EFFECTIVENESS OF AQUAPONIC AND HYDROPONIC GARDENING TO TRADITIONAL GARDENING

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Abstract

Aquaponics is the integration of aquaculture and hydroponics. There is expanding interest in aquaponics as a form of aquaculture that can be used to produce food closer to urban centers. Commercial aquaponics uses methods and equipment from both the hydroponics and aquaculture industries. There have been few studies of commercial-scale aquaponics production.

Traditional farming contributes to household food security by providing direct access to food that can be harvested, prepared and fed to family members, often on a daily basis.

Even very poor, landless or near landless people practise gardening on small patches of homestead land, vacant lots, roadsides or edges of a field, or in containers. Traditional farming may be done with virtually no economic resources, using locally available planting materials, green manures, “live” fencing and indigenous methods of pest control. Our survey findings provide a better understanding of the business of aquaponics, which may enhance future commercial operations.

Keywords: Aquaponic, hydroponics, traditional gardening, soil based, soil-less, urban farming; water scarcity, land problem, fish, plants, vegetables

INTRODUCTION

The paper is based on a thorough review of the scientific literature on aquaponics, hydroponics and traditional gardening, discussions with specialist aquaponics researchers and producers; analysis of web resources; an online survey of aquaponics initiatives and traditional gardening; and visits to operating aquaponics initiatives.

By 2050 world population is projected to increase to 9 Billion and by the same time it has been estimated that as much as 50% of the world's arable land may be unusable. In order to feed this burgeoning population food production will have to increase by 110%. Clearly this is not possible without a radical rethink of production techniques and dietary needs. The western diet needs to change away from its dependency on high protein meat sources and over consumption. The West has to address our wanton wastage of food where we are currently throwing away 30% of the food we buy. Governments will also have to address the thorny subject of land tenure. China and the Gulf States are already looking at purchasing land in other countries in order to feed their own populations. It may well be time for us all to look at the consequences of nationalising productive land in order to ensure an equitable distribution of food, Griffith, P. et al., 2015.

Unnatural roots of the food crisis

Feeding the world requires healthy ecosystems and equitable governance. The current model of market-driven food production is leaving people hungry. It has turned food into a commodity subject to all the market failures that create inequities and negative impacts on the environment. There is a global food crisis. A myriad of events are convening the international community to reflect on the urgent situation. Just in the past month, the UN Commission on Sustainable
Development and the UN Convention on Biological Diversity focused considerable attention on agriculture and food security.

But this crisis has been long coming. Unsustainable agricultural policies and technologies, inequitable trade rules, agricultural subsidies that distort the markets, and the systematic marginalisation of small producers lie at the heart of the problem.
In addition, there is chronic under-investment in agriculture in developing countries, and a real neglect of the basic premise that ecosystems have to be in good shape in order to provide good food.

**Costs of production**
The past 50 years have seen massive expansion of agriculture, with food production more than doubling in order to meet demand.

But it has left us with 60% of all ecosystem services degraded, accelerated species extinction, and huge loss in genetic diversity. Neglecting ecosystems concerns has provoked a fisheries crisis too. Currently, four plant species - wheat, maize, rice and potato - provide more than half of the plant-based calories in the human diet, while about a dozen animal species provide 90% of animal protein consumed globally. We have already lost three-quarters of the genetic diversity of agricultural crops.

As the agricultural frontier has expanded, those farmers previously dependant on a more diverse source of livelihood have converted to cash crops.

As traditional varieties and breeds die out, so too do the traditional knowledge and practices of local farmers. Those same practices could now be critical in adapting to climate change.

The focus on agricultural commodities rather than on food production to meet the basic needs of people has undermined diversity and self-reliance, and left farmers vulnerable to volatile markets, political instability and environmental change. Increased food production in some parts of the world has been at the expense of natural and semi-natural ecosystems that provide us greater long-term security. Amazingly, there is very little attention being paid to what fundamentally underpins all of our food systems – biodiversity and the services provided by ecosystems.

In Britain, studies have shown that hay production is higher in meadows with a greater number of species. In Australia, crop yields are higher in regions where native biodiversity has been preserved. In the seas, too, areas with a higher number of conserved species generate more fish for humans to catch and eat.

There are many other examples from land and sea to show that a healthy environment means more food and a greater capacity to survive natural disasters.

The current food crisis, meanwhile, will only be exacerbated by climate change, with southern Africa and South Asia expected to be particularly badly affected.
Market transformation
So what are the solutions to feeding a growing world population in the face of climate change? There is information about a Green Revolution for Africa, major irrigation and fertilisation programmes, genetically modified seed varieties, as well as banning the use of crops for biofuel production. Amazingly, there is very little attention being paid to what fundamentally underpins all of our food systems - biodiversity and the services provided by ecosystems, such as soil, water and resilience to disasters. There is need to attack market failures and change the economic rules of current food production systems. There is need to eliminate agricultural and fisheries subsidies that support elites in the North, and get rid of protectionist measures in OECD countries for agricultural products. There is urgent need to allow for value-added trade for the benefit of the South, and expand fair trade and labelling processes that create incentives and add benefits to producers in the South. We must change food production systems, moving from the existing model based on high inputs (such as fertilisers) accessible through markets, to systems based on locally available and more environmentally-friendly inputs. Developments such as aquaponics and hydroponics can reduce farmer’s use of resources.

There is need to create alternative trade rules and circuits that reduce the payout to middlemen and big agribusinesses. There must be greater investment, including by bilateral and multilateral development co-operation, to support food production systems that feed the poor and supply local markets. The governance model related to natural resources has to change. There is need to expand small farmers' and landless peasants' access to productive assets in countries of the South - lands, water sources and fisheries. There needs to be a shift away from the prevailing model of concentration of land in small groups of big landowners who are dropping food production for local markets and moving to big industrial production of commodities that produce no local benefits, Gonzalo Oviedo, 2015.

Differences between Aquaponics and Traditional Foods
The differences between aquaponics, hydroponics and traditional foods stem directly from the farming methods that were used during the food’s production. Many people are unaware of some of the differences between the two practices. Agriculture has a direct effect on our environment, so understanding what goes into our agriculture is important. Below is a diagram showing some of the key differences between soil-based traditional system and recirculating aquaponic system.
Figure 1. Diagram showing some of the key differences between soil-based agricultural system and recirculating aquaponic system

One of the biggest differences that is seen time and time again across all research between the two farming practices is the effect on the land. Aquaponics combines fish farming (aquaculture) with the practice of raising plants in water (hydroponics). It’s organic by definition: instead of using chemical fertilizers, plants are fertilized by the fish poo (and pesticides/herbicides can’t be introduced to kill pests because they could harm the fish). Since the plants don’t need dirt, aquaponics allows gardeners to produce more food in less space. And in addition to the vegetables they can grow, most aquaponics gardeners cultivate edible fish as well.
Aquaponics Systems the Ideal

Today, modern aquaponics is a viable resource to sustainability that combines aquaculture (growing fish and plants in a controlled environment) and hydroponics (growing plants without soil). The system relies on fish waste to provide organic food and nutrients to help the plants grown; in turn, the plants clean, filter, and recycle the water back to the fish creating a symbiotic relationship (Dunn, 2012).

Aquaponics may be regarded as the integration of two relatively well established production technologies: recirculating aquaculture systems in which fish tank effluent is treated and cleaned before being returned to the fish tank; and hydroponic (or soil-less) nutrient solution based horticulture systems. Bringing the two together allows for the plants to utilize the waste nutrients produced by the fish. In principle it is very similar to a freshwater aquarium in which both plants and fish are grown.

