Aquaponics quick-reference handout

Note: The section below reproduces the chapter summaries from the FAO aquaponic publication (see citation below). It is intended to be a short and easy-to-reproduce supplement, envisioned for use in education, extension and outreach applications and is designed to be provided to students, workers and farmers.

The full technical paper can be found at: www.fao.org/publications/en/

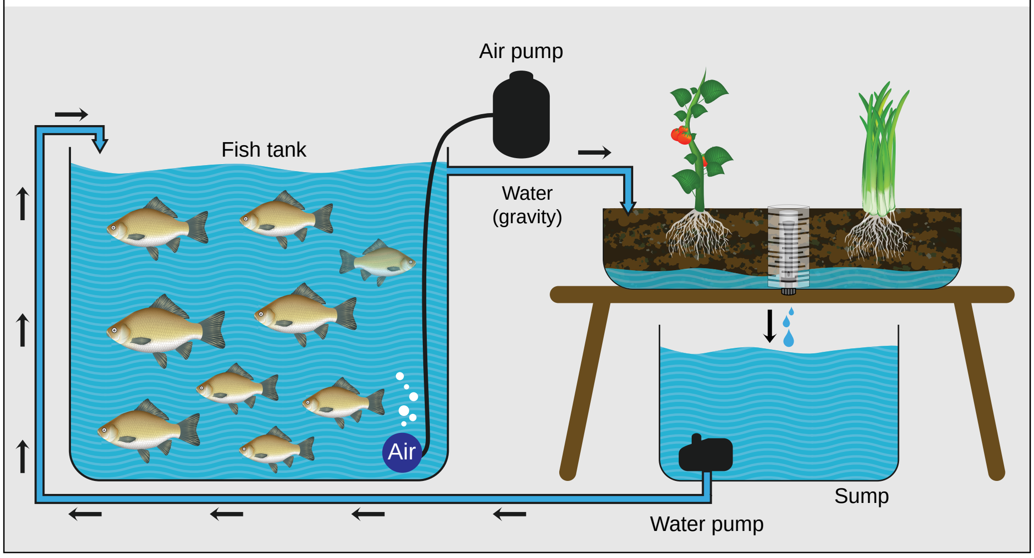
Somerville, C., Cohen, M., Pantanella, E., Stankus, A. & Lovatelli, A. 2014. *Small-scale aquaponic food production. Integrated fish and plant farming*. FAO Fisheries and Aquaculture Technical Paper. No. 589. Rome, FAO. 262 pp.

INTRODUCTION TO AQUAPONICS

Aquaponics is the integration of recirculating aquaculture system (RAS) and hydroponics in one production system. In an aquaponic unit, water from the fish tank cycles through filters, plant grow beds and then back to the fish. In the filters the water is cleaned from the fish wastes by a mechanical filter that removes the solid part, and a biofilter that processes the dissolved wastes. The biofilter provides a location for bacteria to convert ammonia, which is toxic for fish, into nitrate, a more accessible nutrient for plants. This process is called nitrification. As the water (containing nitrate and other nutrients) travels through plant grow beds the plants uptake these nutrients, and finally the water returns to the fish tank purified. This process allows the fish, plants, and bacteria to thrive symbiotically and to work together to create a healthy growing environment for each other, provided that the system is properly balanced. Although the production of fish and vegetables is the most visible output of aquaponic units, it is essential to understand that aquaponics is the management of a complete ecosystem that includes three major groups of organisms: fish, plants and bacteria.

In aquaponics, the aquaculture effluent is diverted through plant beds and not released to the environment, while at the same time the nutrients for the plants are supplied from a sustainable, cost-effective and non-chemical source. This integration removes some of the unsustainable factors of running aquaculture and hydroponic systems independently. Beyond the benefits derived by this integration, aquaponics has shown that its plant and fish productions are comparable with hydroponics and RASs. Aquaponics can be much more productive and economically feasible in certain situations, especially where land and water are limited. However, aquaponics is complicated and requires substantial start-up costs. The increased production must compensate for the higher investment costs needed to integrate the two systems. Before committing to a large or expensive system, a full business plan considering economic, environmental, social and logistical aspects should be conducted.

