact</td>
<td></td>
<td>IV</td>
<td>Aphids, armyworms, fruit flies, spider mites,</td>
<td>1 day</td>
<td>0.5 - 3.0 tsp / gal of water</td>
<td></td>
</tr>
<tr>
<td>Lettuce</td>
<td>Aza-Direct</td>
<td><em>Azadiracin</em></td>
<td>Contact</td>
<td>Botanical</td>
<td>IV</td>
<td>Cutworms, leaf beetles, leafhoppers, loppers, mites etc.</td>
<td>0 days</td>
<td>2-4 tsp / gal of water</td>
<td></td>
</tr>
<tr>
<td>Sweet Peppers</td>
<td>Neem-X</td>
<td><em>Azadiracin</em></td>
<td>Contact</td>
<td>Botanical</td>
<td>IV</td>
<td>Aphids, caterpillars, leaf miners, mites, etc.</td>
<td>0 days</td>
<td>1-2 tsp / gal of water</td>
<td></td>
</tr>
<tr>
<td>Tomatoes</td>
<td>Tracer</td>
<td>Spinosad</td>
<td>Contact/</td>
<td>Naturalyte</td>
<td>III</td>
<td>Diamondback moth, cucumber worm, leaf miner, aphids</td>
<td>3 days</td>
<td>1 ml / gal</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>translaminar</td>
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</tr>
<tr>
<td></td>
<td>BioLife</td>
<td>Citrus-based</td>
<td>Contact/</td>
<td>Botanical</td>
<td>III</td>
<td>Virus, bacteria and fungus</td>
<td>0 days</td>
<td>1-2 tsp / gal of water</td>
<td>Apply strictly to foliage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>translaminar</td>
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<tr>
<td></td>
<td>MilStop</td>
<td>Potassium bicarbonate</td>
<td>Contact</td>
<td>Fungicide</td>
<td>III</td>
<td>Fungus</td>
<td>3</td>
<td>1-2 tsp / gal of water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Botani-Gard</td>
<td>Fungus-based</td>
<td>Contact</td>
<td>Microbial</td>
<td>III</td>
<td>White flies and aphids</td>
<td>3</td>
<td>1-2 tsp / gal of water</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M-Pede</td>
<td>Potassium salts and fatty acids</td>
<td>Contact</td>
<td>Insecticide, miticide and fungicide</td>
<td>II</td>
<td>Powdery mildews, white flies, aphids and mites</td>
<td>3</td>
<td>1-2 tsp / gal of water</td>
<td></td>
</tr>
</tbody>
</table>

Hazard Classification (According to the World Health Organization)

CLASS I A: Extremely hazardous. This class of pesticides must have the words “very toxic” on the label.
CLASS I B: Highly hazardous. This class of pesticides must have the word “toxic” on the label.
CLASS II: Moderately hazardous. The word “harmful” must be displayed on the label.
CLASS III: Slightly hazardous. These pesticides must have “caution” written on the label.
CLASS IV: Caution
### Table B-8. Home Recipes for Organic Pest Control

<table>
<thead>
<tr>
<th>Description</th>
<th>Recipes for Treating Plants in Aquaponics Systems</th>
<th>Pests Controlled</th>
</tr>
</thead>
</table>
| Aphid control instructions | 1. The first line of attack is to harvest crops early.  
2. Sow seeds in trays and transplant them to grow beds.  
3. Treat all transplants with soapy water solutions before they are transferred to the grow beds.  
4. Wash the areas surrounding the grow beds with soapy water. **DO NOT USE SOAP, OIL, WAX OR PEPPER SPRAYS** in the grow beds of an aquaponic system. These items will eventually kill the fish.  
5. Spread diatomaceous earth in a 3-inch band on the top of the grow bed walls. This will prevent ants from bringing in the aphids. Diatomaceous earth is a white powdery type of naturally occurring earth. It is NOT marl or limestone. It can be found at local garden centres. Use 100% diatomaceous earth, food grade if possible. Do not use diatomaceous earth that is for swimming pools. If the diatomaceous earth becomes damp, it must be replaced.  
6. Wood ash may be as effective; however, be careful as this increases the pH if it gets in the system. Conduct pH tests regularly.  
7. All plant material must be removed from around the aquaponic system. A wide band, at least 10 feet wide, must surround the system and be sprayed regularly with agents that will kill ants.  
8. There are two biological control agents that can be used on the plants: BotaniGard, which contains the fungus organism *Beauveria bassiana*, and *Bacillus thuringiensis*, subspecies kurstaki, which is marketed under several brand names. Both are very effective against aphids (see table above). | Aphids |
| Potassium bicarbonate fungicide | Mix 4 teaspoons (about 1 rounded tablespoon) of potassium bicarbonate into 1 gallon of water. Spray lightly on foliage of plants afflicted with black spot, powdery mildew, brown patch and other fungal diseases. Potassium bicarbonate is a good substitute for baking soda. | Black spot, powdery mildew, brown patch and other fungal diseases |

<table>
<thead>
<tr>
<th>Description</th>
<th>Recipes for Treating Plants OUTSIDE of Aquaponics Systems – <strong>DO NOT USE WITHIN AN AQUAPONICS SYSTEM</strong></th>
<th>Pests Controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horticultural oil spray</td>
<td>Mix 1 tablespoon vegetable cooking oil and 1 teaspoon of NON-DEGREASING liquid dishwashing detergent per gallon of water. Citrus oil and molasses can be used instead of cooking oil.</td>
<td>Fungus (base for other remedies below)</td>
</tr>
<tr>
<td>Baking soda fungicide</td>
<td>Mix 4 teaspoons (about 1 rounded tablespoon) of baking soda and 1 tablespoon of horticultural oil into 1 gallon of water. Spray lightly on foliage of plants afflicted with black spot, powdery mildew, brown patch and other fungal diseases. Avoid over-using or pouring on the soil. Potassium bicarbonate is a good substitute for baking soda. Citrus oil and molasses can be used instead of horticultural oil.</td>
<td>Black spot, powdery mildew, brown patch and other fungal diseases</td>
</tr>
<tr>
<td>Vinegar fungicide</td>
<td>Mix 3 tablespoons of natural apple cider vinegar in 1 gallon of water. Spray during the cool part of the day. Add molasses at 1 tablespoon per gallon for additional strength.</td>
<td>Fungal diseases</td>
</tr>
<tr>
<td>Cornmeal juice</td>
<td>Cornmeal juice is a natural fungal control for use in any kind of sprayer. Soak horticultural cornmeal in water at 1 cup per gallon of water. Put the cornmeal in a nylon stocking bag to hold in the larger particles. The milky juice of the cornmeal will permeate the water. This mix should be sprayed without further diluting. Cornmeal juice can be mixed with compost tea, Garrett Juice (see below) or any other natural foliar feeding spray.</td>
<td>Fungal diseases</td>
</tr>
<tr>
<td><strong>Garlic pepper tea</strong></td>
<td>Liquefy 2 bulbs of garlic and 2 hot peppers in a blender 1/2 to 2/3 full of water. Strain the solids and add enough water to the garlic/pepper juice to make 1 gallon of concentrate. Use 1/4 cup of concentrate per gallon of spray. To make garlic tea, simply omit the pepper and add another bulb of garlic. Add two tablespoons of molasses for more strength.</td>
<td>Insect and fungal diseases</td>
</tr>
<tr>
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</tr>
<tr>
<td><strong>Compost tea</strong></td>
<td>Manure compost tea is effective on many pests because of certain microorganisms that exist in it naturally. Use any 5-15 gallon container, such as a plastic bucket. Fill the bucket half full of compost and finish filling with water. Let the mix sit for 10-14 days and then dilute and spray on the foliage of any and all plants, especially those that are regularly attacked by insects or fungal pests. It is very effective, for example, against early blight on tomatoes. Dilute the dark compost tea before using, depending on the compost, but generally dilute the leachate down to one part compost liquid to 4 to 10 parts water. Be sure to strain the solids out with old pantyhose, cheese cloth or row cover material. Add two tablespoons of molasses to each gallon of spray for more strength. Add citrus oil for even greater strength.</td>
<td>Insect, fungal diseases (e.g., early blight on tomatoes)</td>
</tr>
<tr>
<td></td>
<td>To make compost, a pile of organic material can be started in sun or shade at any time of the year. Good ingredients include leaves, hay, grass clippings, tree trimmings, food scraps, bark, sawdust, rice hulls, weeds, nut hulls and animal manure. Mix the ingredients together in a container of wood, hay bales, hog wire or concrete blocks or simply pile the material on the ground. The best mixture is 75-80% vegetative matter and 20-25% animal waste, although any mix will compost. The ingredients should be a mix of coarse and fine-textured material. Avoid having all the pieces of material the same size, since the variety of sizes will help air to move through the pile. Oxygen is a critical ingredient. Turn the pile at least once a month, more often to speed up the decomposition process. Keep the pile moist, roughly the moisture of a squeezed-out sponge, to help the living microorganisms thrive and decompose the material. Compost is ready to use when the ingredients are no longer identifiable. The colour will be dark brown, the texture soft and crumbly, and the aroma that of a forest floor.</td>
<td></td>
</tr>
</tbody>
</table>
| **Garrett Juice (ready to spray)** | Mix the following ingredients in 1 gallon of water.  
• 1 cup manure-based compost tea  
• 1 ounce molasses  
• 1 ounce natural apple cider vinegar  
• 1 ounce liquid seaweed  
• For more fertilizer value, add 2 oz. liquid fish  
For disease and insect control add:  
• ¼ cup garlic tea or  
• ¼ cup garlic/pepper tea or 1 ounce of orange oil  
For homemade fire ant killer add:  
• 2 ounces of citrus oil per gallon of Garrett Juice | Insect, fungal diseases |
B.6 Crop Production Guidelines

Growing any type of crop in an aquaponics system requires a disciplined approach. This must include careful planning of what crops to plant (based on price and market) to maximize profitability, timing, careful observations, prompt responses to issues and good record keeping. In Jamaica, bell peppers are in high demand and are difficult to optimally produce in open field conditions. They also require plenty water for high production. They enjoy good prices year round. This makes bell or sweet peppers an excellent choice for aquaponic farmers. Below (Table B-9) is a guide for growing sweet peppers.