Fish produce ammonia (among other things) as a waste product of respiration and their general metabolic processes. While ultimately deadly to fish, this chemical is a potential boon for plants. All they require to is a little help from naturally occurring and largely omnipresent nitrifying (meaning they convert the ammonia to nitrates) bacteria, which reside in a porous, inert growing medium, inside a plant grow-bed. Nitrifying bacteria convert fish wastes into plant-available nutrients. The plants use these nutrients as their main nutrient supply. The fish benefit from this process also, as the water is filtered by the plants, giving the fish clean water to live in. With Aquaponics, both the fish and the plants not only grow well, they flourish.

Water from the fish reservoir is pumped into the grow-bed, where the bacteria process the ammonia into a form available to plants, which then take it up and flourish. The water, now ‘biologically filtered’, is returned to the fish tank, gaining oxygen along the way.

The ideal of Aquaponics systems came from combination of Aquaculture and Hydroponic systems. It came as the best solve for the negative sides for both Hydroponic and Aquaculture.
Aquaponic systems come in a wide variety of forms, ranging from a simple fish tank set below a gravel filled vegetable bed (which also serves as a simple biofilter), with water from the fish tank pumped up and through the grow bed; to highly sophisticated systems incorporating multiple fish tanks, solid waste removal systems, aerobic and anaerobic biofilters, intensive aeration systems for both plants and fish, and sophisticated water quality monitoring and backup (i.e. fail-safe) systems.

Aquaponic systems are dominated by vegetable production in terms of area and quantity of product. This is biologically determined by the quantity of plant production required to absorb the waste nutrients generated by fish. In some of the more commercial systems, the fish are simply regarded as a source of high quality organic nutrients, rather than as marketable product in their own right.

The technology of aquaponics has been with us since the 1960’s, but interest has increased rapidly in recent years due to widespread interest in local sustainable food initiatives, and awareness amongst development agencies that aquaponics may allow for the production of both vegetables and fish in water-deficient or soil-deficient zones. The technology is also of particular interest to aquaculture scientists as a possible tool for the reduction/remediation of nutrient waste from intensive aquaculture production. Scientists, educators and community or development NGOs are, furthermore, particularly attracted to a technology that represents a small managed “ecosystem” comprising a highly productive balance of fish, bacteria and plants.

All operations appeared to rely on a niche market and price premium, associated in most cases with a local farm shop, visitor attraction or café outlet. Others were able to sell into more mainstream but high value markets (e.g. in Hawaii) and generate a small “sustainability” or organic premium.
Table 2: Types of aquaponic enterprise

<table>
<thead>
<tr>
<th>Type</th>
<th>Key characteristics</th>
<th>Funding/profitability/motivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kitchen window</td>
<td>Very small scale household systems suitable for growing a few herbs and salad</td>
<td>Convenience/quality of life/interest rather than profitable</td>
</tr>
<tr>
<td>Backyard/smallholder</td>
<td>Small scale enthusiasts system similar to owning a greenhouse for home vegetable production</td>
<td>Primarily a hobby activity but yielding significant production for home consumption and sharing with neighbours.</td>
</tr>
<tr>
<td>Research/demonstration</td>
<td>Small-medium and medium large systems designed for research and demonstration purposes</td>
<td>Primarily research funding; may sell some produce to contribute towards running costs; excellent education/training tool</td>
</tr>
<tr>
<td>Community initiative</td>
<td>Varied in character but typically medium scale enterprise built using public funds and operated by local community NGOs. Often combined with waste recycling initiatives, work placements, and/or organic and local food initiatives</td>
<td>Usually public investment from local, national, regional and international social and economic development funds</td>
</tr>
<tr>
<td>Sustainable food outlet</td>
<td>More commercial and entrepreneurial</td>
<td>Funding for the aquaponic system is either cross subsidy from the food outlet, or enhanced margins related to sustainability image</td>
</tr>
<tr>
<td>Sustainable research, training, supplies and consultancy services</td>
<td>Selling “sustainability” – ideas, products, services, training, research</td>
<td>Primarily from sales of equipment and services rather than from fish/vegetables</td>
</tr>
<tr>
<td>Organic hydroponics</td>
<td>Primarily a hydroponics vegetable production system using fish a source of organic fertilizer and sustainability image booster</td>
<td>Primarily from sales of vegetables in premium gourmet, organic and local markets</td>
</tr>
<tr>
<td>Organic re-circulating aquaculture</td>
<td>Primarily intensive fish production in recirculation system with fertilization of vegetables as secondary waste treatment</td>
<td>Intensive aquaculture has a mixed reputation with regard to input use and waste generation, and this is an attempt to minimise waste from intensive production systems while at the same time benefitting from organic or sustainability credentials/image</td>
</tr>
<tr>
<td>Smallholder integrated fish agriculture systems</td>
<td>Fish grown in ponds; vegetables grown in ponds; pond sludge used to fertilize plants</td>
<td>Primarily subsistence systems, still common in S and SE Asia, but generally in decline and being replaced by more specialist intensive systems</td>
</tr>
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</table>

Global experience

Aquaponics initiatives can be found throughout the world, from deserts to northern cities to tropical islands. The industry is dominated by technology and training suppliers, consultants, “backyard” systems and community/organic/local food initiatives. There are very few well established commercial systems (i.e. competing profitably in the open market) and most of those that are have been cross-subsidized by other economic activities, at least in the start-up phase. Many initiatives in temperate zones appear to be struggling. High capital, energy and labour costs on the one hand, and lack of flexibility in meeting market demand on the other, along with constraints on pest management, have been the major problems to date.
It is notable that those that are commercial or near commercial are located primarily in Hawaii - because it has a relatively stable temperature regime; a long history of demonstration and research; significant constraints on more conventional forms of horticulture; high food import costs; and significant demand for “sustainable”, organic and other niche food products.

**Could aquaponics be used by farmers in developing countries?**

“Aquaponics has huge potential to be used by developing countries - both as commercial ventures and a way to provide food,” Leslie Ter Morshuizen, owner and founder of Aquaculture Innovations.

Aquaculture advocates also say it is sustainable and eco-friendly. “Water is a precious commodity in developing nations, and because the majority of the water used is recycled through the aquaponics system, significantly less water is consumed than in traditional farming,” explains Tony Abuta, founder of Amsha Africa Foundation.

According to Ken Konschel, project founder of Aquaponics Africa, the possibilities are limitless. “Fish grow their own food, so the system is self-supporting. It could improve people in developing countries’ lives by increasing food security, employment opportunities and economic growth.”

As nutrition is a key issue for developing nations, who rely mainly on staple crops such as wheat and rice, the fish farmed could also provide a valuable source of protein. Abuta adds: “By building Aquaponic systems in developing nations like those in Africa, there would be more food for the population, and it would be more nourishing.”

**Strengths/advantages of aquaponics**

Efficiency of water use. Aquaponic systems use 10% or less of the water used in conventional soil based horticulture systems. Water use efficiency in hydroponic systems is probably comparable to that of aquaponics, but more variable, depending on the frequency with which nutrient solution is discarded or dumped.

**Independence from soil.** These systems can be established in urban or harsh rural environments where land is very limited or of very poor quality. This advantage applies also to hydroponics and recirculating aquaculture systems.

High levels of nutrient utilization. This is the core rationale for aquaponics and a significant advantage in those countries or locations where nutrient enrichment 1 is a problem (as for example in some Pacific lagoons). The fish and plants in most aquaponic systems capture roughly 70% of the nutrients input in the form of fish feed; and the residual solid waste is relatively easy to manage and may be applied to fruit trees or conventional horticultural crops.
Although hydroponic systems also capture a high proportion of nutrients most operators dump the system water periodically to prevent the accumulation of salts and pathogens and allow for thorough cleaning and sterilization. In most cases this relatively dilute waste will not be a problem, and may be used for conventional crop irrigation; on a large scale in sensitive locations treatment may be required in an open pond or lagoon. The requirement or otherwise for this will depend on local conditions and regulations.