Simple aquaponic unit



NOTES:

BENEFITS AND WEAKNESSES OF AQUAPONIC FOOD PRODUCTION

Major benefits of aquaponic food production:

- Sustainable and intensive food production system.
- Two agricultural products (fish and vegetables) are produced from one nitrogen source (fish food).
- Extremely water-efficient.
- Does not require soil.
- Does not use fertilizers or chemical pesticides.
- Higher yields and qualitative production.
- Organic-like management and production.
- Higher level of biosecurity and lower risks from outer contaminants.
- Higher control on production leading to lower losses.
- Can be used on non-arable land such as deserts; degraded or salty soils; urban plots; and sandy islands.
- Creates little waste.
- Daily tasks, harvesting and planting are labour-saving and therefore can include all genders and ages.
- Economical production of either family food production or cash crops in many locations.
- Can be built in many ways according to the materials available.

Major weaknesses of aquaponic food production:

- Expensive initial start-up costs compared with soil production or hydroponics.
- Knowledge of fish, bacteria and plant production is needed for each farmer to be successful.
- Fish and plant requirements do not always match perfectly.
- Not recommended in places where cultured fish and plants cannot meet their optimal temperature ranges.
- Reduced management choices compared with stand-alone aquaculture or hydroponic systems (no pesticides for the plants, no antibiotics for the fish)
- Mistakes or accidents can cause catastrophic collapse of system.
- Daily management is mandatory.
- Energy demanding.
- Requires reliable access to electricity, fish fingerlings and plant seeds.
- Alone, aquaponics will not provide a complete diet.

NOTES:

TECHNICAL INTRODUCTION

- Aquaponics is a production system that combines fish farming with soil-less vegetable production in one recirculating system.
- Nitrifying bacteria convert fish waste (ammonia) into plant food (nitrate).
- The same nitrification process that happens in soil also happens in the aquaponic system.
- The most important part of aquaponics, the bacteria, is invisible to the naked eye.
- The key factors for maintaining healthy bacteria are water temperature, pH, dissolved oxygen and adequate surface area on which the bacteria can grow.
- Successful aquaponic systems are balanced. The **feed rate ratio** is the main guideline to balance the amount of fish feed to plant growing area, which is measured in grams of daily feed per square metre of plant growing space.
- The feed rate ratio for leafy vegetables is 20–50 g/m^2/day; fruiting vegetables require 50–80 g/m^2/day.
- Daily health monitoring of the fish and the plants will provide feedback on the balance of the system. Disease, nutritional deficiencies and death are mainly symptoms of an unbalanced system.
- Weekly nitrogen testing will provide information on the balance of the system. High ammonia or nitrite indicates insufficient biofiltration; low nitrate indicates too many plants or not enough fish/feed; increasing nitrate is desirable and indicates adequate nutrients for the plants, though water needs to be exchanged when nitrate is greater than 150 mg/litre.

NOTES:

WATER QUALITY IN AQUAPONICS

- Water is the life-blood of an aquaponic system. It is the medium through which plants receive their nutrients and the fish receive their oxygen. It is very important to understand water quality and basic water chemistry in order to properly manage aquaponics.
- There are five key water quality parameters for aquaponics: dissolved oxygen (DO), pH, water temperature, total nitrogen concentrations and hardness (KH). Knowing the effects of each parameter on fish, plants and bacteria is crucial.
- Compromises are made for some water quality parameters to meet the needs of each organism in aquaponics.
- The target ranges for each parameter are as follows:

pH	6–7
water temperature	18–30 °C
DO	5–8 mg/litre
ammonia	0 mg/litre
nitrite	0 mg/litre
nitrate	5–150 mg/litre
KH	60–140 mg/litre

- There are simple ways to adjust pH. Bases, and less often acids, can be added in small amounts to the water in order to increase or lower the pH, respectively. Acids and bases should always be added slowly, deliberately and carefully. Rainwater can be alternatively used to let the system naturally lower the pH through nitrifying bacteria consuming the system's alkalinity. Calcium carbonate from limestone, seashells or egg shells increases KH and buffers pH against the natural acidification.
- Some aspects of the water quality and water chemistry knowledge needed for aquaponics can be complicated, in particular the relationship between pH and hardness, but basic water tests are used to simplify water quality management.
- Water testing is essential to maintaining good water quality in the system. Test and record the following water quality parameters each week: pH, water temperature, nitrate and carbonate hardness. Ammonia and nitrite tests should be used especially at system start-up and if abnormal fish mortality raises toxicity concerns.

