Publication 15

Secure Fisheries
Secure Futures

SMALL SCALE AQUAPONIC
Food Production

INDIAN OCEAN COMMISSION

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Introducing this manual

Terms of Reference:

This manual primarily focuses on small-scale aquaponic units for the three most popular methods of aquaponics, namely the Media Bed units, Nutrient Film Technique (NFT) units and Deep Water Culture (DWC) units, although some key considerations for commercial operations are highlighted in Annex 5: Guidelines for selecting where to establish and operate small-scale & commercial aquaponic units.

Manual Summary

In total, there are nine chapters to this manual and seven annexes. The first chapter introduces the **concept of aquaponics** and a brief history of its development and place within the larger 'soilless culture' category of modern agriculture. The second chapter discusses **the main theoretical concepts of aquaponics** which include: the nitrogen cycle, the nitrification process and 'balancing' an aquaponics unit over a growing season. Chapter 3 will cover everything that needs to be known about **water quality** for aquaponics. In chapter 4, all **unit design** theory and methods will be covered for the 3 main methods of aquaponic systems (Media Beds, Nutrient Film Technique (NFT) and Deep Water Culture (DWC) units.

Chapters 5, 6 and 7 will go into depth on the 3 living organisms that make up the aquaponics eco-system which are **bacteria**, **plants** and **fish** respectively. Chapter 8 will then attempt to bring the key learning's from previous chapters and structure them into **management strategies and troubleshooting practices**. The 9th final chapter of the manual will present other topics related to small scale aquaponics with a specific focus on methods to secure aquaponics inputs (i.e. fish feed, organic fertilizer) domestically and organically so the unit can be as **sustainable** as possible.

The 7 annexes discuss some key topics for small scale not addressed in the chapters listed above. The first lists a vegetable **'companion planting' guide** for growers. The second describes the **12 most common vegetables and herbs grown in aquaponics** with specific details on ideal conditions for each crop. The third annex shows how to calculate the amount of bio-filtration media needed for a certain amount of fish feed. The fourth is a short guide to produc **homemade fish food.** As mentioned above, the fifth offers some **guidelines and considerations on where to establish aquaponic units globally and locally**. The sixth annex presents a **cost benefit analysis** of a small scale media bed aquaponic unit. Finally, the seventh annex is a comprehensive **step by step guide** to building small scale version of the 3 aquaponic methods using materials that are universally available.

Target Audience:

This manual will be helpful for anyone looking to start with aquaponics on a small scale yet it was written in mind for Development/NGO or Community Based Organization practitioners looking to get involved with aquaponics and whose programmatic focus incorporates at least one of the following topics: sustainable agriculture, resilient methods of domestic food production or urban & peri-urban food security. Although not strictly necessary, it is advantageous for each reader to have some experience with growing vegetables for domestic consumption and/or growing fish at any capacity.

Chapter 1) Introduction to Aquaponics and Soilless Culture

Chapter Introduction:

This first chapter primarily gives a full description of the concept of aquaponics. To begin, there will be a brief account of the development and nature of 'soilless culture', which sets the scene for fully explaining the aquaponic concept. Following this, aquaponic technology will be explained and a brief history of its development will be given. After this, there will be a brief account of the major strengths and weaknesses of aquaponic food production and the places and contexts where it's most appropriate. Finally there will be a short description of the major applications of aquaponics seen today.

Fig. 1.1 Plants Grown Using Aquaponics

By the end of this chapter the reader will have a good understanding of the theoretical concepts of aquaponics and its place within the larger discipline of 'soilless culture'. The reader will also have an understanding of the major benefits and weaknesses of aquaponics and where the technology is most applicable.

Fig. 1.2 Tilapia in an Aquaponics Fish Tank

1) Introducing Soilless Culture

In order to best explain the concept of aquaponics, an initial introduction of 'soilless culture' is necessary, as it will give you a framework of where aquaponics fits within the many new forms of food production practiced around the world today.

Soilless culture by definition is the method of growing agricultural crops (including vegetables, cut flowers, bedding plants and herbs) without the use of ground soil. In its place, various inert grow media (substrate) such as: rock wool, vermiculite, expanded clay (hydroton), perlite, rice husk ash, and volcanic tuff are used primarily for plant support. Irrigation systems are then integrated into the production area allowing a nutrient solution to pass through the plants' root zone. **Hydroponics** is a form of soilless culture that solely relies on nutrient solutions for all the essential plant nutrients. For this method, plants are either suspended in water or inert substrate to support the plant. Other forms of soilless culture use an organic substrate, such as compost, coco fiber or peat, as plant support but also as a secondary nutrient supply.