A further possible advantage lies in the complex organic nature of the aquaponic nutrient solution compared with the relatively simple chemical based solutions used in hydroponics. There is some evidence that this has pro-biotic properties, promoting nutrient uptake and protecting against some disease. There is also some limited evidence of improved product flavour and extended shelf life. Higher levels of anti-oxidants have been observed in aquaponically grown plants. Not surprisingly these benefits will depend on the quality of the nutrients entering the system – and it has been shown for example that higher concentrations of anti-oxidants are related to the quality of the fish food.

**Reduced labour & improved working conditions.** Labour inputs to conventional horticulture are hugely varied dependent on the degree of mechanisation and chemical usage. Aquaponic and hydroponic systems usually use raised beds and do not need weeding. Some of those involved say that there is less work, and the work involved is of a higher quality than that required in more conventional systems. The lack of well established specialist commercial aquaponics enterprises makes comparison difficult.

**Two for the price of one.** There is a widespread belief in aquaponic circles that growing fish and vegetables together must save money – you get two products for your investment, labour, and other operating costs. The indications are that this assumption is false. Keeping fish in aquaponic systems adds significantly to both capital and operating costs when compared with a hydroponic system, and some producers have explicitly stated that the fish lose money. The cost is regarded as necessary in order to generate complex dissolved organic nutrients, and produce a product which can be sold at an “organic” premium.

**Weaknesses/disadvantages**

It is unfortunate that the essential and desirable characteristic of aquaponics – closely integrated production of plants and fish to maximise nutrient utilization – also introduces significant disadvantages from both production and marketing perspectives.

**Compounding of risk.** Intensive aquaculture production may be subject to losses or reduced productivity related to water chemistry, temperature, lack of oxygen, and disease. Intensive horticulture (including hydroponics) may also be subject to losses from system failure (water supply), pests and diseases. Integration of intensive horticulture with intensive aquaculture compounds these risks since problems or failure of one component are likely to reduce performance of the other. Some risks may even be increased – biosecurity (exclusion of pathogens) is a key issue for intensive recirculating aquaculture systems and may be compromised by recirculation through a large outdoor vegetable production facility. Furthermore, the range of management responses (such as pest or disease management) for each component is constrained by the sensitivities of the other, and it may take some time to restore the whole system to optimal performance. These
production risks are further compounded by high capital and fixed operating costs. Any break in production will have substantial cost implications.

**Constraints on optimisation and economies of scale.** The drive towards efficiency in conventional food production has resulted in both specialisation and intensification. Specialist farmers or fish farmers are able to bring all their skills and effort to bear on optimisation of their production system for a particular product, and achieve economies of scale in sourcing, production and marketing. While the desirability of this may be questioned on many other levels, there is no doubt that existing economic incentives at both local and global levels continue to strongly favour this trend. Integration in aquaponics not only flies in the face of these incentives, but the intimacy of the integration prevents optimisation of each component. Optimal water chemistry and temperature are slightly different for fish and plants in most cases.

**Constraints on production and marketing.** Commercial producers adjust their rates of production as far as possible to meet market demand for different products, and according to seasonality of demand. Some hydroponic producers in Rarotonga for example reduce or stop their production when the market is seasonally flooded with conventionally grown vegetables. Maintaining (roughly) a fixed ratio of fish to plant production, and the long delays and high costs related to shutting down and restarting an aquaponic system, significantly constrain flexibility to adjust production in line with demand.

**Energy costs.** Most aquaponic systems will require more energy than conventional horticulture or hydroponics systems, primarily related to the oxygen demand of both fish and bacteria, and the corresponding need for intensive aeration as well as pumping.

**Management costs and demands.** Routine maintenance, water quality monitoring and management can be demanding, requiring both skills and dedication. Furthermore, in order to cover the relatively high capital and operating costs, production from these systems must be maximised, requiring high levels of organisation and management in production scheduling, and highly effective sales and marketing.

**Limited range of suitable fish species.** Tilapia is by far the preferred fish for aquaponic systems, especially in the tropics and sub-tropics. This is because it is extremely easy to breed, adapts well to high density, is tolerant of low oxygen concentrations (and therefore less susceptible to temporary power failure of system blockage) and tolerant of high nutrient concentrations. Flesh quality is also generally good. However, it is non-native to the Pacific region, and introductions of such a robust species in some countries (such as Australia) has had negative impact on native fauna. While such impacts are unlikely to be as severe in biodiversity limited small islands, there may be issues in some countries. Dependence on highly tolerant species also restricts market opportunity.

Nutrient utilization efficiency is not specifically recognised in sustainable food certifications such as organic, and the apparent advantage of aquaponics and hydroponics over conventional agriculture in this regard cannot be readily translated into a price premium on the open market. Indeed organic certification of soilless cultivation is still not possible for many organic labels.
Although aquaponics uses nutrients efficiently, any assessment of sustainability must also take into account the source of nutrients. Unfortunately the most successful aquaponic systems (in terms of system performance and product quality) use high quality fish feed as the primary nutrient source, with up to 40% protein and often a high proportion of fish meal. They also focus on plant rather than fish production. The logic of using fish feed as a source of nutrients for vegetable production in the name of sustainability and food security is questionable. A more rational approach from the perspective of global or regional sustainability would be to use nutrient wastes from other intensive food production systems (including agriculture and aquaculture) as inputs to hydroponic systems. Conclusions The overall balance

Recirculating aquaculture systems, hydroponic systems and (integrated) aquaponic systems all share the advantage of reduced water use per unit production, and are therefore of interest for development in water deficient islands in the Pacific.

From a purely commercial, or economic development perspective, in almost all circumstances, the disadvantages of aquaponics would outweigh the advantages. Integrating recirculating aquaculture with hydroponic plant production increases complexity, compounds risk, compromises system optimisation for either product, restricts management responses – especially in relation to pest, disease and water quality - and constrains marketing. Energy use is relatively high because of the need for both aeration and pumping in most systems. System failure may result in a two month restart and rebalancing period during which time high fixed costs must be covered. Given that most aquaponic systems are dominated by plant production this is a heavy price to pay, and would require a substantial “organic” premium to compensate.

From a sustainability perspective there are substantial questions related to use of high quality fish feeds as the nutrient source for systems focused primarily on plant production, and energy use is also relatively high. Solar or wind driven systems would usually be required to make them both economically viable and environmentally sustainable. From a food security perspective, especially in water constrained islands, it would appear that hydroponics and aquaculture undertaken as independent activities according to local market need would normally be more attractive, although it is possible that if both became successful, the advantages of integration might then be explored.

**Plants: hydroponics**

A Deep Water Culture hydroponic system, where plant grow directly into the effluent rich water without a soil medium. Plant can be spaced closer together because the roots do not need to expand outwards to support the weight of the plant.

Plants are grown as in hydroponics systems, with their roots immersed in the nutrient-rich effluent water. This enables them to filter out the ammonia that is toxic to the aquatic animals, or its metabolites. After the water has passed through the hydroponic subsystem, it is cleaned and oxygenated, and can return to the aquaculture vessels. This cycle is continuous. Common aquaponic applications of hydroponic systems include:
• **Recirculating aquaponics**: solid media such as gravel or clay beads, held in a container that is flooded with water from the aquaculture. This type of aquaponics is also known as *closed-loop aquaponics*.

• **Reciprocating aquaponics**: solid media in a container that is alternately flooded and drained utilizing different types of siphon drains. This type of aquaponics is also known as *flood-and-drain aquaponics* or *ebb-and-flow aquaponics*.

• **Deep-water raft aquaponics**: styrofoam rafts floating in a relatively deep aquaculture basin in troughs.

• Other systems use towers that are trickle-fed from the top, nutrient film technique channels, horizontal PVC pipes with holes for the pots, plastic barrels cut in half with gravel or rafts in them. Each approach has its own benefits, (Lennard, et al, 2006).