Table B-9. Aquaponic Production Guide for Sweet Peppers

<table>
<thead>
<tr>
<th>Stages</th>
<th>Timing</th>
<th>Description and General Comments</th>
<th>Nutrient Consideration</th>
<th>pH/Temperature Considerations</th>
<th>Pest and Disease Consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed selection</td>
<td>Days or weeks prior to planting</td>
<td>Seed selection is very important. It is based on market needs, crop variety and conditions of the planting environment. Select seeds that are new, stored in cool, dark conditions and are not more than one year old. Seeds for aquaponic conditions may be of the same type used in hydroponic/ greenhouse conditions. Also remember to select seeds based on the climatic zone where they will be planted. Store safely in dry, cool conditions away from direct sunlight and from pests like rats, ants and roaches. Seeds usually get their nutrients from their cotyledons. Ensure that the surroundings are pest-free and conditions suitable for germination.</td>
<td>Seeds usually get their nutrients from their cotyledons</td>
<td>Ensure storage of seeds in cool, dark conditions</td>
<td>Avoid access to insects and keep dry until planted</td>
</tr>
<tr>
<td>Pre-planting</td>
<td>Day(s) before</td>
<td>It is essential to properly prepare for planting seeds. Decide on the following: timing, variety of seeds, germination rate, quantity to plant, seed cell size, medium to plant in, placement for growth, watering plan and growth conditions. For aquaponics, here are some Do's and Don'ts. In some cases, seeds may be soaked overnight in a moistened towel to allow for easier germination. pH should be at 7 for best results. Acidic conditions (pH&lt;7) will create conditions suitable for fungus. Ensure that the surroundings are pest-free and conditions suitable for germination.</td>
<td>Do not use soil – it may cause fungus issues</td>
<td>Ensure storage of seeds in cool, dark conditions</td>
<td>Avoid access to insects and keep dry until planted</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Do: Use sterile growth medium like peat moss, coir or vermiculite. Do not use soil if it may cause fungus issues. Do not re-use cells, especially if soil was used previously. Check the expiry date on seed. Do not use seeds if expired or close to expiry date. Use sterile cells. Do not place planted cells on the soil. Calculate the amount of seeds you need to plant. Do not over-expose seeds prior to planting.</td>
<td>Do not use soil – it may cause fungus issues</td>
<td>Ensure storage of seeds in cool, dark conditions</td>
<td>Avoid access to insects and keep dry until planted</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Growth Stages</th>
<th>Day Range From</th>
<th>To</th>
<th>Description and General Comments</th>
<th>Nutrient Consideration</th>
<th>pH Consideration</th>
<th>Pest and Disease Consideration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seed planting (start)</td>
<td>1</td>
<td></td>
<td>Moisten medium prior to planting. Fill cells leaving about 1/8 inch from top. This is to allow for medium to cover seeds. Plant single seed to cell. Lightly cover with moist medium. Place tray safely off soil.</td>
<td>No nutrients needed</td>
<td>Temperature should range between 70-85°F for best germination results</td>
<td>Be aware of ants and mice that may dig up seeds. Elevate seedling trays off ground level.</td>
</tr>
<tr>
<td>Germination</td>
<td>5</td>
<td>10</td>
<td>Keep cells slightly damp. Avoid wetting too late in evening. Scratch medium away gently to examine seeds for germination within the timeframe. Cover seeds and moisten. If seeds do not germinate as expected. Replant a different variety. Waiting too long will create delays in production and is a sign of inferior seeds. This will lead to inferior plants.</td>
<td>No nutrients needed</td>
<td>pH 6.5</td>
<td>Downy mildew is likely if wetting occurs too late in the day.</td>
</tr>
<tr>
<td>Emergence</td>
<td>7</td>
<td>12</td>
<td>This is when the tiny plants have broken the surface, seeking direct light. Avoid direct sunlight if possible; this may cause wilting and cells drying too fast. Examine for normalcy. Most plants will emerge with 2 tiny cotyledon leaves. Keep medium moist. Do not over-wet. This will promote fungal growth especially when excess moisture remains overnight.</td>
<td>No nutrients needed</td>
<td>pH 6.5 ideal for sweet peppers</td>
<td></td>
</tr>
<tr>
<td>Cotyledon leaves</td>
<td>10</td>
<td>15</td>
<td>These are the first two appearances of greens emerging from the seed. They should be uniform in appearance and have one shade in colour. These usually provide nutrients coming from the seed to aid in the development process of other leaves that form true leaves. Cotyledon leaves are present from within the seed.</td>
<td>Nitrogen, phosphorus, potassium (NPK) ratio of 9:45:15 is great to start</td>
<td>pH 6.5 ideal for sweet peppers</td>
<td>Downy mildew is likely if wetting occurs too late in the day. Be watchful for mole crickets, caterpillars and snails. They will cut the emerging and young leaves.</td>
</tr>
<tr>
<td>True leaves</td>
<td>20</td>
<td>25</td>
<td>True leaves usually emerge from between the two cotyledon leaves. These leaves will now become the primary leaves for the further development of other leaves and for photosynthesis to occur. These leaves develop after emergence.</td>
<td>Spray weekly with aquaponic water</td>
<td>pH 6.5 ideal for sweet peppers</td>
<td></td>
</tr>
<tr>
<td>Four- to six-leaf stage</td>
<td>30</td>
<td>40</td>
<td>As stated, this is the appearance of four to six true leaves of a seedling. This shows a level of maturity in the plant and by appearance should indicate health of a seedling. The number true leaves, height of respective plants together with hardness of stem will determine maturity level. Plants can be placed in more direct light for strengthening.</td>
<td>Spray weekly with Aquaponic water</td>
<td></td>
<td></td>
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<tr>
<td>Growth Stages</td>
<td>Day Range</td>
<td>Description and General Comments</td>
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<td>pH Consideration</td>
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<tr>
<td>Root development /balling</td>
<td>35-45</td>
<td>At the four-to-six true leaves stage, the root system of a plant would be at a reasonable stage of development. The plant should be supporting itself, and have a main root structure with smaller offshoots. A root ball develops when there is little or no more space for it to develop in the cell. This will lead to seedlings hardening; the size becomes stunted until further rooting room is found.</td>
<td>Spray weekly with aquaponic water</td>
<td>pH of 7 or higher will slow growth development of plants. This may cause an appearance of nutrient deficiency.</td>
<td>Same as above</td>
<td></td>
</tr>
<tr>
<td>Stalk hardening</td>
<td>45-55</td>
<td>As the plant develops and water uptake becomes restricted due to root balling and more direct sunlight exposure, the stalk will harden. This is a key time to observe the best plants for selection for transplant.</td>
<td>May have to dip plants in a nutrient mix of 9:45:15</td>
<td></td>
<td>Spray with preventative pesticide at this stage to prevent white flies and aphids</td>
<td></td>
</tr>
<tr>
<td>Ready seedling</td>
<td>45-55</td>
<td>A ready seedling will be bright green in colour, have a good root ball, four to six true leaves, and a stem that is hardening from the base up.</td>
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<tr>
<td>Transplant</td>
<td>1</td>
<td>The transplant area should be weed free, moist and prepared for transplant. In aquaponic systems, the excess medium is washed from the roots in fish water outside the system. Try to transplant only healthy seedlings and within the same day. To reduce stresses, it is best to do transplanting in the cooler times of the day. The plant spacing should be determined prior to planting. In the case of sweet peppers, one foot apart if trellised staggered is recommended. The seedlings should be placed in a hole about three inches deep covering all the roots freely (to avoid damage) and up to the base of the hardened stem. Handle seedlings gently.</td>
<td>Ensure pH between 6.5 and 7 in the system.</td>
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<tr>
<td>Wilting stage</td>
<td>1-3</td>
<td>The seedlings, once transplanted, will be stressed because the roots have been disturbed and will be without nutrients for a short time. This is a normal expectation even if plants are watered on a scheduled basis. During wilt, the plant may droop in appearance.</td>
<td>No nutrients need to be added to system</td>
<td>May need to balance pH. Tendency for pH to go to 8 especially in gravel system. Potassium hydroxide may be used.</td>
<td>Do not apply any pesticides until plants are showing signs of good development</td>
<td></td>
</tr>
<tr>
<td>Growth Stages</td>
<td>Day Range</td>
<td>Description and General Comments</td>
<td>Nutrient Consideration</td>
<td>pH Consideration</td>
<td>Pest and Disease Consideration</td>
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<tr>
<td>Root development</td>
<td>1–28</td>
<td>With the additional room for growth after transplanting, the plant roots will quickly spread. Growth and development of roots will continue throughout the life of the plant, slowing as the plant reaches closer to productive maturity, at which point it will grow even slower. This is on the assumption that the right nutrient balance is available. Strong roots provide for strong plants. If one should pull one plant, the root system should be fibrous with a main root and smaller shoots branching. Concern should be raised if it appears lumpy, discoloured, slimy, milky or rotting. Evidence of poor rooting will be seen in the leaves or a weakened plant. If this happens, the plant must be removed.</td>
<td>A nutrient solution of monopotassium-phosphate or phosphoric acid can be applied to the system if root development is below expectations.</td>
<td>Phosphoric acid will lower pH, so it is best applied when the system indicates a higher than 7 pH.</td>
<td>Acidic conditions will favour fungal growth; therefore, it is best that the leaves are applied with a light solution of potassium bicarbonate.</td>
<td></td>
</tr>
<tr>
<td>Vegetative growth</td>
<td>7–28</td>
<td>Strong vegetative growth depends on strong roots. The lushest period of growth takes place during this time. Leaves get darker and larger, the stem strengthens and gets thicker, and new branches are formed. It is during this stage that plants like sweet pepper begin to fork or divide into main stems. If plants appear stunted or discoloured or leaves are falling off, something is wrong. Take closer note to properly diagnose the problem.</td>
<td>At this stage, be aware of the signs of iron deficiency in the system.</td>
<td></td>
<td>Signs of mites will show in new leaves as wiry leaves. Apply the relevant pesticide weekly to counter this pest.</td>
<td></td>
</tr>
<tr>
<td>Budding</td>
<td>21–25</td>
<td>During the vegetative growth period, plants will indicate a level of maturity and start to bud. This shows that they are preparing for fruiting. It is an early indication that the nutrient requirement needs to become focused on flowering and fruit development. Budding also indicates that hormonally, the plants are normal. In rare cases, early budding could be sign of stresses, especially if there is a pH imbalance and plants do not appear healthy enough to bear fruit. In any case, it is best to remove early buds, giving time for the roots to develop properly and for the plants to thrive.</td>
<td>Budding is a sign of plants reaching maturity; the nutrient requirement here is key. Carefully examine plants for deficiencies.</td>
<td>Plants may become vulnerable to pests when bearing fruit especially if they have not properly developed strong roots and leaves.</td>
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<tr>
<td>Growth Stages</td>
<td>Day Range</td>
<td>Description and General Comments</td>
<td>Nutrient Consideration</td>
<td>pH Consideration</td>
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<tr>
<td>Flowering</td>
<td>24-28</td>
<td>Mature buds turn into flowers. It is a part of the reproductive stage of a flowering plant. A flowering plant will reveal a lot based on the condition of the flower. How it is positioned on the plant will reveal how a fruit will set. With sweet peppers, if a flower is opening upwards or directly sideward, it’s an indication of stress on the plant. A positive sign is when the flower is opening downwards. Remove early or stressed flowers.</td>
<td>Allow plants to develop a strong rooting system prior to bearing fruit. It may be necessary to remove first fruits to strengthen plants.</td>
<td></td>
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<tr>
<td>Fruit set</td>
<td>30-35</td>
<td>When a sweet pepper flower has been fertilized, the petals fall and a small green fruit appears from the centre. A positive sign is if the stem is hangs downwards and is green. A yellowing stem indicates abortion of a fruit. This may be normal in some cases when the plant is healthy. However, if a large percentage is aborted it is a sign of nutrient or stress issues.</td>
<td>The main nutrients, nitrogen, phosphorus and potassium, must be in adequate supply for bell peppers to set and develop properly. Watch carefully for signs of deficiency before any application may be needed to the system. It may be necessary, however, for a weekly application to the system of .5 lb of magnesium sulphate; 0.5 lb potassium sulphate should guarantee fruit set, development and healthy fruits. Iron should be added at .25 lb weekly</td>
<td></td>
<td>Pest to be aware of at this stage are stink bugs and caterpillars. Plants showing wilting and rotting of the stem should be removed from the system. Fruits indicating rotting/blackening at the base should be removed. This is a sign of calcium deficiency and may be corrected by foliar application of calcium nitrate weekly.</td>
<td></td>
</tr>
<tr>
<td>Fruit development</td>
<td>33-65</td>
<td>When the sweet pepper reaches the size of a coin, it is likely that the fruit will continue to develop unless stressful factors impede its further growth. During this stage, the plant needs to be supplied with nutrients to supply fruit growth, root development and new leaf growth, allowing it to continually produce new fruits. Remove unhealthy fruits.</td>
<td></td>
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<tr>
<td>Fruit maturity</td>
<td>60-70</td>
<td>As the fruit continues to develop, care should be taken not to disturb it for risk of breaking the stem. An &quot;A&quot; grade fruit should have three or four well shaped lobes. The fruit should be blemish free. No spotting should be on it and it should be monotone unless ripening to colour.</td>
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<tr>
<td>Fruit ripening starts</td>
<td>75-85</td>
<td>Ripening starts showing about one or two weeks after a green sweet pepper is fully mature. At this time fruits can be susceptible to direct sunlight, and scorching may appear on the exposed side of a fruit. Sweet pepper plants may be pruned to avoid scorching while producing healthy &quot;A&quot; grade fruits.</td>
<td></td>
<td></td>
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<tr>
<td>Harvesting starts</td>
<td>60-85</td>
<td>Fruits may be harvested</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Crop maintenance</td>
<td>35-220</td>
<td>Fruits may be harvested</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous harvest</td>
<td>60-220</td>
<td>Fruits may be harvested</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Appendix C