This form of agriculture is a product of major scientific, economic and technological development in the general field of agriculture over the last 2 centuries. In general, but predominately in the West, there has been an increasing demand for out-of-season, high value crops. This is due to widespread improvement in standards of living. This increase in demand has led to the expansion of protected cultivation systems, from low-tech plastic screens to fully automated greenhouses, to boost production capacity and prolong the supply of crops during a season or off-season. Within these protected systems crops were grown in soil yet in order to stay competitive with open field agriculture, production intensity was forced to increase to offset the higher production costs associated with controlled environment agriculture.

As a result, there was a major shift from soil production due to the proliferation of soil-borne diseases caused by intensively cultivating areas. Instead of soil, organic or inorganic substrates were used as pest and disease-free alternatives, which could be reused once disinfected/disinfested between crops. The reuse of substrates makes them far more suitable than soil for intensive production. After initial trials of soilless production many farmers made the transition to this form of production. Farmers enjoyed improved plant performance due to the fact that different substrates allowed the grower to control several crucial factors to plant growth. Some substrates proved to be far better than soil, particularly in areas such as water holding capacity and oxygen supply at the root zone. Nutrient availability at plant roots could hereby be better manipulated and controlled, leading to better production.

To summarize, the two main reasons why soilless culture is a growing in practice today are: 1) it allows the grower to de-contaminate the grow media after every use; 2) plants can be grown in their optimal conditions. Soilless culture is now gaining even more traction, as this method is seen as a solution for regions of the world facing issues of water scarcity and infertile or unsuitable soils (most soilless culture methods use less than 20% of the water needed for soil production). Additionally, with the rise in demand for organic produce grown in more sustainable agricultural practices, organic soilless methods are now being researched extensively (see chapter 6 for more information on the comparison between soil and soilless production).

2) What is Aquaponics?

Aquaponics is the combination of two agricultural techniques – **aquaculture** and **hydroponics**. In order to explore aquaponics comprehensively, and its major benefits, it will be helpful to begin by briefly explaining these two agricultural techniques.

Aquaculture:

Aquaculture is the term used to describe many different methods of producing varied types of fish and other aquatic species. Many methods of aquaculture have been developed in various regions of the world and have thus been adapted to the specific environmental and climatic conditions of that region. The 3 major categories of methods are as follows: 1) Floating cages in fresh water rivers, estuaries and saltwater environs and, 2) Fish pond culture and 3) Recirculating Aquaculture Systems with various solid removal and biological filtration techniques to remove and/or treat the fish waste.

Regarding sustainability, the major problem for aquaculture is nitrate-rich wastewater which is the byproduct for all the aquaculture methods mentioned above. This forces the farmers to either treat or dispose of this water, which is both is expensive and potentially environmentally hazardous.

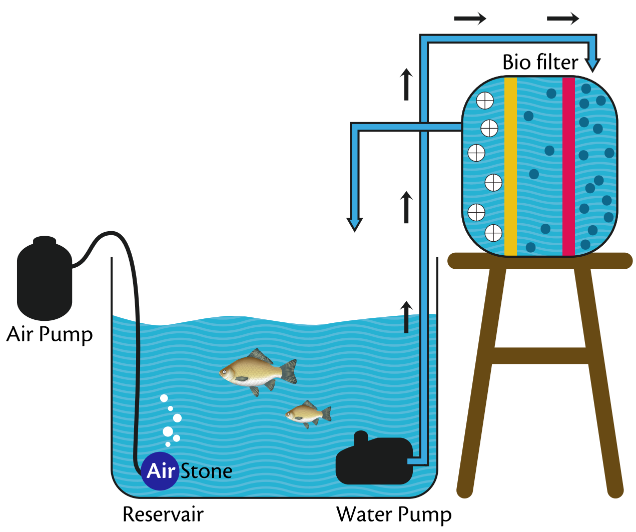


Fig. 1.3 Recirculating Aquaculture System

Hydroponics:

As previously mentioned, Hydroponics is a form of soilless culture and the term is used to describe different methods of growing plants (vegetables, herbs, flowers and even some small fruit trees) solely using water as the medium for all plant nutrients. Hydroponic food production systems irrigate plants with nutrient solution; this process is known as fertigation. Organic nutrient solutions can also be used, but the vast majority of commercial systems use a balanced inorganic fertilizer formulae to supply plants with optimal micro and macro nutrients.

Hydroponics is far more water efficient than ground grown crop production, as the water is continuously re-circulating in a closed loop system or micro-irrigated in an open system. The major problem regarding the sustainability of hydroponics is the complete reliance on chemical fertilizers to produce food.