Most green leaf vegetables grow well in the hydroponic subsystem, although most profitable are varieties of Chinese cabbage, lettuce, basil, roses, tomatoes, okra, cantaloupe and bell peppers. Other species of vegetables that grow well in an aquaponic system include beans, peas, kohlrabi, watercress, taro, radishes, strawberries, melons, onions, turnips, parsnips, sweet potato and herbs. Since plants at different growth stages require different amounts of minerals and nutrients, plant harvesting is staggered with seedlings growing at the same time as mature plants. This ensures stable nutrient content in the water because of continuous symbiotic cleansing of toxins from the water.

**Animals: aquaculture**

Filter water from the hydroponics system drains into a catfish tank for re-circulation. Freshwater fish are the most common aquatic animals raised using aquaponics, although freshwater crayfish and prawns are also sometimes used (Rakocy...et al, 2013). In practice, tilapia are the most popular fish for home and commercial projects that are intended to raise edible fish, although barramundi, silver perch, eel-tailed catfish or tandanus catfish, jade perch and murray, cod are also used (Rakocy...et al, 2013). For temperate climates when there isn’t ability or desire to maintain water temperature, bluegill and catfish species are suitable fish species for home systems. Koi and goldfish may also be used, if the fish in the system need not be edible.

**Bacteria**

Nitrification, the aerobic conversion of ammonia into nitrates, is one of the most important functions in an aquaponics system as it reduces the toxicity of the water for fish, and allows the resulting nitrate compounds to be removed by the plants for nourishment (Diver,..et al, 2006). Ammonia is steadily released into the water through the excreta and gills of fish as a product of their metabolism, but must be filtered out of the water since higher concentrations of ammonia (commonly between 0.5 and 1 ppm) can kill fish. Although plants can absorb ammonia from the water to some degree, nitrates are assimilated more easily (Diver,..et al, 2006) thereby efficiently reducing the toxicity of the water for fish (Rakocy., 2013). Ammonia can be converted into other nitrogenous compounds through healthy populations of:
• *Nitrosomonas*: bacteria that convert ammonia into nitrites, and

• *Nitrobacter*: bacteria that convert nitrites into nitrates.

In an aquaponics system, the bacteria responsible for this process form a biofilm on all solid surfaces throughout the system that are in constant contact with the water. The submerged roots of the vegetables combined have a large surface area where many bacteria can accumulate. Together with the concentrations of ammonia and nitrites in the water, the surface area determines the speed with which nitrification takes place. Care for these bacterial colonies is important as to regulate the full assimilation of ammonia and nitrite. This is why most aquaponics systems include a biofiltering unit, which helps facilitate growth of these microorganisms. Typically, after a system has stabilized ammonia levels range from 0.25 to 2.0 ppm; nitrite levels range from 0.25 to 1 ppm, and nitrate levels range from 2 to 150 ppm. During system startup, spikes may occur in the levels of ammonia (up to 6.0 ppm) and nitrite (up to 15 ppm), with nitrate levels peaking later in the startup phase. Since the nitrification process acidifies the water, non-sodium bases such as potassium hydroxide or calcium hydroxide can be added for neutralizing the water's pH (Rakocy... et al, 2013) if insufficient quantities are naturally present in the water to provide a buffer against acidification. In addition, selected minerals or nutrients such as iron can be added in addition to the fish waste that serves as the main source of nutrients to plants (Rakocy.... et al, 2013).

A good way to deal with solids buildup in aquaponics is the use of worms, which liquefy the solid organic matter so that it can be utilized by the plants and/or other animals in the system.

**Operation**

The five main inputs to the system are water, oxygen, light, feed given to the aquatic animals, and electricity to pump, filter, and oxygenate the water. Spawn or fry may be added to replace grown fish that are taken out from the system to retain a stable system. In terms of outputs, an aquaponics system may continually yield plants such as vegetables grown in hydroponics, and edible aquatic species raised in an aquaculture. Typical build ratios are .5 to 1 square foot of grow space for every 1 U.S. gal (3.8 L) of aquaculture water in the system. 1 U.S. gal (3.8 L) of water can support between .5 lb (0.23 kg) and 1 lb (0.45 kg) of fish stock depending on aeration and filtration (Diver.. et al, 2006).

Ten primary guiding principles for creating successful aquaponics systems were issued by Dr. James Rakocy, the director of the aquaponics research team at the University of the Virgin Islands, based on extensive research done as part of the *Agricultural Experiment Station* aquaculture program (Rakocy.... et al, 2013).

• Be careful with aggregates
• Oversize pipes
• Use biological pest control
• Ensure adequate biofiltration
• Control pH
• Use a feeding rate ratio for design calculations
• Keep feed input relatively constant
• Supplement with calcium, potassium and iron
• Ensure good aeration
• Remove solids

Feed source
As in all aquaculture based systems, stock feed usually consists of fish meal derived from lower-value species. Ongoing depletion of wild fish stocks makes this practice unsustainable. Organic fish feeds may prove to be a viable alternative that relieves this concern. Other alternatives include growing duckweed with an aquaponics system that feeds the same fish grown on the system (Rakocy...et al, 2013). excess worms grown from vermiculture composting, using prepared kitchen scraps (Rakocy...et al, 2013).as well as growing black soldier fly larvae to feed to the fish using composting grub growers,( Rakocy...et al, 2013).

Water usage
Aquaponic systems do not typically discharge or exchange water under normal operation, but instead recirculate and reuse water very effectively. The system relies on the relationship between the animals and the plants to maintain a stable aquatic environment that experience a minimum of fluctuation in ambient nutrient and oxygen levels. Water is added only to replace water loss from absorption and transpiration by plants, evaporation into the air from surface water, overflow from the system from rainfall, and removal of biomass such as settled solid wastes from the system. As a result, aquaponics uses approximately 2% of the water that a conventionally irrigated farm requires for the same vegetable production. This allows for aquaponic production of both crops and fish in areas where water or fertile land is scarce. Aquaponic systems can also be used to replicate controlled wetland conditions. Constructed wetlands can be useful for biofiltration and treatment of typical household sewage (Rakocy..et al, 2013).The nutrient-filled overflow water can be accumulated in catchment tanks, and reused to accelerate growth of crops planted in soil, or it may be pumped back into the aquaponic system to top up the water level.

Energy usage
Aquaponic installations rely in varying degrees on man-made energy, technological solutions, and environmental control to achieve recirculation and water/ambient temperatures. However, if a system is designed with energy conservation in mind, using alternative energy and a reduced number of pumps by letting the water flow downwards as much as possible, it can be highly energy efficient. While careful design can minimize the risk, aquaponics systems can have multiple 'single points of failure' where problems such as an electrical failure or a pipe blockage can lead to a complete loss of fish stock.
Traditional Farming

- Conventional farming makes use of chemicals, synthetics, and other materials to manage weeds and pests
- Conventional farming uses unnatural farming methods
- Conventional farming use of pesticides has garnered attention towards acceptable levels of toxicity, and whether there should actually be an acceptable level
- Pesticides used in conventional farming can be damaging to your health.

There are many other differences between aquaponics and traditional farming, but these seem to be the most spoken of in regards to consumer health. There have been arguments around whether or not traditional farming methods are safe for one’s health. This is because of the pesticides and GMO’s used in the conventional farming practices. Many people are concerned that those growing practices promote unsafe chemical use, especially because the level of toxicity is said to be under a “safe” level, but what is really safe?