Fingerling Production Guidelines
Fingerling Production Guidelines

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C.1 Tilapia Reproductive (Breeding) Cycle

There are several elaborate breeding methods used by professional fish growers to produce tilapia fingerlings, but the method presented here is one method that it is relatively easy and inexpensive for the aquaponics farmer to implement.

In nature, the male tilapia (*Oreochromis species*) creates a nest or small depression in the sandy bottom of a stream and attracts the female to the nest. If the female accepts the nest, she will lay her eggs at the site. The male spreads his semen over the eggs. The female then places the fertilized eggs in her mouth until they hatch. Thus, female tilapia are known as “mouth brooders.” It is easy to spot a “pregnant” female by the swollen area around the mouth parts. During the incubation period, the female does not eat. The incubation period lasts about 10 days, at which time the fry (young fingerling with the egg sac still attached) will appear near the mother’s mouth. The fry will venture out of her mouth and begin the process of maturation. If danger appears, they will swim back inside the mother’s mouth. Over the course of several days, the egg sac disappears and the fry becomes a fingerling, in time learning to feed and become independent.

C.2 Breeding, Incubation and Grow-Out Tanks

The following materials are needed to establish a tilapia breeding colony composed of five females and one male. These items can generally be found at garden centres and aquarium and/or pet stores.

- One 100–125-gallon (400–500-litre) fish tank / aquarium for breeding
- Two or three 10-gallon (40-litre) fish tanks for incubation and fry emergence
- One 30–50-gallon (100–200-litre) fish tank for fingerling grow-out
- Five or six sections of plastic pipe (4 inches in diameter x 8 inches long or 10 cm x 20 cm)
- One 8-inch (10 cm) flower pot to use as the nest site
- Simple filters and air stones for the three types of fish tanks
- One air pump of sufficient size to cover the needs of the multiple fish tanks
- Plastic tubing for the pump, filters and air stones

Based on the natural reproductive cycle described above as a model, the following procedures are suggested for controlled tilapia breeding.

1. The primary breeding tank is a 100 – 125 gallon (400 – 500 litre) tank equipped with heaters, filters and gravel on the tank floor (see Figure C-1 below):
   - Place five or six pieces of plastic pipe on the floor of the tank. The pipes serve as a place for the females to escape attention from male harassment.
   - Place a medium-size flower pot in the tank. The flower pot is used as a replacement for the “nest” that is found in nature.
   - Fill the tank with de-chlorinated, clean water that is approximately 80° F (27° C).
   - Place your breeding stock – five females and one male – in the tank.
• Observe the tank daily. Within a week or two, one or more of the females should have a bulge around the mouth parts. This is an indication that she is incubating fertilized eggs in her mouth.
• Using a fish net, very carefully transfer the “mother” to a separate 10-gallon (38 litre) incubation tank.

2. The incubation and fry tank should contain 10 gallons (40 litres) of de-chlorinated, clean water, equipped with a heater and filter, at a temperature of 80°F. Do not place gravel on the floor of tank. Place netting over the water filter intake in anticipation of emerging fry.
• After transferring the “pregnant” mother from the breeding tank to the incubation tank, do not feed this breeder fish, as she does not eat during the incubation period.
• Observe the tank daily. Within seven to 10 days, small fry will be swimming around the female’s mouth parts.
• After 24 hours (or when it appears that all of the eggs have hatched), transfer the breeder female back to the breeding tank, where she will resume eating.
• At this stage, the fry are free swimming and ready to be fed. Be sure the netting over the water filter intake is secure to prevent the fry from being sucked up into the filter.
• Begin feeding the fry small amounts of finely ground protein fish food. It is best to feed small amounts of food several times a day. Do not over-feed the fry, which will result in poor water quality.
• The fry will absorb their nutrient-dense egg sac as they begin feeding and become fingerlings. The new fry will double in size in the first 24 hours.
• When the fingerlings grow to a size of 1 inch (2.5 cm) and/or 1 ounce (25 grams), transfer the juvenile fingerlings to a separate 30-50 gallon grow-out tank.

3. The grow-out tank should contain 30 to 50 gallons (100 to 200 litres) of de-chlorinated, clean water, equipped with a heater, filter and gravel on the tank floor, at a temperature of 80°F to allow fingerlings to mature.
• After transferring the juvenile fingerlings to the grow-out tank, continue feeding the fingerlings until they reach a size of 6 to 8 inches (15 to 20 cm) and/or weight of 2 to 4 ounces (20 to 100 grams). At this growth size, they are ready for stocking in the aquaponic system or to be sold to other growers.
C.3 Converting the Duckweed Bed to Fingerling Production

The duckweed (middle) grow bed may be also used for breeding tilapia. While a separate system may be preferable (e.g., to reduce disease mobility between connected tanks), the middle grow bed can function well for fingerling production on site. This will not only ensure a continuous supply of fingerlings to replenish the aquaponic system, but will reduce fingerling purchasing and transportation costs and may provide additional income by selling excess fingerlings to other producers.

To prepare the middle grow bed, the plumbing should be modified such that a screen is placed over the overflow drain pipe that deposits into the sump tank (to contain the fingerlings), and the bed should be filled to capacity with clean water. All other aspects of the grow bed remain the same.

The grow bed should then be separated into three separate chambers, divided by screen nets. The section furthest away from the fish tanks will be 6 feet long and used as the brood stock tank. The middle section will be 8 feet long and contain fry (with a temporary, removable screen placed in the middle). The third section closest to the fish tanks will be 10 feet long and used to grow the fingerlings for up to 2 months.
The breeding section will hold three female and one male mature tilapia, which will produce about 750 to 1,000 fry every six weeks. A small amount of gravel should be placed in this bed to cover the bottom and provide a substrate for egg laying. Breeding takes place when the females lay eggs on the bed and the male passes sperm over the eggs to fertilize them. The female will then scoop the translucent eggs into its mouth to protect the roe until they are hatched.

One should be vigilant to identify these fertilized egg-bearing females and move them to the middle fry section prior to hatching. The temporary screen dividing this middle section will separate the hatching fry from more mature fry. As soon as fry have hatched, the breeder female tilapia will be placed back into the first brood stock tank. Hatched fry may be further separated from a newly placed female about to hatch her eggs using the temporary screen.