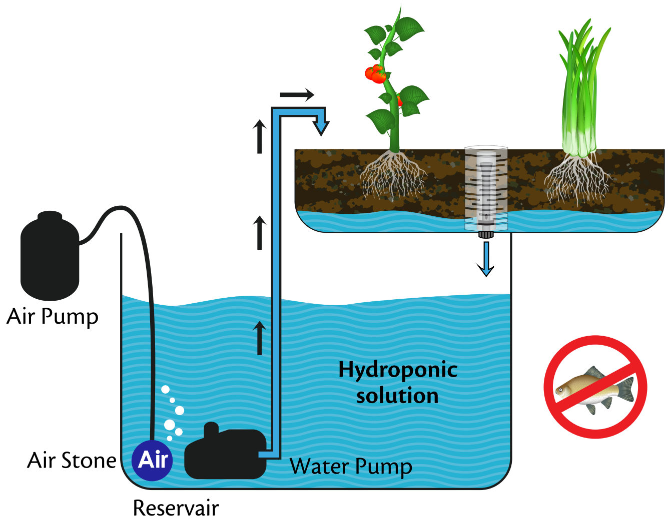
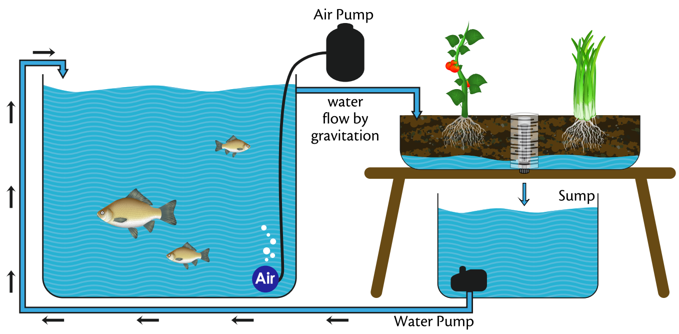


Fig. 1.4 Simple Hydroponic Unit

Aquaponics:

Aquaponics is the integration of **aqua**culture and hydro**ponics** in one production system. This integration removes the unsustainable factors of running aquaculture and hydroponic systems independently as mentioned above.

Aquaponics relies on fish waste to be used as an organic nutrient solution to grow vegetables. In a system, water flows from the fish tank into a biofilter where bacteria break down the fish waste into an organic nutrient solution for the growing vegetables. The plants then absorb the nutrients from the water which essentially cleans it before being re-circulated back into the fish tanks.



The bacteria are fundamental to this process. They convert the ammonia, which is a major component of fish waste, into nitrate (a more accessible form of nitrogen for plants), preventing the water from becoming toxic to the fish (this conversion of ammonia to nitrate is known as the nitrification process, see chapter 2 for more details). It is vital that every aquaponics unit has a biological filtration component to house the bacteria, allowing them to constantly convert the ammonia into nitrate. Although the production of fish and vegetables are the most sought after outputs of aquaponic units, it is essential to understand that aquaponics is the management of an eco-system of **three** major organisms: **fish**, **plants** and **bacteria.**

3) Why Aquaponics?

The following list highlights some of the major benefits of aquaponic food production:

- Two agricultural products (fish and vegetables) can be produced from only one input (fish food).
- Aquaponic production units are extremely water-efficient (they use less than 20% of the water needed for normal soil farming).
- Aquaponic food production creates ZERO waste during the process.
- Aquaponic units can be installed on non-arable land or in urban areas (rooftops, patios, community centers, etc.) and allow for high density crop production
- The technological requirements for each unit are very basic (primarily plastic containers, gravel, water pumps, plumbing, water and electricity).
- Harvesting methods are very simple.
- Soilless culture (aquaponics) removes most environmental factors that impair root growth in soil (soil compaction, shortage of water, insufficient soil aeration and soil temps).
- To some extent, aquaponic systems are transportable- allowing for relocation if necessary

Along with the benefits, some weaknesses should be noted:

- Relatively expensive initial startup costs compared with soil vegetable production or hydroponics
- Knowledge of fish, bacteria and plant productionis needed for each farmer to be successful
- Daily management is mandatory
- Bio-security threats are present (along with all other forms of food production)
- Small-scale aquaponic food production relies on access to fish or fingerlings so it may not be applicable in areas where there are no local fish hatcheries (Please see annex on guide lines for selecting areas suitable for aquaponic activities for more on this topic).

4) A Brief History of Modern Aquaponic Technology

The concept of using fish waste to fertilize plants has existed for centuries, with early civilizations in both Asia and South America applying this method. It was during the 1980s and 1990s that this basic form of aquaponics, that had existed largely in lakes, river beds and estuaries, evolved into the modern food production systems seen today. Prior to the technological advances seen in the 1980s, most attempts to integrate hydroponics and aquaculture had limited success.The 1980s and 1990s saw innovations that led to the creation of closed systems that allow for the recycling of water. North Carolina State University showed in their initial aquaponic systems that water consumption in integrated systems was just 5% of that used in pond culture for growing tilapia. This development, amongst other key initiatives, pointed to the suitability of integrated aquaculture and hydroponics systems for raising fish and growing vegetables particularly in semi-arid and arid regions.