Aquaponics Vs. Traditional Farming

Why is aquaponics better than traditional farming?

i. Aquaponics is capable of growing more produce compared to produce grown conventionally in the ground. Vegetables usually grow significantly faster, and at three to four times the density.

ii. Aquaponics eliminates one of the biggest costs in an aquaculture operation that is filtering the water of fish waste accumulations. However when combined with hydroponics, the plants are the sole source of filtration. Therefore eliminating an enormous cost.

iii. Aquaponics not only grows veggies and fruits, it also produces great tasting fish! Any fresh water fish can be used in aquaponics. The fish are raised without hormones or antibiotics and in the comfort of your own home.

iv. Aquaponics is the perfect solution to many world problems and would be ideal for 3rd world countries. It is also a great solution for drought situations or for those who live in a desert climate. An aquaponics system can produce vegetables and fresh fish with little water and solar power.

v. Aquaponics is a sustainable food production system that combines aquaculture, (raising fish, prawns, crayfish, etc in tanks), with hydroponics (growing plants in water) in a symbiotic environment so that both grow better.

vi. Aquaponics systems are capable of producing an abundance of food in very small and urban spaces. The food produced is completely organic.
vii. Aquaponics is a great sustainable option for food production for the current age and future. An aquaponics system offers the opportunity to produce healthy and local food in an economically and environmentally sustainable fashion.

viii. In an aquaponics system you have the option to use beautiful tilapia or koi fish to suit your vegetarian or vegan lifestyle. Having an aquaponics garden is very therapeutic, relaxing and fun for children. It is also incredibly rewarding to eat food that you have personally grown yourself.

ix. Aquaponics uses only a fraction of the water used in conventional farming and aquaculture, which is why it's the farming of the future.

x. Aquaponics is for everybody!!

**Petroleum Use: Aquaponics vs. Traditional Agriculture**

Because there is no soil to till, there is no longer a need to use tractors and gas-powered farm equipment. Commercial aquaponics operations typically employ either a raft method, where the plants float in water until they are harvested, or media. Neither requires the kind of labor that soil-based farming does.

Since there are no weeds in aquaponics, there is no need to mechanically remove weeds or spray herbicides. Since the plant nutrients and water are both integral to an aquaponics system, there is no need for petroleum-based fertilizers or truck-mounted irrigators. Since aquaponically grown plants are either growing in waist-high grow beds or in rafts floating in water, they are much easier to harvest than soil-grown plants.

**Location, Location, Any Location!**

Aquaponic systems can be set up anywhere you have, or can artificially establish, an appropriate climate for the plants. Poor soil? No problem. Aquaponics is particularly well adapted to providing food to local communities that might not otherwise have fertile land available for growing.

Since over half of humanity now lives in our cities, it is important that food-growing facilities be established where the people are, rather than trucking food in from distant locations. Currently, most of our produce is shipped hundreds, if not thousands of miles. Imagine how much fuel could be saved if we actually grew our food in our city centers.

**Water Use: Aquaponics vs. Traditional Agriculture**

Modern agricultural methods waste an incredible amount of water. Water is either sprayed or flooded through fields where a huge amount either evaporates into the air on a hot day, or seeps past the plant roots and into the water table, pulling chemical fertilizers, herbicides and pesticides down with it.
Aquaponics, on the other hand, is a closed, recirculating system. The only water that leaves the system is the small amounts taken up by the plants (some of which transpires through the leaves) or that evaporates from the top of the tank. That's it. Aquaponics uses less than a tenth the amount of water a comparable soil-based garden uses.

Aquaponics is even more water thrifty than it's horticultural cousin, hydroponics. Since aquaponics is an organic ecosystem in which the nutrients are balanced naturally, there is never any toxic build-up of nutrients. In fact, because the water in an aquaponics system is so full of healthy biology, it is recommended that if possible, you never discharge the water from your fish tank. The only reason why you ever would is if something caused extreme amounts of ammonia to overwhelm your biofilter's ability to convert it and you therefore needed to do a partial water change to dilute the ammonia. An example of this would be a dead, decomposing fish that you were unaware of. Even if such a rare event were to occur, the discharge from your aquaponics system is completely organic and will only benefit any soil lucky enough to be watered by it.

Climate Change: Aquaponics vs. Traditional Agriculture

An aquaponics system is a food-growing system that could have zero impact on our environment, especially if the pumps and heaters are powered through renewable energy sources. Except for purely wild food-growing systems, such as the ocean, and most permaculture techniques, no other food system that I know of can make that claim.

On the other hand, traditional agriculture is the single largest contributor of CO₂ emissions, while simultaneously contributing to the ongoing shrinking of the earth's CO₂ filter through the need for more and more land for growing crops and raising cattle. The main pollutant sources are CO₂ emissions from all the petroleum being used in farm production and food transportation, methane from cattle production, and nitrous oxide from over-fertilizing. Aquaponics requires none of these inputs. Petroleum needs in aquaponics range from much less to zero. Fish don't produce methane as cattle do, and there is no chance of over-fertilizing an aquaponics system.

Aquaponics in the City’s old Factory and Warehouses:

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from much less to zero. Fish don't produce methane as cattle do, and there is no chance of over-fertilizing an aquaponics system.

Perhaps most importantly, aquaponic systems can be started anywhere. So now instead of clearing jungles and forests we can instead focus on our urban centers and begin to think of old factory and warehouse buildings as the farms of our future. While perhaps not suited to growing vast fields of grain, aquaponics can now grow any vegetable and many types of fruit crops, and do it in a way that is even more productive on a square foot basis, even in an urban setting. Aquaponics can produce 50,000 pounds of tilapia and 100,000 pounds of vegetables per year in a single acre of space. By contrast, one grass-fed cow requires eight acres of grassland. Another way of looking at it is that over the course of a year, aquaponics will generate about 35,000 pounds of edible flesh per acre, while the grass-fed beef will generate about 75 pounds in the same space.

**Being Self-Sufficient in the City**

Is the notion of producing at least some portion of our food in our urban centers a science fiction fantasy? Not at all. In fact, in her essay "Reconsidering Cities," author Sharon Astyk pointed out that it isn't as unusual as you might think for city dwellers to grow a meaningful portion of the food they eat. She explains that Hong Kong and Singapore already both produce more than 20 percent of their meat and vegetables within the city limits.

In 2002, with more than six million people, Hong Kong was producing 33 percent of the produce, 14 percent of the pigs, 36 percent of the chickens and 20 percent of the farmed fish eaten in the city limits.

**Benefits of Hydroponic Gardening vs (Growing Vegetables in Soil)**

A branch of agriculture, hydroponics is a soil-free method used to grow many types of plants. Depending on the type of hydroponic system used, the plants' roots are suspended in, flooded with or misted with nutrient-rich water that provides them with all the nutrients they need for healthy growth. While the history of hydroponic gardening is believed to date back to at least 600 B.C., in our society this soil-less method of growing plants has really taken off only recently.

Below, we take a look at some of the benefits of hydroponic gardening (vs soil-based gardening). Many of these benefits also apply to aquaponics, a type of food production method that combines aquaculture, i.e. raising aquatic animals such as fish, and hydroponics. (If you're interested in learning more about how you can use aquaponics to produce food in your own home, see aquaponic fish tanks & herb growing kits).
Benefits of Hydroponics vs. (Soil-Based Methods)

It's a great way grow plants in places where space is at a premium.

Hydroponics offers both commercial vegetable growers and home gardeners to grow food in places where traditional agriculture is not possible or cost-effective. As the water used in hydroponic gardening is recycled and reused, and no water goes to waste, areas with arid climates or limited water supplies can greatly benefit from this method, and people in those areas will be able to enjoy fresh, locally grown produce. Hydroponic systems are also useful in urban areas where little space is available as hydroponically-grown plants don't need space for developing large root systems to get access to the nutrients they need – all the nutrients they need are readily available in the growing liquid. With Aero Garden' hydroponic indoor cherry tomato growing kit equipped with LED lights, for example, you will be able to grow healthy and nutritious cherry tomatoes even in a small city apartment.