The newly hatched fry will grow relatively quickly by feeding on algae, insect larvae and commercially available feeds. After 2 weeks, the temporary screen in the middle section may be removed (unless there is yet another female about to hatch her eggs) to allow all fry to develop. When fry are about 1 month old, they can be released/transferred to the third fingerling section and fed high-protein feed. After 1 more month, once they are approximately 50 grams each, the fingerlings can be placed in the aquaponics fish tanks to continue growing. This separation of growth stages will help to reduce the risk of cannibalism of smaller fish by larger fish.
Appendix D

Monitoring Templates and Forms
# System Monitoring Templates and Forms

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### D-1. Aquaponics Input Costs

<table>
<thead>
<tr>
<th>INPUT/COST FACTORS</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
<th>TOTAL COST</th>
<th>TOTAL AMOUNT</th>
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<tbody>
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<td>Land preparation (weeding, fencing, terracing, trenching, ploughing, bedding)</td>
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<tr>
<td>Technical assistance/training</td>
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<tr>
<td>Disaster loss (crop value)</td>
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<tr>
<td>Disaster loss (damage)</td>
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<tr>
<td>Loan repayment</td>
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<td></td>
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</tr>
</tbody>
</table>
D-2. Tilapia Feeding and Water Quality Data

This document should be used to record activities around the raising of tilapia in INMED aquaponic systems. The charts embedded are to assist in documenting data. The tilapia feeding rates are based on feed conversion ratio of 1:1.3 as a guide to assess growth rates. Growth rates will vary according to protein content of feed, temperature and condition of water quality. The number of times for daily feeding is indicated in the fish feeding chart. As best as possible, space feeding equally throughout the times recommended. One sheet will record activities for two days. To get average weight for fish, weigh total weight for about 25 fish, divide the total weight by 25 for the average weight/fish, and multiply the approximate # of fish in the tank by the average weight to calculate the total weight of fish per tank.

<table>
<thead>
<tr>
<th>No. of fish in relevant tank(s)</th>
<th>Weather</th>
<th>Scale Description for Data Entries</th>
<th>Fish Growth and Feeding Chart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tank # (1-4)</td>
<td>Overcast (O)</td>
<td>Sunny (S)</td>
<td>Rainy (R)</td>
</tr>
<tr>
<td>Cloud cover</td>
<td>None (0)</td>
<td>1/4 (1)</td>
<td>1/3 (2)</td>
</tr>
<tr>
<td>Feed Type (Hi-Pro Pellets (HP), Hi-Pro Mash (HM) Float Feed (FF)) Other:</td>
<td>Tank water capacity</td>
<td>None (0)</td>
<td>1/4 (1)</td>
</tr>
<tr>
<td>Expected daily feed rate (grams)</td>
<td>Tank water cloudiness</td>
<td>Clear (0)</td>
<td>25% (1)</td>
</tr>
<tr>
<td>Tank water odor</td>
<td>no smell (0)</td>
<td>slightly (1)</td>
<td>moderate (2)</td>
</tr>
</tbody>
</table>

Date:__________
Notes:

Recommended feed times:

<table>
<thead>
<tr>
<th>9:00</th>
<th>11:00</th>
<th>1:00</th>
<th>3:00</th>
<th>5:00</th>
</tr>
</thead>
</table>

Actual times fed:

<table>
<thead>
<tr>
<th>Powder</th>
<th>Powder</th>
<th>Powder</th>
<th>Powder</th>
</tr>
</thead>
</table>

Feed amount consumed (g):

<table>
<thead>
<tr>
<th>2.0</th>
<th>1</th>
<th>5</th>
<th>160g</th>
</tr>
</thead>
</table>

Feed duration (in minutes):

<table>
<thead>
<tr>
<th>1.7mm</th>
<th>7.0</th>
<th>5</th>
<th>5</th>
<th>370g</th>
</tr>
</thead>
</table>

Weather (O, S, R):

<table>
<thead>
<tr>
<th>1.7mm</th>
<th>9.0</th>
<th>6</th>
<th>5</th>
<th>470g</th>
</tr>
</thead>
</table>

Cloud cover (0-5):

<table>
<thead>
<tr>
<th>2-4 mm</th>
<th>12.0</th>
<th>7</th>
<th>5</th>
<th>600g</th>
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</thead>
</table>

Tank water capacity (0-5):

<table>
<thead>
<tr>
<th>2-4 mm</th>
<th>15.0</th>
<th>8</th>
<th>5</th>
<th>750g</th>
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</thead>
</table>

Tank water cloudiness (0-4):

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<thead>
<tr>
<th>2-4 mm</th>
<th>20.0</th>
<th>9</th>
<th>5</th>
<th>950g</th>
</tr>
</thead>
</table>

Tank water odor (0-3):

| 2-4 mm | 24.0 | 10 | 5 | 950g |

Fish gasping (0-100%):

<table>
<thead>
<tr>
<th>4-6mm</th>
<th>28.0</th>
<th>11</th>
<th>4</th>
<th>1kg</th>
</tr>
</thead>
</table>

pH (actual reading):

<table>
<thead>
<tr>
<th>4-6mm</th>
<th>34.0</th>
<th>12</th>
<th>4</th>
<th>1.2kg</th>
</tr>
</thead>
</table>

Tank water temperature (F):

<table>
<thead>
<tr>
<th>4-6mm</th>
<th>40.0</th>
<th>13</th>
<th>4</th>
<th>1.4kg</th>
</tr>
</thead>
</table>

Electrical conductivity (actual):

<table>
<thead>
<tr>
<th>4-6mm</th>
<th>47.0</th>
<th>14</th>
<th>4</th>
<th>1.7kg</th>
</tr>
</thead>
</table>

Fish mortality (no.)

<p>| 6-8mm | 56.0 | 15 | 4 | 2kg |</p>
<table>
<thead>
<tr>
<th>Date: Notes:</th>
<th>Recommended feed times</th>
<th>9:00</th>
<th>11:00</th>
<th>1:00</th>
<th>3:00</th>
<th>5:00</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual times fed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Feed amount consumed (g)</td>
<td>6-8mm</td>
<td>66.5</td>
<td>16</td>
<td>4</td>
<td>2.3kg</td>
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<td></td>
<td>Feed duration (in minutes)</td>
<td>6-8mm</td>
<td>79.0</td>
<td>17</td>
<td>4</td>
<td>2.8kg</td>
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<tr>
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<td>Weather (O, S, R)</td>
<td>6-8mm</td>
<td>93.5</td>
<td>18</td>
<td>4</td>
<td>3.3kg</td>
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<tr>
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<td>Cloud cover (0-5)</td>
<td>6-8mm</td>
<td>150.0</td>
<td>21</td>
<td>3</td>
<td>4kg</td>
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<td>Tank water capacity (0-5)</td>
<td>6-8mm</td>
<td>170.0</td>
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<td>3</td>
<td>4.3kg</td>
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<td>Tank water cloudiness (0-4)</td>
<td>6-8mm</td>
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<td>23</td>
<td>3</td>
<td>4.8kg</td>
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<td></td>
<td>Tank water odour (0-3)</td>
<td>6-8mm</td>
<td>215.0</td>
<td>24</td>
<td>3</td>
<td>5.5kg</td>
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<tr>
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<td>Fish gasping (0-100%)</td>
<td>6-8mm</td>
<td>245.0</td>
<td>25</td>
<td>2</td>
<td>6.1kg</td>
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<td></td>
<td>pH (actual reading)</td>
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<td>280.0</td>
<td>26</td>
<td>2</td>
<td>7kg</td>
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<tr>
<td></td>
<td>Tank water temperature (F)</td>
<td>6-8mm</td>
<td>315.0</td>
<td>27</td>
<td>2</td>
<td>8kg</td>
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<tr>
<td></td>
<td>Electrical conductivity (actual)</td>
<td>6-8mm</td>
<td>355.0</td>
<td>28</td>
<td>2</td>
<td>9kg</td>
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<tr>
<td></td>
<td>Fish mortality (no.)</td>
<td>6-8mm</td>
<td>405.0</td>
<td>29</td>
<td>2</td>
<td>10kg</td>
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<td></td>
<td>6-8mm</td>
<td>460.0</td>
<td>30</td>
<td>2</td>
<td>11.5kg</td>
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Name: ________________________________________________________________

Signature: ___________________________________________________________
## D-3. Crop Activity

<table>
<thead>
<tr>
<th>Log sheet no.</th>
<th>Plant type:</th>
<th>Variety:</th>
<th>Date sown:</th>
<th>Quantity sown:</th>
<th>Date transplanted:</th>
<th>Quantity transplanted:</th>
<th>Date of summary:</th>
<th>Quantity lost to date:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Timeframe</th>
<th>Significant observation or action</th>
<th>Additives used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Stage of growth</td>
<td>Observation</td>
</tr>
<tr>
<td>Name</td>
<td>Name</td>
<td>Name</td>
</tr>
</tbody>
</table>

Name: ____________________________  Signature: ____________________________
## D-4. Production Volume and Sales

**Location:** ________________________________

<table>
<thead>
<tr>
<th>CROP/PRODUCE</th>
<th>Market Date</th>
<th>Months to Produce</th>
<th>Production Area* ft(^2)</th>
<th>Quantity Produced</th>
<th>Quantity Lost</th>
<th>Quantity Sold</th>
<th>Unit of Measure</th>
<th>Unit Price J$</th>
<th>INCOME J$</th>
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* NOTE: One medium commercial-size grow bed has an area of 8.9 m\(^2\) (or 95.8 ft\(^2\)) and one fish tank holds a volume of about 1.6 m\(^3\) of water (or 423 gallons).
Appendix E

Aquaponics Business and Financial Model
AQUAPONICS FARMING IN JAMAICA

Business Model and Financial Strategy

INMED Partnerships for Children

Prepared by: Economic Ventures Limited/Lloyd Brown
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Executive Summary

The improvement of food security, while advancing sustainable economic activity in developing countries, is considered a top priority in all economic areas of the world. Aquaponics farming, the combination of hydroponics and aquaculture, may be considered the most versatile agricultural system to address these needs given that in an increasingly urbanized world it can be successfully practiced in both urban and rural settings. INMED Partnership for Children is seeking to collaborate with stakeholders in Jamaica, such as the Government through the Development Bank and the Ministry of Agriculture, farmers and consumer entities, to promote aquaponics farming to enhance food production and reduce import dependency. The efforts are aimed at initiating medium sized systems of approximately 768 square feet of growing space, operated by one (1) farmer, to demonstrate practical application and viability in relation to ease of operation, reduced operational cost, pollution reduction and revenue returns. This demonstration is geared to encourage the adoption of the technology as a principal farming method among small and larger farmers in Jamaica.