NOTES:

AQUAPONIC UNIT DESIGN

- The main factors when deciding where to place a unit are: stability of ground; access to sunlight and shading; exposure to wind and rain; availability of utilities; and availability of a greenhouse or shading structure.
- There are three main types of aquaponics: the media bed method, also known as particulate bed; the nutrient film technique (NFT) method; and the deep water culture (DWC) method, also known as the raft method or floating system.
- The essential components for all aquaponic units are: the fish tank, the mechanical and biological filtration, the plant growing units (media beds, NFT pipes or DWC canals), and the water/air pumps.
- The media beds must: (i) be made of strong inert material; (ii) have a depth of about 30 cm; (iii) be filled with media containing a high surface area; (iv) provide adequate mechanical and biological filtration; (v) provide separate zones for different organisms to grow; and (vi) be sufficiently wetted through flood-and-drain or other irrigation techniques to ensure good filtration.
- For NFT and DWC units, mechanical and biofiltration components are necessary in order to respectively remove the suspended solids and oxidize the dissolved wastes (ammonia to nitrate).
- For NFT units, the flow rate for each grow pipe should be 1–2 litres/minute to ensure good plant growth.
- For DWC units each canal should have a retention time of 1–4 hours.
- High DO concentration is essential to secure good fish, plant and bacteria growth. In the fish tank DO is supplied by means of air stones. Media bed units have an interface between the wet zone and dry zone that provides a high availability of atmospheric oxygen. In NFT units, additional aeration is provided into the biofilter, while in DWC air stones are positioned in the biofilter and plant canals.

NOTES:

Illustration of a small media bed unit

BACTERIA IN AQUAPONICS

- In aquaponics, ammonia must be oxidized into nitrate to prevent toxicity to fish.
- The nitrification process is a two-step bacterial process where ammonia-oxidizing bacteria convert ammonia (NH_3) into nitrite (NO_2^-), and then nitrite-oxidizing bacteria convert nitrite into nitrate (NO_3^-).
- The five most important factors for good nitrification are: high surface area media for bacteria to grow and colonize; pH (6–7); water temperature (17–34 °C); DO (4–8 mg/litre); cover from direct exposure to sunlight
- System cycling is the initial process of building a nitrifying bacteria colony in a new aquaponic unit. This 3–5 week process involves adding an ammonia source into the system (fish feed, ammonia-based fertilizer, up to a concentration in water of 1-2 mg/litre) in order to stimulate nitrifying bacteria growth. This should be done slowly and consistently. Ammonia, nitrite and nitrate are monitored to determine the status of the biofilter: the peak and subsequent drop of ammonia is followed by a similar pattern of nitrite before nitrate starts to accumulate. Fish and plants are only added when ammonia and nitrite levels are low and the nitrate level begins to rise.
- Ammonia and nitrite tests are used to monitor the function of the nitrifying bacteria and the performance of the biofilter. In a functioning system, ammonia and nitrite should be close to 0 mg/litre. High levels of either ammonia or nitrite require a water change and management action. Usually, poor nitrification is due to a change in water temperature, DO or pH levels.
- Another class of micro-organisms naturally occurring in aquaponics is that of heterotrophic bacteria. They decompose the solid fish waste, releasing some of the nutrients into the water in a process called mineralization.

NOTES:

PLANTS IN AQUAPONICS

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

NOTES:

FISH IN AQUAPONICS

- Standard manufactured fish feed pellets are recommended for use in aquaponics because they are a whole feed containing the correct balance of proteins, carbohydrates, fats, vitamins and minerals needed for fish.
- Protein is the most important component for building fish body mass. Omnivorous fish such as tilapia and common carp need about 32 percent protein in their diet, carnivorous fish need more.
- Never overfeed the fish, and remove uneaten food after 30 minutes to reduce risks of ammonia or hydrogen sulphide toxicity.
- Water quality needs to be maintained for fish. Ammonia and nitrite must be close to 0 mg/litre as they are toxic at any detectable levels. Nitrate should be less than 400 mg/litre. DO should be 4–8 mg/litre.
- Tilapia, carp, and catfish are highly suitable for aquaponics in tropical or arid conditions as they grow quickly and can survive in poor quality water and at lower DO levels. Trout grow well in cold water, but require better water quality.
- Fish health should be monitored daily, and stress should be minimized. Poor and/or changing water quality, overcrowding, and physical disturbance can cause stress, which may lead to disease outbreaks.
- Abnormalities or changes in physical behaviour can indicate stress, bad water quality, parasites or disease. Take the time to observe and monitor the fish in order to recognize symptoms early and provide treatment.

NOTES:

BALANCING THE FISH AND PLANTS: COMPONENT CALCULATIONS

Aquaponic systems need to be balanced. The fish (and thus, fish feed) need to supply adequate nutrients to the plants; the number of plants should be adequate to use all the nutrients released, but not in excess to prevent any risk of deficiencies. The biofilter needs to be large enough to process all of the fish wastes, and enough water volume is needed to circulate this system. This balance can be tricky to achieve in a new system, but this section provides helpful calculations to estimate the sizes of each of the components.

The most successful way to balance an aquaponic system is to use the feed rate ratio described in Section 2.1.4 of this publication. This ratio is the most important calculation for aquaponics so that the fish and plants can thrive symbiotically within the aquaponic ecosystem.

The ratio estimates how much fish feed should be added each day to the system, and it is calculated based on the area available for plant growth. This ratio depends on the type of plant being grown; fruiting vegetables require about one-third more nutrients than leafy greens to support flowers and fruit development. The type of feed also influences the feed rate ratio, and all calculations provided here assume an industry standard fish feed with 32 percent protein. Lower-protein feeds can be fed at higher rates.

Leafy green plants	Fruiting vegetables
40–50 g of fish feed per square metre	50–80 g of fish feed per square metre

The recommended first step in the calculation is to determine how many plants are needed. Plants are most likely the most profitable part in small-scale aquaponics because of the high turnover rate. On average, plants can be grown at the following planting density. These figures are only averages, and many variables exist depending on plant type and harvest size, and therefore should only be used as guidelines.

Leafy green plants	Fruiting vegetables
20–25 plants per square metre	4 plants per square metre

Choose the amount of growing area needed using the above metric (leafy vs. fruiting). The surface area needs to be chosen by the farmer to meet market or food production targets. This also depends on the crop, because some plants require more space and grow more slowly than others. Once the desired number of plants has been chosen, it is then possible to determine the amount of growing area needed and, consequently, the amount of fish feed that should be added to the system every day.

Once the amount of fish feed has been calculated, it is possible to determine the biomass of the fish needed to eat this fish feed. Different-sized fish have different feed requirements and regimes, this means that many small fish eat as much as a few large fish. In terms of balancing an aquaponic unit, the actual number of fish is not as important as the total biomass of fish in the tank. On average, the fish will consume 1–2 percent of their body weight per day during the grow-out stage, which correspond to a body mass above 50g. On the contrary small/young fish eat more than large ones, as a percentage of body weight.

Fish feeding rate
1–2 % of total body weight per day

The following example demonstrates how to conduct this set of calculations: In order to produce 25 heads of lettuce per week, an aquaponic system should have 10–20 kg of fish, fed 200 grams of feed per day, and have a growing area of 4 m^2. The calculations are as follows:

Lettuce requires 4 weeks to grow once the seedlings are transplanted into the system, and 25 heads per week are harvested, therefore:

$$\text{25 heads/week} \times \text{4 weeks} = \text{100 heads in system}$$

Each 25 heads of lettuce require 1 m^2 of growing space, therefore:

$$\text{100 heads} \times \frac{1\ m^2}{\text{25 heads}} = 4\ m^2$$

Each square metre of growing space requires 50 g of fish feed per day, therefore:

$$4\ m^2 \times \frac{\text{50 grams feed/day}}{1\ m^2} = \text{200 grams feed/day}$$

The fish (biomass) in a system eats 1–2 percent of their body weight per day, therefore:

$$\text{200 grams feed/day} \times \frac{\text{100 grams fish}}{\text{1-2 grams feed/day}} = \text{10-20 kg of fish biomass}$$