Chemical-free, eco-friendly farming at its best

Organic farming is booming as people are worried about harmful pesticides and other unnatural chemicals getting into their bodies and causing health problems. One of the best things about hydroponic farming is that it requires little or no pesticides as weeds, soil-loving bugs and plant diseases that spread in soil are eliminated. The uptake of nutrients by plants grown in hydroponic systems is also higher compared with plants grown in soil, so the use of fertilizers can be reduced dramatically. All of this means cost-savings to hydroponic farmers, but also cleaner food and a cleaner environment.

Shorter harvest times and higher yields

Not only does the efficient uptake of nutrients by hydroponically-grown plants reduce the need for fertilizers, it also shortens the harvest time, meaning you will get more crops our of your hydroponic garden per year than you would from a traditional soil-based vegetable garden. As explained above, plants that are grown hydroponically have direct access to water and nutrients, and therefore, they don't have to "waste" energy developing extensive root systems to get the nutrients they need. Instead, the plants can focus their energy on developing the foliage and the fruit.

It's time-tested – and NASA-tested

If you're skeptical about switching from soil-based gardening to hydroponics, know this: Even though the term hydroponics was only coined in the 1930s, the use of nutrient-rich water as a growing medium for plants has a very long history. It is believed that the ancient Babylonians used hydroponics for their famous hanging gardens which were built around 600 B.C., and during the 10th and 11th centuries, the Aztecs developed a system of floating gardens based on the principle of hydroponics. In the modern world, hydroponic farming is successfully used around the world, from Japan to Holland, from Australia to Canada. Aquaponics, which
combines aquaculture (raising fish) with hydroponics, has also been tested extensively by NASA scientists who are looking for ways to produce nutritious food in the space.

**Plants in aquaponics**

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

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

### 6.1 Major differences between soil and soil-less crop production

There are many similarities between in-ground soil-based agriculture and soilless production, while the basic plant biology is always the same (Table 1). However it is worth investigating major differences between soil and soil-less production in order to bridge the gap between traditional in-ground practices and newer soil-less techniques. Generally, the differences are between the use of fertilizer and consumption of water, the ability to use non-arable land, and overall productivity. In addition, soil-less agriculture is typically less labour-intensive. Finally, soil-less techniques support monocultures better than does in-ground agriculture intensive in-ground cultivation. However, farmers cannot fully control the delivery of these nutrients to plants because of the complex processes occurring in the soil, including biotic and abiotic interactions. The sum of these interactions determines the availability of the nutrients to the plant roots. Conversely, in soil-less culture, the nutrients are dissolved in a solution that is delivered directly to the plants, and can be tailored specifically to plants’ needs. Plants in soil-less culture grow in contained inert media. These media do not interfere with the delivery of nutrients, which can occur in soil. In addition, the media physically support the plants and keep the roots wet and aerated. Moreover, with in-ground agriculture, some of the fertilizer may be lost to weeds and runoff, which can decrease efficiency while causing environmental concerns. Fertilizer is expensive and can make up a large part of the budget for in-ground farming.

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

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

6.1.3 Utilization of non-arable land

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

6.1.4 Productivity and yield

The most intensive hydroponic culture can achieve 20–25 percent higher yields than the most intensive soil-based culture, although rounded down data by hydroponic experts claim productivity 2–5 times higher. This is when hydroponic culture uses exhaustive greenhouse management, including expensive inputs to sterilize and fertilize the plants. Even without the expensive inputs, the aquaponic techniques described in this publication can equal hydroponic yields and be more productive than soil. The main reason is the fact that soil-less culture allows the farmer to monitor, maintain

6.1.5 Reduced workload

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

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

6.1.7 Increased complication and high initial investment

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

**TABLE 1: Summary table comparing soil-based and soil-less plant production**

<table>
<thead>
<tr>
<th>Category</th>
<th>Soil-based</th>
<th>Soil-less</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>Yield Variable, depending on soil characteristics and management.</td>
<td>Very high with dense crop production</td>
</tr>
<tr>
<td>Production quality</td>
<td>Dependent on soil characteristics and management. Products can be of lower quality due to inadequate fertilization/treatments.</td>
<td>Full control over delivery of appropriate nutrients at different plant growth stages. Removal of environmental, biotic and abiotic factors that impair plant growth in soil (soil structure, soil chemistry, pathogens, pests).</td>
</tr>
<tr>
<td>Sanitation</td>
<td>Risk of contamination due to use of low quality water and/or use of contaminated organic matter as fertilizer.</td>
<td>Minimal risk of contamination for human health.</td>
</tr>
<tr>
<td>Nutrition</td>
<td>Nutrient delivery High variability depending on the soil characteristics and structure. Difficult to control the levels of nutrients at the root zone.</td>
<td>Real time control of nutrients and pH to plants at the root zone. Homogeneous and accurate supply of nutrients according to plants' growth stages. Needs monitoring and expertise.</td>
</tr>
<tr>
<td>Nutrient use efficiency</td>
<td>Fertilizers widely distributed with minimum control of nutrients according to growth stage. Potentially high nutrient loss due to leaching and runoff.</td>
<td>Minimal amount used. Uniform distribution and real time adjustable flow of nutrients. No leaching.</td>
</tr>
<tr>
<td>Water use</td>
<td>System efficiency Very sensitive to soil characteristics, possible water stress in plants, high dispersal of nutrients.</td>
<td>Maximized, all water loss can be avoided. Supply of water can be fully controlled by sensors. No labour costs for watering, but higher investment.</td>
</tr>
<tr>
<td>Salinity</td>
<td>Susceptible to salt build up, depending on soil and water characteristics. Flushing salt out uses large amounts of water.</td>
<td>Depends on soil and water characteristics. Can use saline water, but needs salt flush-out that requires higher volumes of water.</td>
</tr>
<tr>
<td>Management</td>
<td>Labour and equipment Standard, but machines are needed for soil treatment (ploughing) and harvesting which rely on fossil fuels. More manpower needed for operations.</td>
<td>Expertise and daily monitoring using relatively costly equipment are both essential. High initial set-up costs. Simpler handling operations for harvest.</td>
</tr>
</tbody>
</table>
6.1.7 Increased complication and high initial investment

Variable, depending on soil characteristics and management. Very high with dense crop production. Production quality Dependent on soil characteristics and management. Products can be of lower quality due to inadequate fertilization/treatments. Full control over delivery of appropriate nutrients at different plant growth stages. Removal of environmental, biotic and abiotic factors that impair plant growth in soil (soil structure, soil chemistry, pathogens, pests). Sanitation Risk of contamination due to use of low quality water and/or use of contaminated organic matter as fertilizer. Minimal risk of contamination for human health. Nutrition Nutrient delivery High variability depending on the soil characteristics and structure. Difficult to control the levels of nutrients at the root zone. Real time control of nutrients and pH to plants at the root zone. Homogeneous and accurate supply of nutrients according to plants’ growth stages. Needs monitoring and expertise. Nutrient use efficiency Fertilizers widely distributed with minimum control of nutrients according to growth stage. Potentially high nutrient loss due to leaching and runoff. Minimal amount used. Uniform distribution and real time.

An Alternative to Traditional Farming: Aquaponics

With the increasing demand for sustainable and environmentally friendly agricultural solutions, more individuals are turning to and investing in the Aquaponics system. The aquaponics system is a financially viable and eco-friendly option as its water consumption is far less than that used with conventional farming methods. Aquaponics is the symbiotic relationship between fish farming and hydroponics, which enables food to be grown all year round without soil.

Getting started with an aquaponics system can cost anywhere from $800 to $6,000, but the benefits seem to far outweigh the initial start-up capital. Systems can be started for small individual home use, or larger commercial ones are available as well. With one gallon of water in your fish tank, you can have a grow bed that is ½ to 1 sq feet of grow space, and one lb of fish requires roughly 10 gallons of water. The most popular fish that people decide to use for their aquaponics system is Tilapia, while some other individuals have opted to go with catfish, trout, or some other variety. The system can be setup indoors or outside, and food can be grown all year.