The system being demonstrated in this business case (768 sq. ft. growing space – total space 2,178 sq. ft.) carries an average set-up cost of J$1.96 million (US$15,691) with further operational cost of approximately J$320,000 (US$2,560) for the average 16 weeks to first harvest. The system is capable of supporting over 50 different vegetable and spice/herb crops, however the crops chosen in this model are pepper and tomato along with the complementary products of fish for nutrients and scallion to assist pest control. These crops are expected to produce minimum annual revenues of J$1.74 million (US$13,933) and return net profits (after non-cash provisions – depreciation, deferred – of $62,675) of J$558,227 (US$4,465), but retain the potential of increasing by more than 50% at optimal levels. The system faces challenges in the areas of financing – large initial capital outlay for small farmers with minimal support from financial institutions due to perceived risks-, acceptance – slow take up of technology until it is sufficiently proven – and adoption – fear of replacement of familiar, proven practices and outcomes with new unfamiliar technology and possible financial losses.

The business case outlined in the following pages is intended to act as an information guide, from a financial perspective, to the stakeholders, (government, financiers, farmers, etc.) in implementing, assessing and operating these systems.
1. Introduction

Developing nations such as Jamaica will encounter challenges of marginalization of sectors of society, food security and in the allocation of resources to provide an equitable environment with opportunities for advancement for all its population. These challenges in the Jamaican environment have resulted in rapid urbanization, reduced farming activities, greater dependency on imports with consequent social ill effects such as environmental degradation, unhealthy diets and increased measured poverty levels.

Jamaica also has an increasing urban population measuring approximately 50%, gross domestic product per person in 2015 of J$611,572 (less than US$5,000) and gross disposable income of J$648,458 (approximately US$5,000), with an unemployment rate of approximately 8.9% (labour force being approximately 1,355,500) (Statistical institute of Jamaica). Any intervention that presents single individuals with the means to achieve earnings that exceed the national averages can significantly advance the economic outcomes for the individual and the country as a whole.

Aquaponic farming has been identified as a best practice method of food production that is sustainable, socially acceptable, environmentally friendly, lucrative, and can be pursued in either urban or rural areas. Medium sized units of only 768 square feet of planting area (effective 2,178 sq. ft. of total space) can be operated by one individual and have the capacity to produce conservative minimum gross revenues averaging over J$2 million (US$15,000) per year – over 300% of the national GDP per person.

Policies and strategies are being encouraged to create partnerships and innovative methods and means to alleviate or reverse harmful social and economic trends.

2. Current Situation

Poverty alleviation/eradication, control of the factors creating over-urbanization, and sustainable food production are among the top priorities of the Jamaican government and most international organizations concerned with the economic welfare of the world. Local aggravating factors that require attention to assist in rebalancing these factors include:

- Utilization of arable land for housing and urban expansion reducing the amount of land available for traditional farming activities
- Urban drift in pursuit of economic opportunities
- Stigmatization of rural and subsistence farming and the shunning of these activities especially by youths creating a relative reduction in total farming outputs and a higher dependency on food imports
• Persistence of the concept that small farming is a “last resort” occupation not be pursued by the “educated” reduces agricultural asset replacement as older farmers retire
• Overuse of pesticides, weedicides and fertilizers effectively “killing” the land and polluting water sources, rivers and the marine environment and reduces production output and aquatic stock
• Changes in the local weather pattern resulting in recent cycles of extensive droughts and devastating flooding
• Unavailability of affordable financing for start up agricultural production projects from commercial sources in Jamaica (average of only 1.77%, highly collateralized, of all commercial loans, annual average of J$457.2B) for the last 3 years.

Aquaponics farming may be identified as the single best programme that possesses the factors that can assist in addressing all the stated challenges.

3. Project Objectives

The objective of this business model is to assist in the initialization of a programme of financing and project implementation that will promote sustainable farming and provide a channel to economic independence for individuals in both the urban and rural areas of Jamaica. It is also visualized that this project will become a viable example of entrepreneurship that will focus communities to better utilize local resources to their economic benefit. A total of 25 projects is recommended to be targeted for the first year.

This presentation will provide the financial considerations, operations, outcomes and impacts of a single project along with suggestions for strategic alliances with stakeholders and implementation procedures.

4. Stakeholders

The implementation actions and beneficial outcomes are expected to involve the following stakeholders:

• **INMED Partnership for Children:** INMED has responsibility for the initiation and coordination of the implementation of the project. INMED will provide and/or coordinate the technical inputs and training involved in the selection and training of candidates for the programme as well as advise on the set up and initialization of the systems.
• **Development Bank of Jamaica (DBJ):** To provide concessionary funding of not less than $50 million at an interest rate of 4% to 5% and guarantee individual loans through secondary financial institutions. Bank will ensure maximum retail interest rate cap between 7% and 9% and convert loan repayments to a revolving facility to be augmented with additional capital as necessary in the subsequent years.

• **Hotels, Restaurants and Local Purveyors of Agricultural produce:** To provide market take-up of the products produced from individuals or coalition of systems. Note that hotel rooms in Jamaica have increased by 73% (27,000 to 46,000) between 2008 and 2016 and is scheduled to have another 14,000 rooms in the next 3 years (*Ministry of Tourism*).

• **Ministry of Industry, Commerce, Agriculture and Fisheries (MICAF):** To assist in the provision of technical and physical inputs in the projects, and give any required assistance in the monitoring and promotion of the project as a part of their programme for sustainable food production and water management.

• **System Operators:** To be initially selected from graduates and teachers of agricultural colleges, inner city youth organizations, community clubs, as other dedicated entrepreneurs.

• **Communities and Country:** Participating communities will realize the benefits of sustainable farming practices. Stimulation of community to engage in entrepreneurial endeavours, and reduced requirements for imports.

5. **Summary Costs and Financing**

The costs involved in the set-up and initialization of INMED’s media bed aquaponic system may be considered prohibitive to the targeted sector with limited resources. The assessed construction cost, quantified by a licensed quantity surveyor (see Appendices 8 - 9), are summarized in Tables 1a and 1b below.

<table>
<thead>
<tr>
<th><strong>Table 1a: Summary of Construction Costs by Structure for 768 sq. ft. Media Bed Aquaponic System</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Page No.</strong></td>
</tr>
<tr>
<td>Foundation</td>
</tr>
<tr>
<td>Walling &amp; Masonry</td>
</tr>
<tr>
<td>Reinforced concrete slab &amp; Fill</td>
</tr>
<tr>
<td>Fish Tank</td>
</tr>
<tr>
<td>Valve Chamber</td>
</tr>
<tr>
<td>Piping work Installation (Provisional) including pump</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
</tr>
</tbody>
</table>

*Prepared by: Davidson Hanna Quantity Surveyors*
The costing has been prepared using urban commercial building rates for 768 square feet of growing space and 562 cubic feet of fish tanks. The establishment costs are projected to the value of approximately J$1.8 million (approximately US$14,000) by loan guaranteed by the Development Bank of Jamaica. It is factored that a significant portion of the casual labour component along with minimal cash expenditures will be input as equity by the recipient. It may also be noted that construction costs in inner city and rural areas may be considerably less as rates in these areas are usually lower than urban commercial rates.

6. Business and Operational Outcomes

The establishment and operation outcomes of the 768 sq. ft. media bed aquaponic system being presented are dependent on the following prerequisites:

- Establishment and operational cost of the system up to the reaping of the first crop is estimated at J$2.28 million as per capitalization provided in Table 2
- Loan funds of J$2 million to be received from small business financing entity with the DBJ guarantee for the full amount as collateral security
- Owner will provide equity of approximately 12% (J$281,476) as cash and kind in the set-up and grow out period of the project
- Funds to be offered for a maximum repayment period of 5 years at a maximum interest rate not exceeding 9.5%
- Technical assistance and training to be offered at no cost to recipients through INMED, DBJ training and development programme and/or MICAF agricultural extension services.
- Sales of the products from individual systems are small enough to be taken up by local users and purveyors, however INMED will coordinate a marketing programme to hotels in the given area; individual names and contact information of all systems, will be presented to the purchasing departments of the hotels, to be forwarded to their contractors (who will pay cash) as potential primary suppliers (*individual hotel contracts are difficult and expensive to maintain as products must be delivered whether or not there is a production lull and payment period generally range between 3 and 6 weeks – effective 2 to 5 weeks of receivables which will be unaffordable in the short term*).
- The system will be predominantly operated by the owner with all returns accruing to his/her benefit.

### Table 2: Project Cost and Financing Sources

<table>
<thead>
<tr>
<th>Investment Items</th>
<th>Total Capital</th>
<th>DBJ/AIF</th>
<th>Equity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Cost</td>
<td>1,655,952</td>
<td>1,494,476</td>
<td>161,476</td>
</tr>
<tr>
<td>Covering</td>
<td>192,000</td>
<td>192,000</td>
<td></td>
</tr>
<tr>
<td>Equipment - Solar &amp; Air Pumps</td>
<td>113,524</td>
<td>113,524</td>
<td></td>
</tr>
<tr>
<td>Working Capital - feed, fish &amp; supplies</td>
<td>290,000</td>
<td>200,000</td>
<td>90,000</td>
</tr>
<tr>
<td>Fees and charges - bank, professional</td>
<td>30,000</td>
<td>0</td>
<td>30,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>J$2,281,476</strong></td>
<td><strong>J$2,000,000</strong></td>
<td><strong>J$281,476</strong></td>
</tr>
<tr>
<td><strong>Debt-to-Equity Ratio</strong></td>
<td><strong>87.7%</strong></td>
<td><strong>12%</strong></td>
<td></td>
</tr>
</tbody>
</table>

Construction of the unit is projected to require a maximum of 3 weeks and all inputs are readily available. Working capital support of J$200,000 is to be financed by loan funds to purchase fish, seed and any other supplies. The proposed primary products for the presented system are sweet pepper, tomato and scallion, with grow out and production periods as presented in Table 3 below.

### Table 3. Farm Production Cycles

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pepper</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tomatoes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scallion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**LEDGEN/KEY**

- Pepper Planting
- Pepper Reaping
- Tomato Planting
- Tomato Reaping
- Scallion Planting
- Scallion Reaping
- Fish Stocking
- Fish Reaping
The expected yields per plant per month are projected in Table 4 and revenues are calculated at average price per products as published by The Ministry of Industry, Commerce, Agriculture and Fisheries. Yields per plant per month – Pepper at 0.75 lb. (2 fruits), tomato at 1 lb. (2-6 fruits) and scallion at 1 ounce (1 stalk) are projected at the lower range of potential outputs.