Although extremely helpful, this feed ratio is really only a guide, particularly for small-scale units. There are many variables involved with this ratio, including the size and type of fish, water temperature, protein content of the feed, and nutrient demands of the plants, which may change significantly over a growing season. These changes may require the farmer to adjust the feeding rate. Testing the water for nitrogen helps to determine if the system remains in balance. If nitrate levels are too low (less than 5 mg/litre), then slowly increase the feed rate per day without overfeeding the fish. If the nitrate levels are stable, then there may be deficiencies in other nutrients and supplementation may be required especially for calcium, potassium and iron. If nitrate levels are increasing then occasional water exchanges will be necessary as nitrate rises above 150 mg/litre. Increasing nitrate levels suggest that the concentration of other essential nutrients is adequate.

Practical system design guide for small-scale aquaponic units

Fish tank volume (litre)	Max. fish biomass[1] (Kg)	Feed rate[2] (g/day)	Pump flow rate (litre/h)	Filters volume[3] (litre)	Min. volume of biofilter media[4] (litre)		Plant growing area[5] (m^2)
					Volcanic tuff	Bioballs®	
200	5	50	800	20	50	25	1
500	10	100	1 200	20–50	100	50	2
1 000	20	200	2 000	100–200	200	100	4
1 500	30	300	2 500	200–300	300	150	6
2 000	40	400	3 200	300–400	400	200	8
3 000	60	600	4 500	400–500	600	300	12

Notes:

1. The recommended fish density is based on a maximum stocking density of 20 kg/1 000 litres. Higher densities are possible with further aeration and mechanical filtration, but this is not recommended for beginners.
2. The recommended feeding rate is 1 percent of body weight per day for fish of more than 100 g of body mass. The feeding rate ratio is: 40–50 g/m^2 for leafy greens; and 50–80 g/m^2 for fruiting vegetables.
3. The volumes for mechanical separator and biofilter should be 10–30 percent of total fish tank volume. In reality, the choice of containers depends on their size, cost and availability. Biofilters are only needed for NFT and DWC units; mechanical separators are applicable for NFT, DWC units and media bed units with a fish density of more than 20 kg/1 000 litres.
4. These figures assume the bacteria are in optimal conditions all the time. If not, for a certain period (winter), extra filtration media may need to be added as a buffer. Different values are provided for the two most common biofilter media based on their respective specific surface area.
5. Figures for plant growing space include only leafy greens. Fruiting vegetables would have a slightly lower area.

NOTES:

ADDITIONAL TOPICS IN AQUAPONICS

- Compost tea can be used to supplement nutrients for the plants and be produced on a small scale by composting vegetable wastes.
- Alternative and supplemental fish feed can be grown and produced on a small scale, including duckweed, *Azolla* spp., insects and moringa.
- Seeds can be collected and stored using simple techniques to reduce costs of reseeding.
- Rainwater collection and storage provides a cost-effective way of replenishing aquaponic water.
- Redundancies and failsafe methods should be employed to prevent catastrophic loss-of-water events that can kill the fish
- Aquaponic water can be used to fertilize and irrigate other gardening activities.
- Other types and methods exist beyond the examples outlined in this publication.

NOTES:

TEN KEY GUIDELINES FOR SUCCESSFUL AQUAPONICS

- Observe and monitor the system every day.
- Ensure adequate aeration and water circulation with water pumps and air pumps.
- Maintain good water quality: pH 6–7; DO > 5 mg/litre; TAN < 1 mg/litre; NO_2^- < 1 mg/litre; NO_3^- 5–150 mg/litre; temperature 18–30 °C.
- Choose fish and plants according to seasonal climate.
- Do not overcrowd the fish tanks (< 20 kg/1 000 litres).
- Avoid overfeeding, and remove any uneaten food after 30 minutes.
- Remove solid wastes, and keep tanks clean and shaded.
- Balance the number of plants, fish and size of biofilter.
- Stagger harvesting and restocking/replanting to maintain balance.
- Do not let pathogens enter the system from people or animals, and do not contaminate produce by letting system water wet the leaves.

NOTES:

GENERAL NOTES

GENERAL NOTES

GENERAL NOTES