To get started, the system does require reliable access to electricity and water, and will continuously require careful water quality monitoring. Aquaponics is showing to be the best of both hydroponics and aquaculture, it is increasingly described as being more efficient than traditional soil based farming and gardening. Although urban homesteading can sometimes make more economic and ecological sense. With the growing trend of conscious consumers, it isn’t surprising that more individuals are opting for a convenient, and sustainable, solutions which gives them direct control over what goes into the food that their families are eating.
Traditional gardening to improve household food security

Whether they are known as home, mixed, backyard, kitchen, farmyard, compound or homestead gardens, family food production systems are found in most regions of most countries worldwide. They may be the oldest production system known and their very persistence is proof of their intrinsic economic and nutritional merit. Traditional tropical gardens typically exhibit a wide diversity of perennial and semi-perennial crops, trees and shrubs, well adapted to local microclimates and maintained with a minimum of purchased inputs. Studies on traditional mixed gardens have emphasized their ecologically sound and regenerative characteristics, by which they “recreate natural forest conditions” and minimize the need for crop management (UNICEF, 1982). The dynamic role of home gardening in family nutrition and household welfare must be assessed in the context of the wider farming system and household economy. Usually, the functions and output of the home garden complement field agriculture. Whereas field crops provide the bulk of energy needed by the household, the garden supplements the diet with vitamin-rich vegetables and fruits, energy-rich vegetable staples, animal sources of protein and herbs and condiments.

Some studies indicate that gardening is not cost-effective as a nutrition intervention as compared with fortification, supplementation and targeted subsidies (Popkin et al., 1980; Brownrigg, 1985). Another common criticism is that gardening is only feasible for households with access to land, water and technical assistance, leaving out many of the food insecure. Further, opponents claim that homestead production is often embraced as a panacea for food insecurity, when in fact it has proved unreliable as a steady source of food and income for poor households.

Advocates of gardening cite evidence that home gardening can be a sustainable strategy for improving food security and incomes when gardens are well adapted to local agronomic and resource conditions, cultural traditions and preferences (Midmore, Niñez and Venkataraman, 1991; IIRR, 1991). This type of gardening is accessible to the poorest people since it relies on low-cost, low-risk technology and may be adapted to hostile environments (e.g. dryland gardens, flooding gardens). Landless households also benefit from simple hydroponics, container gardening and community or school gardening.

Finally, proponents note that comparative cost-effectiveness studies tend to focus on narrow achievements, such as reduction in vitamin A deficiency, and fail to account for the full array of home gardening benefits. Were these benefits considered, the benefit/cost ratio of gardening projects would be likely to compare more favourably with alternative interventions. Moreover, in terms of alleviating food insecurity, advocates claim that food production controlled by households is more reliable and sustainable than nutrition interventions that rely on government goodwill and financial support (Niñez, 1984; Von Braun et al., 1993; Moskow, 1996).

Supporters of gardening do not refute the evidence on mismanagement of gardening projects. Many believe that mismanagement and lack of sustainability are largely results of failure to invest the necessary resources in understanding the existing garden system in the context of changing household objectives (Niñez, 1984;
Brownrigg, 1985; UNICEF, 1982; Midmore, Niñez and Venkataraman, 1991). Therefore, “improved” gardens are planned and developed for which the effort and costs for the household often outweigh the benefits, leading to eventual abandonment of the gardens after the project subsidies terminate. Were the improved gardens to build on the characteristics and objectives of traditional gardens in the region, many resource constraint problems could be anticipated and avoided.

Thus, Traditional farming at some level is a production system that the poor can easily enter. Gardening provides a diversity of fresh foods that improve the quantity and quality of nutrients available to the family.

Households with gardens typically obtain from them more than 50 percent of their supply of vegetables and fruits (including such secondary staples as plantains, cassava, taro and sweet potato), medicinal plants and herbs; those households having garden systems that include animal-raising also obtain their primary and often only source of animal protein (Soleri, Cleveland and Frankenberger, 1991; Marsh and Talukder, 1994; UNDP, 1996). Very small mixed vegetable gardens can provide a significant percentage of the recommended dietary allowance for protein (10 to 20 percent), iron (20 percent), calcium (20 percent), vitamin A (80 percent) and vitamin C (100 percent) (Marsh and Talukder, 1994; AVRDC, 1983-1989). Homestead production is also an important source of supplementary income for poor rural and urban households around the world. The combined value of garden production, including sale of surplus vegetable produce and animal products combined with savings in food and medical expenses, varies seasonally but constitutes a significant proportion of total income (upwards of 20 percent) for many households. The garden may become the principal source of household food and income during periods of stress, e.g. the pre-harvest lean season, harvest failure, prolonged unemployment, health or other disabilities suffered by family members or agricultural and economic disruption caused by war. For instance, in Kampala, Uganda, after the civil war, traditional urban agriculture substantially fed the city in non-cereal foods (UNDP, 1996). Also, in Baghdad, Iraq and Sarajevo, Bosnia and Herzegovina, in the 1990s, residents have relied on traditional gardening to provide for many of their nutritional needs (UNDP, 1996).

**Work towards an integrated food security strategy**

Traditional gardening is only one of the possible interventions for enhancing food security for the poor, and it should be considered in the context of a broader national food security strategy. Indeed, the complex synergies of food availability, access, consumption and nutritional status with poverty, health, mental ability, productivity and economic development demand an integrated approach to solving food insecurity in the long term. Traditional gardening has a special role in this strategy, in providing direct access to food through self-reliance rather than dependence on externally supported programmes such as food-for-work, targeted subsidies and supplementation and fortification schemes, none of which can be counted on for sustained support.
“The basic concept of Traditional gardening as a strategy to help resolve the food crisis is the opposite of a relief food grant approach. It requires participation, and that people work for themselves. But it also demands as a precondition that people have access to certain productive resources; that they not be denied access to a piece of land, or water, or advice from government extension agents, or be forbidden to trellis beans from the balcony of their housing project homes” (Brownrigg, 1985).

**Apartment Balcony Gardens**

The modern day grocery stores, as we know them, have only really been around for the last seventy years or so. Before that, people ate what they grew or bartered for. Chain supermarkets exploded around the 1920s but at that time were small counter service stores. They were operated by two or three employees and most often had no meat or produce departments. Grocery shopping required at least a stop by the supermarket and a second stop at the butcher. By the 1940s the supermarkets had evolved into something that more closely resembles what we know today, complete with a meat and produce department.

Since the development of the modern day supermarket, there has also been a significant population explosion and an ever increasing demand for protein. Additionally, the demand for money and profits by the people at the top of the food chain has forced the hand of agriculture. Now there are things in our food that we can’t pronounce and probably shouldn’t eat, to say the least. These synthetic additions to our “food” are necessary to make it last longer on the grocery store shelves and increase the profits of the right wing bureaucrats at the top of the food chain. Fish are farmed and fed hormones to make them grow faster. Cows are fed corn instead of grass, and they have come up with very creative ways to stretch the almighty dollar.

**A Safe Effective Alternative**

So, what is a safe, effective alternative to get some natural back into your food? Some natural protein, natural greenery, and all that stuff we now have to pay extra for at the store is what I’m talking about. Well there are a couple of alternatives and the good news is that you don’t have to live way out in the country to do it. You don’t even have to live next door to an empty lot in the city like on “The Magic School Bus.” One realistic, innovative, and effective solution is an apartment balcony garden.

Apartment balcony gardens are not necessary huge elaborate set ups. They are made to be effective and efficient. They can be as pretty or as rustic as you want them to be. Most successful apartment balcony gardens utilize and aquaponics design. Aquawhat? Aquaponics is a system of aquaculture (water life) where the fish you raise in a medium to large size tank, supply the nutrients for the related plants, which in turn, purify the water. I know it sounds elaborate but it really isn’t, unless you want it to be.