Table 4: Annual Projected yields and revenues

<table>
<thead>
<tr>
<th></th>
<th>Planting and Growing (Months)</th>
<th>Harvesting (Months)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Costs/Yield</td>
<td>1</td>
</tr>
<tr>
<td>Pepper Plants</td>
<td>768</td>
<td></td>
</tr>
<tr>
<td>Planting Costs</td>
<td>$14 each</td>
<td>14,000</td>
</tr>
<tr>
<td>Yields (lbs per month @ plant)</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>Revenue $ per lb</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>Tomato Plants</td>
<td>384</td>
<td></td>
</tr>
<tr>
<td>Planting Costs</td>
<td>at $3 each</td>
<td>1,500</td>
</tr>
<tr>
<td>Plant Supplement s</td>
<td>11,325</td>
<td></td>
</tr>
<tr>
<td>Yields (lbs per month)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Revenue ($ per lb)</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>Scallion Plants</td>
<td>1 oz. each</td>
<td>1,880</td>
</tr>
<tr>
<td>Planting Cost</td>
<td>150 @ lb</td>
<td></td>
</tr>
<tr>
<td>Yields (oz. per plant per month)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Revenue @$ per lb</td>
<td>150</td>
<td></td>
</tr>
</tbody>
</table>

The outputs projected will provide revenues starting at J$1.74 million in year one and should grow to approximately J$2.5 million in year five. Direct system inputs are predominantly seeds and feed for the fish, consequently it provides a gross profit margin averaging 86% which will produce net profit margins averaging over 42% and ranging between J$588,227 and J$1.225,753 million over the 5 year period.
This level of profitability will give the system the capacity to afford debt financing of approximately $4 million and consequently provide a debt coverage ratio averaging 2.2 for the debt of $2 million used for the set-up.

<table>
<thead>
<tr>
<th>Table 6: Debt Service Coverage Ratio (J$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
</tr>
<tr>
<td>Profit</td>
</tr>
<tr>
<td>Interest</td>
</tr>
<tr>
<td>Depreciation &amp; Deferred. Expenses</td>
</tr>
<tr>
<td>Total Available</td>
</tr>
<tr>
<td>Loan Liability</td>
</tr>
<tr>
<td>Coverage %</td>
</tr>
</tbody>
</table>

Detailed financial statements, cash flow and notes are presented in appendix 1 to 4 attached.

7. Summary

Medium sized system establishment will be best achieved through maximum input and involvement of the owner/operator with technical inputs and monitoring assistance from INMED and the financial guarantee of DBJ to a maximum of J$2 million. Calculations are based on conservative estimates (i.e., low end production values).

The proposal is based on the standard Jamaican crops (pepper, tomato, scallion), which are easily cultivated and readily marketable; however the system can be managed to enhance revenues by seasonal cultivation of high value gourmet crops such as Swiss chard, cilantro, broccoli and others which fetch high prices during the winter season. System outputs have also been principally based on proven outputs from operations that experienced some adverse effects from weather and lack of covering for the complete cycles, consequently a well-managed system may therefore produce substantially more. Seed suppliers’ rated outputs are also substantially more (2 to 4 times) than the outputs used in these projections.
8. Recommendations

The project should be undertaken through a strategic relationship with a government/internationally funded organization such as the Development Bank of Jamaica (DBJ), with the following conditions.

- INMED should seek to develop a maximum of 25 projects in selected areas island-wide, as model projects to stimulate interest and provide examples of entrepreneurship.
- DBJ should be engaged in the partnership to provide J$50 million to underwrite each individual project with a guarantee of J$2 million.
- Given that DBJ does not undertake direct lending, the lending agency (agencies) should be mandated by the DBJ to on-lend funds at a maximum interest rate between 7% and 9% for up to 5 years repayment terms.
- Repaid loans to be committed to a revolving fund for the development of more aquaponics system over a minimum of 5 years.
- INMED to coordinate the provision of training and technical assistance in the set up and operation of each project for a minimum period of 2 years in association with the DBJ and any other identified external funding.
- INMED should seek to further develop strategic relationship with the Ministry of Industry, Commerce, Agriculture and Fisheries to adopt and assist in the promotion of the project as a mainstream method for the production of the selected production.

9. SWOT Analysis

<table>
<thead>
<tr>
<th>Benefits and Weakness of Aquaponic Food Production in Jamaica</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Major benefits of aquaponic food production</td>
<td>Major weaknesses of aquaponic food production</td>
</tr>
<tr>
<td>Sustainable and intensive food production system; can be located anywhere</td>
<td>Expensive initial start-up costs compared with soil or vegetable production or hydroponics</td>
</tr>
<tr>
<td>Two agricultural products (fish and vegetables) are produced from one nitrogen source (fish waste)</td>
<td>Knowledge of fish, bacteria and plant production is needed for each farmer to be successful</td>
</tr>
<tr>
<td>Extremely water efficient</td>
<td>Daily management is mandatory</td>
</tr>
<tr>
<td>Can be located closer to home to discourage praedial larceny</td>
<td>Easy target for praedial larceny to reap large quantities quickly</td>
</tr>
<tr>
<td>Does not use inorganic fertilizers or chemical pesticides</td>
<td>Debt funding for start-up not embraced by a large percentage of the targeted population</td>
</tr>
<tr>
<td>Predictable higher yields and qualitative production with relatively quicker recovery time from adverse events than traditional farming</td>
<td>Reduced management choices compared with standalone aquaculture or hydroponics systems</td>
</tr>
<tr>
<td>May be considered attractive to youths because it can be considered “clean” and different</td>
<td>Mistakes or accidents can cause stress or breakdown of the production system</td>
</tr>
<tr>
<td>Higher control on production leading to lower losses</td>
<td>Requires constant energy</td>
</tr>
<tr>
<td>Daily tasks, harvesting and planting are labour saving and therefore can include all genders and ages</td>
<td>Farming method sparsely known in Jamaica and may be viewed with suspicion</td>
</tr>
<tr>
<td>Can enter into supply contracts and be assured of consistent quality and quantity as agreed</td>
<td>Limited returns per annum can be unattractive to youths</td>
</tr>
</tbody>
</table>
### Appendix 1

<table>
<thead>
<tr>
<th>NOTES TO FINANCIAL PROJECTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>The attached cash flow and financial statements are projected from the following assumptions and information for a scalable aquaponics system covering 1/2 square chain - 2,178 sq. ft. (0.02 hectare) and covered with 40% shaded greenhouse plastic to restrict direct rainfall and sunlight.</td>
</tr>
</tbody>
</table>

1. The system will provide 768 sq. ft. of grow bed space utilizing 4 grow beds measuring 4 ft wide, 48 ft. long and 1 ft. deep spaced 2 ft. apart and draining into 2 tanks measuring 6 ft. wide, 8 ft. long and 4.5 ft. deep.

2. The optimal crops of sweet pepper and tomatoes intercropped with scallion are projected for this system in the proportion of 2/4 grow beds (384 sq. ft.) for pepper and 4 grow beds (384 sq. ft.) for tomatoes.

3. Approximately 2,000 fingerlings (young fish) (140 lbs) will be introduced and grown to provide the nutrient support for the system.

4. Fish will be fed to convert at an approximate average rate of 1:2.8 to realize average growth of 1.5 ounces per month and sized periodically to maintain approximate weight balances in each tank.

5. Feed purchases are computed at $33.63 per lb for the consumption of an average 2.11 lbs of feed to produce a live weight of approximately 12 ounces.

6. The grow-out period (germination to reaping) for pepper is approximately 4 months with an active reaping period of 8 months giving an effective life span of 1 year.

7. The grow-out period (germination to reaping) for tomato is approximately 4 months with an active reaping period of 8 months giving an effective lifespan of 1 year.

8. Scallion will produce continuously after a grow out period of approximately 12 weeks and requires no material for replanting.

9. Pepper will be planted at a spacing of 12” x 12” to realize 192 plants per grow bed.

10. Tomato will be planted at a spacing of 18” x 24” to realize 96 plants per bed.

11. Intercrop scallion will be planted at a spacing of 6’ along the centre line between the rows of pepper and tomatoes to realize 278 plants in each pepper grow bed and 192 plants in each tomato grow bed to realize a total of 2,158 plants for the system.

12. Pepper is projected to yield an average 0.75 lbs per plant per month (2 - 3 fruits) for 8 to 9 months to produce approximately 12.75 lbs per plant per year at an average price of $170 per lb.

13. Tomato is projected to yield an average 1 lbs per plant per month (3 - 4 fruits) for 8 to 9 months to produce approximately 13 lbs per plant per year at an average price of $150 per lb.

14. Scallion is projected to yield an average 1 ounce per plant per month (1 stalk) to produce approximately 0.56 lb (1/2 lb) per plant per year at an average $150 per lb.

15. The supplementary - system compatible - nutrients of monopotassium phosphate, magnesium sulphate and chelated iron for foliage and fruiting are projected to be administered at 4 ounces per bed per week for monopotassium and magnesium and 2 ounces per bed per week for iron from the beginning of flowering to the end of harvesting (months 3 to 12).

16. Natural repellents such as hot pepper and lemon grass are employed in the system as pesticides and fungicides to complement or replace the allowance carried for treatment as necessary.

17. Fish is projected to be reaped at a minimum weight of 12 oz (3/4 lbs) in batches of approximately 600 from month 8 to 12 of each year to produce a minimum of 450 lbs per batch at an average price of $180 per lb.

18. Wages is projected for 1 farm worker at average of $10,000 per week with statutory contributions (National Insurance, Ed tax, NHT and HEART) at 11.5% of wages.

19. The standard solar and air pumps have expected useful lives exceeding 10 years and allowance is made for routine servicing (replacement filter, cleaning, solar panel service) every 6 months.