Although in use since the 1980s, aquaponics is a still relatively new method of food production with only a small number of research and practitioner hubs worldwide with comprehensive aquaponic experience. Dr. James Rakocy has been the industry leader regarding research and development with his floating Raft method in the University of Virgin Islands. He has developed vital ratios and calculations in order to maximize production of both fish and vegetables while maintaining a balanced eco-system. Dr. Wilson Lennard in Australia has also produced key calculations and production plans for Flood & Drain and Nutrient Film Technique units. It is also worth mentioning Dr. Savidov based in Alberta Canada, for his research on comparing production quantities for aquaponics and hydroponics. His research over a two year period produced results showing that aquaponics units had significantly superior production of tomatoes and cucumbers.These research breakthroughs have paved the way for various practitioner groups and support/training companies that are beginning to sprout worldwide.

5) Current Applications of Aquaponics

This final section will briefly mention some of the major applications of aquaponics seen around the world. Again, this list is by no means exhaustive, but rather a small window into activities that are using the aquaponic concept. (Also, please see Annex no. 4 for a further explanation into where aquaponics is most applicable).

A) Domestic/Small-Scale Aquaponics

Small-scale aquaponic units (fish tank size of 1000 litres and growing space of roughly 4 sq. meters) in households have been trialed and tested with great success in virtually all regions around the world. The main purpose for these units is food production for subsistence/domestic use, as many units can have various types of vegetables and herbs growing at once. In the past five years aquaponic groups, societies and forums have developed hugely and serve to disseminate advice and lessons learned on these small-scale units.

Fig. 1.6 Domestic Aquaponics Unit in an Arid Area

B) Semi-Commercial & Commercial Production

Due to the high initial start-up cost and lack of comprehensive experience with this scale, commercial and/or semi commercial aquaponic systems are few in number and most of them adopt monoculture practices (lettuce or basil production). Although many academic institutes in the US, Europe and Asia have constructed considerably large units, most have been for academic research rather than food production to compete with other producers in the private sector. One group of experts in Hawaii have been one of the few fully fledged commercial systems. They have also been able to obtain organic certification for their unit, enabling them to reap a higher financial return for their output. Detailed business plans with thorough market research on the most lucrative plants and fish in local and regional markets are essential for any successful venture.

C) Education

Small-scale aquaponic units are being championed, predominantly in the West, in various educational institutes including: primary and secondary schools, third level educational institutes, as well as community based organizations. The concept is being used as a vehicle to bridge the gap between the general population and sustainable agricultural techniques – including other sustainable activities such as rainwater harvesting, nutrient recycling and organic food production, all of which can be integrated.

Fig.1.8 Combine Aquaponics Unit for Educational Purposes

Humanitarian Relief/Food security Interventions

With the advent of highly efficient aquaponics systems, there has been an interest in discovering how the concept will fare in "developing" countries. Countries in which examples of aquaponics initiatives in this setting include Guatemala, Mexico, Brazil, Botswana, Barbados, Jamaica, Ghana, Thailand, Zimbabwe, Panama, Malaysia, Philippines, Nigeria, India, Ethiopia and Haiti, to name only a few. At a first glance, there appears to be a considerable amount of "aquaponic activity" within the humanitarian sphere. However, having investigated these programs and initiatives further, many attempts are *ad hoc* and opportunistic – in many cases leading to standalone, low-impact interventions.

Small-scale aquaponic units are beginning to be prominent activities in urban agriculture initiatives, particularly with NGOs and other stakeholders in urban food and nutrition security, due to their ability to be installed in many different urban landscapes. In particular, the Food and Agriculture Organization of the United Nations (UNFAO) in the West Bank and Gaza Strip have piloted small-scale rooftop aquaponic units in the heart of Gaza City in 2012 as a response to the chronic food and nutrition security issues seen across the Gaza Strip. To date, this project, along with phase II of the initial pilot, which sees significant scale up in Gaza city, is one of a growing number of examples around the world where aquaponics is being successfully integrated into medium-large scale emergency food security interventions.

Fig.1.9 small scall Aquaponics Pilot Unit, Ethiopia, 2013

In June 2013, the first International Aquaponics Conference with the subtitle 'Aquaponics and Global Food security' took place in Wisconsin, USA hosted by the University of Wisconsin. Guest speakers from a number of nations came together and shared on different experiences of aquaponics contributing to global food security.

Fig. 1.10 & 1.11 Pictures of FAO Aquaponics Rooftop Pilot Project in Gaza City, 2013