**Why it’s Better**

This is the perfect system for an apartment balcony garden because it gives someone the chance to raise at least a portion of their food, even without a yard or any landscaping at all. Since the system can be as elaborate or as small as you want, it usually works with most any sized balcony. Most balconies have plenty of air and sunlight which are the main two necessities from the environment to allow this system to thrive.
There are many great benefits to having an apartment balcony garden, especially if its aquaponics. One awesome benefit is that everything grown there has been done so without the use of chemicals, so it’s better for you. There are no pesticides, no carcinogens, and no preservatives. This means the food is actually healthier for you to eat. It will also taste better and it is fresher. Another great benefit is that it will save you some money. Knowing that dinner is right out on the balcony means you’ll be stopping by the store a lot less often.

If you have been looking for a healthy alternative to consider, think about aquaponics in your apartment balcony garden. It is a healthier choice for you and the environment. On top of that, it will help line your pockets which are the important ones. Do a little of your own research and I’m sure you’ll agree. An apartment balcony garden is the way to go. Living in an apartment is not a setback, it’s just an avenue.

Some possible applications and development opportunities

Notwithstanding this rather negative overall appraisal, there may be opportunities for specific kinds of aquaponics initiatives in some locations, so long as the key features and risks associated with these systems as described above are fully understood at the outset.

Small-medium scale vertically integrated production/restaurant/retail/resort. In Europe and the US the most successful aquaponics ventures are those where the aquaponic venture is combined with other “visitor attractions” and/or an organic/ local produce shop and/or café or restaurant. The Pacific version of this model might be an aquaponics café/shop in or close to significant urban and tourism centres and/or aquaponics directly linked to a resort, especially on water deficient islands where fresh vegetables are difficult to source. In this case the resort or café fully understands the production limitations and risks, but exploits the intuitive appeal of aquaponic systems. Staff are also likely to be permanently on hand to deal with routine care and maintenance of such systems at limited marginal cost. Again this might be done with either hydroponics or aquaponics but the tourist appeal of the latter is likely to be greater.

Education and social development in small institutions. In so far as an aquaponic system is a microcosm of a freshwater (potentially marine) ecosystem, and illustrates many of the essential processes of life and “ecosystem services” it serves as an excellent educational and skills development tool. The complexity of management and the requirements for dedicated husbandry and significant planning and organisational skills – while being a disadvantage from a commercial perspective – may be considered an advantage when seeking to strengthen communities, team work, and responsibility. As such, the development of aquaponic systems in schools, communities, prisons, military camps etc. may meet a range of other needs while at the same time generating some healthy locally produced food. Again the rationale and opportunity for this will be greater in water and soil deficient islands. There is however a significant risk that such systems will nonetheless break down once the initial flush of enthusiasm is over, and without a strong commercial incentive to maintain efficient production. The absence of a determined “champion”, limited access to high quality cheap fish food, and high costs of electricity are also likely to be a significant constraints on longer term success.
Household scale production may have some potential in water/soil deficient islands, or where people are sufficiently wealthy that investment in backyard gardening becomes a worthwhile hobby activity in its own right. Relatively simple “2 bucket” backyard designs may be fairly robust and resilient, so long as feed inputs are kept below some basic operating thresholds, and so long as Tilapia (or possibly catfish) are available. The main constraint here will be energy cost and energy/equipment reliability. Operating costs may be reduced through investment in solar panels/wind turbines and batteries, and reliability can be addressed through investment in monitoring systems and backup. In most cases however small scale hydroponic systems are likely to serve this need better at least in the first instance. These may be upgraded to aquaponic systems once skills have been developed, and if there is demand for fish and a ready supply of high quality fish feed and seed.

CONCLUSIONS
Aquaponics is a seductive concept which is especially appealing to those seeking to promote more sustainable food production systems. It involves the production of both fish and vegetables, using a single nutrient source – fish feed – and ensures that most of the wastes that would normally be released from intensive fish culture are instead used to grow vegetables. It is important to recognise however that aquaponic systems are primarily vegetable production systems, simply because of the biological nature of the relationship between fish nutrient production and plant nutrient uptake. Intensively grown fish produce a lot of nutrients, the consumption of which requires a large amount of plant production. This is particularly the case if part of the enterprise objective is to minimise solid waste disposal to the environment. In several of the more commercial systems operating at the present time, the fish are regarded as “organic nutrient generators”, rather than as an important product in their own right. The primary advantage of aquaponics, shared with some forms of hydroponics, is water use efficiency. Other oft-cited advantages include nutrient utilization efficiency, product quality and food security. These latter are undermined to some degree by the use of high quality high protein (usually fishmeal based) fish feed as nutrient source in the more efficient and productive systems, and/or the need to add nutritional supplements.

A further possible advantage lies in the complex organic nature of the aquaponic nutrient solution compared with the relatively simple chemical based solutions used in hydroponics. There is some evidence to suggest that this has pro-biotic properties, promoting nutrient uptake, protecting against some disease, improving product flavour and extending shelf life. Against these advantages must be set significant disadvantages, especially from a business or enterprise perspective. Integrating recirculating aquaculture with hydroponic plant production increases complexity, compounds risk, compromises system optimisation for either product, restricts management responses – especially in relation to pest, disease and water quality - and constrains marketing. Energy use is relatively high because of the need for both aeration and pumping in most systems. Capital and fixed operating costs are also high, increasing financial exposure should production fail to reach design targets. System failure may result in a two month restart and rebalancing period. Given that most aquaponic systems are dominated by plant production this is a heavy price to pay.
Aid agencies should be extremely cautious about supporting aquaponics initiatives, and should undertake thorough local feasibility studies before investing in any demonstration systems or support programmes. Such assessments should consider carefully whether aquaponics in a particular location will have any real advantages over hydroponics and/or stand-alone aquaculture production systems (or indeed fisheries) as a means of generating high quality food in water and soil deficient islands; and whether the skills, knowledge and dedication are available to sustain viable aquaponics. In any case, given the complexity of the systems it is arguable that aquaculture and/or hydroponic systems should be introduced first, and if successful may be combined with the other component at a later date, if local physical and economic conditions favour such integration.

The way forward

Aid agencies and NGOs should be extremely cautious about supporting aquaponics initiatives. The focus of development activity should not be on the promotion of aquaponics per se; rather on raising awareness of the range of options available to enable vegetable (and in some cases fish) production in water and soil deficient islands, and facilitation of local initiatives aimed at overcoming these constraints.

Where aquaponics appears to be an attractive option, thorough local feasibility studies should be undertaken before investing in any demonstration systems or support programmes. Such assessments should consider carefully whether aquaponics in a particular location will have any real advantages over hydroponics and/or stand-alone aquaculture production systems (or indeed fisheries) as a means of generating high quality food in water and soil deficient islands; and whether the skills, knowledge and dedication are available to sustain viable aquaponics. In any case, given the complexity of the systems it is arguable that aquaculture and/or hydroponic systems should be introduced first, and if successful may be combined with the other component at a later date, if local physical and economic conditions favour such integration.

To date, aquaponics has been primarily pursued by aquaculturists through aquaculture/fisheries agents, despite the fact that it is primarily a horticultural activity. There needs to be a rebalancing of effort and support, primarily through agricultural training and extension, but also through joint initiatives of fisheries and agriculture services where appropriate.

To date integration of recirculating aquaculture and hydroponics has been promoted as a “good thing”, almost as an article of faith. It is essential that in future the disadvantages of integration – at least in the current economic and marketing climate – are also fully understood.
References


Cook Islands Aquaponics Pilot Project: Simple small-scale aquaponic System


Gonzalo Oviedo, 2015. The Green Room is a series of opinion articles on environmental topics running weekly on the BBC News website.


Leslie Ter Morshuizen, Owner and founder of Aquaculture Innovations.


Tony Abuta, Founder of Amsha Africa Foundation.