20. Subsequent years’ income and expenditures are projected with inflationary allowances of 5% to 10%.
## Appendix 2

### AQUAPONIC PRODUCTION (4356 sq. ft. - 1 sq. chain)

#### PROJECTED BALANCE SHEET

5 YEARS

<table>
<thead>
<tr>
<th></th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FIXED ASSET</strong></td>
<td>1,904,801</td>
<td>1,848,126</td>
<td>1,791,451</td>
<td>1,734,776</td>
<td>1,678,101</td>
</tr>
<tr>
<td><strong>DEFERRED EXPENDITURE</strong></td>
<td>24,000</td>
<td>18,000</td>
<td>12,000</td>
<td>6,000</td>
<td></td>
</tr>
<tr>
<td><strong>CURRENT ASSETS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Livestock &amp; Inventory</td>
<td>728,361</td>
<td>957,818</td>
<td>1,399,007</td>
<td>1,961,291</td>
<td>2,424,142</td>
</tr>
<tr>
<td>Bank &amp; Cash</td>
<td>728,361</td>
<td>957,818</td>
<td>1,399,007</td>
<td>1,961,291</td>
<td>2,424,142</td>
</tr>
<tr>
<td><strong>CURRENT LIABILITIES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Portion of Long Term Loan</td>
<td>392,043</td>
<td>430,953</td>
<td>473,724</td>
<td>520,739</td>
<td></td>
</tr>
<tr>
<td>Taxation Provision</td>
<td>139,557</td>
<td>174,595</td>
<td>246,016</td>
<td>304,837</td>
<td>306,438</td>
</tr>
<tr>
<td></td>
<td>531,600</td>
<td>605,548</td>
<td>719,739</td>
<td>825,577</td>
<td>306,438</td>
</tr>
<tr>
<td><strong>Net Current Assets/Liabilities</strong></td>
<td>196,761</td>
<td>352,270</td>
<td>679,268</td>
<td>1,135,714</td>
<td>2,117,704</td>
</tr>
<tr>
<td></td>
<td>2,125,562</td>
<td>2,218,396</td>
<td>2,482,719</td>
<td>2,876,490</td>
<td>3,795,805</td>
</tr>
<tr>
<td><strong>FINANCED BY</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital</td>
<td>281,476</td>
<td>281,476</td>
<td>281,476</td>
<td>281,476</td>
<td>281,476</td>
</tr>
<tr>
<td>Retained earnings</td>
<td>418,670</td>
<td>942,456</td>
<td>1,680,503</td>
<td>2,595,014</td>
<td>3,514,329</td>
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<tr>
<td></td>
<td>700,146</td>
<td>1,223,932</td>
<td>1,961,979</td>
<td>2,876,490</td>
<td>3,795,805</td>
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<tr>
<td>Long Term Loan</td>
<td>1,425,416</td>
<td>994,463</td>
<td>520,739</td>
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<td>0</td>
</tr>
<tr>
<td></td>
<td>2,125,562</td>
<td>2,218,396</td>
<td>2,482,719</td>
<td>2,876,490</td>
<td>3,795,805</td>
</tr>
</tbody>
</table>
### Appendix 3

**AQUAPONIC PRODUCTION (4356 sq. ft. - 1 sq. chain)**

**PROJECTED PROFIT & LOSS ACCOUNTS**

<table>
<thead>
<tr>
<th>5 years</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sales</strong></td>
<td>$1,471,733</td>
<td>$1,618,906</td>
<td>$1,780,796</td>
<td>$1,958,876</td>
<td>$2,154,764</td>
</tr>
<tr>
<td>Produce</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td>$270,000</td>
<td>$283,500</td>
<td>$421,200</td>
<td>$510,300</td>
<td>$337,500</td>
</tr>
<tr>
<td><strong>Total Income</strong></td>
<td>$1,741,733</td>
<td>$1,902,406</td>
<td>$2,201,996</td>
<td>$2,469,176</td>
<td>$2,492,264</td>
</tr>
<tr>
<td><strong>DIRECT COSTS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting Materials</td>
<td>$33,125</td>
<td>$17,050</td>
<td>$18,755</td>
<td>$20,631</td>
<td>$22,694</td>
</tr>
<tr>
<td>Fish and Feed</td>
<td>$178,150</td>
<td>$199,731</td>
<td>$202,074</td>
<td>$222,620</td>
<td>$228,264</td>
</tr>
<tr>
<td>Supplements &amp; Pesticides</td>
<td>$47,935</td>
<td>$52,729</td>
<td>$58,001</td>
<td>$63,801</td>
<td>$70,182</td>
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<td><strong>Total Direct Costs</strong></td>
<td>$259,210</td>
<td>$269,509</td>
<td>$278,831</td>
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<td>$321,139</td>
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<tr>
<td><strong>Gross Profit</strong></td>
<td>$1,482,523</td>
<td>$1,632,897</td>
<td>$1,923,166</td>
<td>$2,162,124</td>
<td>$2,171,125</td>
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<tr>
<td><strong>EXPENSES</strong></td>
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<tr>
<td>Wages</td>
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<td>$561,960</td>
<td>$590,058</td>
<td>$619,561</td>
<td>$650,539</td>
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<td>Maintenance</td>
<td>$20,000</td>
<td>$22,000</td>
<td>$24,200</td>
<td>$26,620</td>
<td>$29,282</td>
</tr>
<tr>
<td>Travelling &amp; Transportation</td>
<td>$60,000</td>
<td>$66,000</td>
<td>$72,600</td>
<td>$79,860</td>
<td>$87,846</td>
</tr>
<tr>
<td>Telephone, stationery etc.</td>
<td>$60,000</td>
<td>$66,000</td>
<td>$72,600</td>
<td>$79,860</td>
<td>$87,846</td>
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<tr>
<td>Interest - New Loan</td>
<td>$186,420</td>
<td>$155,880</td>
<td>$116,971</td>
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<td>$6,000</td>
<td>$6,000</td>
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<tr>
<td>Depreciation</td>
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<td>$56,675</td>
<td>$56,675</td>
<td>$56,675</td>
<td>$56,675</td>
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<tr>
<td><strong>Net Profits</strong></td>
<td>$558,227</td>
<td>$698,382</td>
<td>$984,062</td>
<td>$1,219,348</td>
<td>$1,225,753</td>
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</table>
### Appendix 4

#### Cash Flow Aquaponic Production (768 sq. ft.) (in J$)

<table>
<thead>
<tr>
<th>Month/Year</th>
<th>Month 1</th>
<th>Month 2</th>
<th>Month 3</th>
<th>Month 4</th>
<th>Month 5</th>
<th>Month 6</th>
<th>Month 7</th>
<th>Month 8</th>
<th>Month 9</th>
<th>Month 10</th>
<th>Month 11</th>
<th>Month 12</th>
<th>YEAR 1</th>
<th>YEAR 2</th>
<th>YEAR 3</th>
<th>YEAR 4</th>
<th>YEAR 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>REVENUES</strong></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td><strong>EQUITY</strong></td>
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<td>50,000</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sales - Pepper</td>
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<td>0</td>
<td>0</td>
<td>48,960</td>
<td>97,920</td>
<td>97,920</td>
<td>97,920</td>
<td>97,920</td>
<td>97,920</td>
<td>97,920</td>
<td>97,920</td>
<td>97,920</td>
<td>832,320</td>
<td>915,552</td>
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<td>0</td>
<td>0</td>
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<td>57,600</td>
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<td>57,600</td>
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<td>0</td>
<td>0</td>
<td>8,813</td>
<td>17,625</td>
<td>17,625</td>
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<td>149,813</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>54,000</td>
<td>54,000</td>
<td>54,000</td>
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<td>54,000</td>
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<td></td>
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<td>15,400</td>
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<td></td>
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<td>1,500</td>
<td>1,650</td>
<td>1,815</td>
<td>1,997</td>
<td>2,196</td>
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<tr>
<td>Purchases - Scallion</td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>17,625</td>
<td></td>
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<td>Purchases - Fish &amp; Feed</td>
<td>17,611</td>
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<td>10,720</td>
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<td>202,074</td>
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<td>40,000</td>
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<td>50,000</td>
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<td>55,200</td>
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<td>60,858</td>
<td>63,901</td>
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## INMED Aquaponics System
### Business Model & Financial Strategy

**Travelling & Transportation**

<table>
<thead>
<tr>
<th>Month/Year</th>
<th>Month 1</th>
<th>Mo 2</th>
<th>Mo 3</th>
<th>Mo 4</th>
<th>Mo 5</th>
<th>Mo 6</th>
<th>Mo 7</th>
<th>Mo 8</th>
<th>Mo 9</th>
<th>Mo 10</th>
<th>Mo 11</th>
<th>Mo 12</th>
<th>YEAR 1</th>
<th>YEAR 2</th>
<th>YEAR 3</th>
<th>YEAR 4</th>
<th>YEAR 5</th>
</tr>
</thead>
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<tr>
<td></td>
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<td>5,000</td>
<td>5,000</td>
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<td>5,000</td>
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<td>5,000</td>
<td>60,000</td>
<td>66,000</td>
<td>72,000</td>
<td>79,860</td>
<td>87,846</td>
</tr>
</tbody>
</table>

**Telephone, Stationery etc.**

|            | 5,000   | 5,000| 5,000| 5,000| 5,000| 5,000| 5,000| 5,000| 5,000| 5,000 | 5,000 | 5,000 | 60,000 | 66,000 | 72,000 | 79,860 | 87,846 |

**Interest - New Loan**


**TOTAL EXPENSES**

|            | 41,333  | 116,995| 98,746| 86,876| 86,197| 105,847| 98,573| 87,012| 100,632| 114,349 | 1,120,830 | 1,141,349 | 1,155,259 | 1,187,153 | 1,203,835 |

**Surplus/Deficit**

|            | 2,140,143 | -66,995| -48,746| -304 | 86,948 | 67,298 | 74,572 | 140,133| 126,513| 146,706 | 123,315 | 112,796 | 2,902,378 | 761,057 | 1,046,737 | 1,282,023 | 1,288,428 |

**Loan Commitment, Mortgage (Fees and Costs)**

|            | 30,000   | 30,000 | 30,000 | 30,000 | 30,000 | 30,000 | 30,000 | 30,000 | 30,000 | 30,000 | 30,000 | 30,000 | 30,000 |

**Capital Expenditures – Construction**

|            | 1,655,952 | 1,655,952 | 1,655,952 | 1,655,952 | 1,655,952 | 1,655,952 | 1,655,952 |

**Capital Expenditures – Equipment**

|            | 305,524   | 305,524 | 305,524 | 305,524 | 305,524 | 305,524 | 305,524 |

**Principal Payments**

|            | 0        | 0       | 0       | 0       | 0       | 29,827  | 30,063  | 30,301  | 30,541  | 30,783  | 31,026  | 182,541  | 392,043  | 430,953  | 473,724  | 520,739  |

**Net Cash Flow**

|            | 148,667  | -66,995| -48,746| -304 | 86,948 | 67,298 | 44,745 | 110,070| 96,212 | 116,165 | 92,532 | 81,769 | 728,361 | 369,013 | 615,785 | 808,300 | 767,689  |

**Net Accumulated Cash Flow**

|            | 148,667  | 81,672 | 32,927 | 32,623 | 119,570| 186,868| 231,613| 341,682| 437,894| 554,059| 646,592| 728,361| 728,361| 1,097,374| 1,713,159| 2,521,459| 3,289,147|
# Appendix 5

## Vegetable production guidelines for 6 common aquaponic plants

<table>
<thead>
<tr>
<th>Produce</th>
<th>PH: 5.5–6.5</th>
<th>Planting Instructions</th>
<th>Harvesting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tomato</strong></td>
<td>Plant spacing: 40–60 cm (3–5 plants/m2)</td>
<td><strong>Planting instructions:</strong> Set stakes or plant support structures before transplanting to prevent root damage. Transplant the seedlings into units 3–6 weeks after germination when the seedling is 10–15 cm and when night-time temperatures are constantly above 10 °C. Once the tomato plants are about 60 cm tall, start to determine the growing method (bush or single stem) by pruning the unnecessary upper branches. Prune all the auxiliary suckers to favour fruit growth. Remove the leaves covering each fruit branch soon before ripening to favour nutrition flow to the fruits and to accelerate maturation.</td>
<td>Harvesting: For best flavour, harvest tomatoes when they are firm and fully coloured. Fruits will continue to ripen if picked half ripe and brought indoors. Fruits can be easily maintained for 2–4 weeks at 5–7 °C under 85–90 percent relative humidity</td>
</tr>
<tr>
<td><strong>Pepper</strong></td>
<td>pH: 5.5–6.5</td>
<td>Growing instructions: Transplant seedlings with 6–8 true leaves to the unit as soon as night temperatures settle above 10 °C. Support bushy, heavy-yielding plants with stakes or vertical strings hanging from iron wires pulled horizontally above the units. For red sweet peppers, leave the green fruits on the plants until they ripen and turn red. Pick the first few flowers that appear on the plant in order to encourage further plant growth. Reduce the number of flowers in the event of excessive fruit setting to favour the growing fruits to reach adequate size.</td>
<td>Harvesting: Begin harvesting when peppers reach a marketable size. Leave peppers on the plants until they ripen fully by changing colour and improve their levels of vitamin C. Harvest continually through the season to favour blossoming, fruit setting and growth. Peppers can be easily stored fresh for 10 days at 10 °C with 90–95 percent humidity, or they can be dehydrated for long-term storage.</td>
</tr>
</tbody>
</table>

**Germination time and temperature:** 4–6 days; 20–30 °C

**Growth time:** 50–70 days till first harvest; fruiting 90–120 days up to 8–10 months

**Optimal temperatures:** 13–16 °C night, 22–26 °C day

**Light exposure:** Full sun

**Planting instructions:**
- Set stakes or plant support structures before transplanting to prevent root damage.
- Transplant the seedlings into units 3–6 weeks after germination when the seedling is 10–15 cm and when night-time temperatures are constantly above 10 °C. Once the tomato plants are about 60 cm tall, start to determine the growing method (bush or single stem) by pruning the unnecessary upper branches. Prune all the auxiliary suckers to favour fruit growth. Remove the leaves covering each fruit branch soon before ripening to favour nutrition flow to the fruits and to accelerate maturation.

**Harvesting:**
- For best flavour, harvest tomatoes when they are firm and fully coloured. Fruits will continue to ripen if picked half ripe and brought indoors. Fruits can be easily maintained for 2–4 weeks at 5–7 °C under 85–90 percent relative humidity.

**Growing instructions:**
- Transplant seedlings with 6–8 true leaves to the unit as soon as night temperatures settle above 10 °C. Support bushy, heavy-yielding plants with stakes or vertical strings hanging from iron wires pulled horizontally above the units. For red sweet peppers, leave the green fruits on the plants until they ripen and turn red. Pick the first few flowers that appear on the plant in order to encourage further plant growth. Reduce the number of flowers in the event of excessive fruit setting to favour the growing fruits to reach adequate size.

**Harvesting:**
- Begin harvesting when peppers reach a marketable size. Leave peppers on the plants until they ripen fully by changing colour and improve their levels of vitamin C. Harvest continually through the season to favour blossoming, fruit setting and growth. Peppers can be easily stored fresh for 10 days at 10 °C with 90–95 percent humidity, or they can be dehydrated for long-term storage.

**Plant height and width:** 60–180 cm; 60–80 cm

**Recommended aquaponic method:** Media beds and DWC

| **Plant spacing:** 40–60 cm (3–5 plants/m2 ) |
| **Germination time and temperature:** 4–6 days; 20–30 °C |
| **Growth time:** 50–70 days till first harvest; fruiting 90–120 days up to 8–10 months |
| **Optimal temperatures:** 13–16 °C night, 22–26 °C day |
| **Light exposure:** Full sun |
| **Plant height and width:** 60–180 cm; 60–80 cm |
| **Recommended aquaponic method:** Media beds and DWC |

<table>
<thead>
<tr>
<th><strong>Tomato</strong></th>
<th><strong>Pepper</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PH:</strong> 5.5–6.5</td>
<td><strong>PH:</strong> 5.5–6.5</td>
</tr>
<tr>
<td><strong>Plant spacing:</strong> 40–60 cm (3–5 plants/m2)</td>
<td><strong>Plant spacing:</strong> 30–60 cm (3–4 plants/m2, or more for small-sized plant varieties)</td>
</tr>
<tr>
<td><strong>Germination time and temperature:</strong> 4–6 days; 20–30 °C (seeds will not germinate below 13 °C)</td>
<td><strong>Germination time and temperature:</strong> 8–12 days; 22–30 °C (seeds will not germinate below 13 °C)</td>
</tr>
<tr>
<td><strong>Growth time:</strong> 50–70 days till first harvest; fruiting 90–120 days up to 8–10 months</td>
<td><strong>Growth time:</strong> 60–95 days</td>
</tr>
<tr>
<td><strong>Temperature:</strong> 14–16 °C night time, 22–30 °C daytime</td>
<td><strong>Temperature:</strong> 14–16 °C night time, 22–30 °C daytime</td>
</tr>
<tr>
<td><strong>Light exposure:</strong> Full sun</td>
<td><strong>Light exposure:</strong> Full sun</td>
</tr>
<tr>
<td><strong>Plant height and width:</strong> 60–180 cm; 60–80 cm</td>
<td><strong>Plant height and width:</strong> 30–90 cm; 30–80 cm</td>
</tr>
</tbody>
</table>

**Recommended aquaponic method:** Media beds
<table>
<thead>
<tr>
<th>Produce</th>
<th>Planting Instructions</th>
<th>Harvesting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lettuce (mixed salad)</strong></td>
<td><strong>Growing instructions</strong>: Seedlings can be transplanted in aquaponic units at three weeks when plants have at least 2–3 true leaves. Moreover, plant hardening, through exposing of seedlings to colder temperatures and direct sunlight, for 3–5 days before transplanting results in higher survival rates. When transplanting lettuce in warm weather, place light sunshade over the plants for 2–3 days to avoid water. If growing in media beds, plant new lettuces where they will be partially shaded by taller nearby plants.</td>
<td><strong>Harvesting</strong>: Harvesting can begin as soon as heads or leaves are large enough to eat. If selling to markets, remove the full plants and roots when harvesting as soon as they reach market weight (250–400 g). Cut the roots out and place them in a compost bin. Harvest early in the morning when leaves are crisp and full of moisture and chill quickly.</td>
</tr>
<tr>
<td><strong>Basil</strong></td>
<td><strong>Growing instructions</strong>: Transplant new seedlings into the aquaponic unit when the seedlings have 4–5 true leaves. Basil can be affected by various fungal diseases, including Fusarium wilt, grey mould, and black spot, particularly under suboptimal temperatures and high humidity conditions. Air ventilation and water temperatures higher than 21 °C, day and night, help to reduce plant stress and incidence of diseases.</td>
<td><strong>Harvesting</strong>: The harvest of leaves starts when plants reach 15 cm in height and continues for 30–50 days. Care should be used when handling leaves at harvest to avoid leaf bruising and blackening. It is advisable to remove flowering tips during plant growth to avoid bitter tastes in leaves and encourage branching. However, basil flowers are attractive to pollinators and beneficial insects, so leaving a few flowering plants can improve the overall garden and ensure a constant supply of basil seeds.</td>
</tr>
<tr>
<td><strong>Swiss chard / mangold</strong></td>
<td><strong>Growing instructions</strong>: Swiss chard seeds produce more than one seedling; therefore, thinning is required as the seedlings begin to grow. As plants become senescent during the season, older leaves can be removed to encourage new growth.</td>
<td><strong>Harvesting</strong>: Swiss chard leaves can be continuously cut whenever they reach harvestable sizes. The removal of larger leaves favours the growth of new ones. Avoid damaging the growing point in the centre of the plant at harvest.</td>
</tr>
<tr>
<td>Produce</td>
<td>Planting Instructions</td>
<td>Harvesting</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Parsley</td>
<td><strong>pH:</strong> 6–7 <strong>Plant spacing:</strong> 15–30 cm (10–15 plants/m²) <strong>Germination time and temperature:</strong> 8–10 days; 20–25 °C <strong>Growth time:</strong> 20–30 days after transplant <strong>Temperature:</strong> 15–25 °C Light exposure: full sun; partial shade at &gt; 25 °C <strong>Plant height and width:</strong> 30–60 cm; 30–40 cm <strong>Recommended aquaponic method:</strong> media beds, NFT and DWC</td>
<td><strong>Growing instructions:</strong> The main difficulty when growing parsley is the initial germination, which can take 2–5 weeks, depending on how fresh the seeds are. To accelerate germination, seeds can be soaked in warm water (20–23 °C) for 24–48 hours to soften the seed husks. Afterwards, drain the water and sow the seeds into propagations trays. Emerging seedlings will have the appearance of grass, with two narrow seed leaves opposite each other. After 5–6 weeks, transplant the seedlings into the aquaponic unit during early spring. <strong>Harvesting:</strong> Harvesting begins once the individual stalks of the plant are at least 15 cm long. Harvest the outer stems from the plant first as this will encourage growth throughout the season. If only the top leaves are cut, the stalks will remain and the plant will be less productive. Parsley dries and freezes well. If dried, plants can be crushed by hand and stored in an airtight container.</td>
</tr>
</tbody>
</table>
Appendix 6

Floorplan for Aquaponic System with 768 sq. ft. of Grow Bed Space
Appendix 7:
Elevation for Aquaponic System with 768 sq. ft. of Grow Bed Space