- *The Kratky method:* Another simpler approach to insuring sufficient oxygen for plants roots using the DWC method is to leave a space of 3-4 cms in between the polystyrene and the water body inside the trough. This technique is called the Kratky method which sees the polystyrene sheets suspended 3-4 cm above the water rather than floating on top to allow air to circulate around the plant roots. This approach removes the need for air stones in the trough as sufficient amounts of oxygen in the air is supplied to the roots. Another advantage of this method is the avoidance of direct contact of the plants with water, which reduces the risks of plant diseases at the collar zone (between root and leaf). Furthermore the increased ventilation due to the space favors the heat dissipation from water, which is ideal in hot climates.

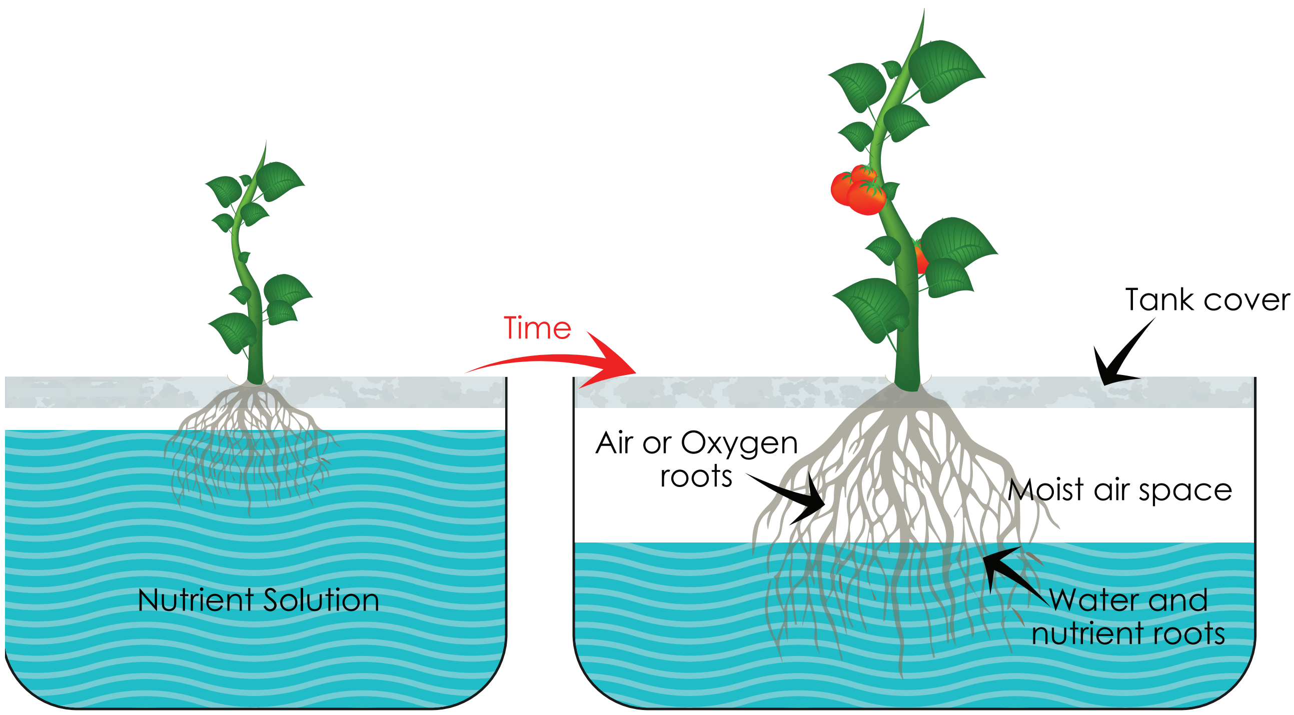



**Fig. 4.77 A Demonstration of Kratky's Method for DWC Planting Removing the Need for Aeration Using an Air Pump**

- *Venturi's:* Low tech venturi's are another simple technique to increase the oxygen levels in the canals. Simply speaking, low tech venturi's are small sections of pipe (i.e. 20mm pipe, 5cms long) thinner than the main water pipe (i.e 25mm thick) which are then inserted into the main pipe. As the water in the 25mm pipe is forced through the thinner 20mm pipe section, it creates a jet effect as the water exits the 5cm section of 20mm pipe (see fig. 4.78-4.82). This jet steam allows you to then cut a hole into 25mm pipe just after the 20mm insert which then sucks the surrounding air into the water flow.

Fig. 4.78

Fig. 4.79

Fig. 4.80

Fig. 4.81

Fig. 4.82

**Fig. 4.78 – 4.82 Venturi's step by step preparation**

Ventur's integrated into each inflow pipe just before the canal facilitates the dissolving of much greater amounts of oxygen into the trough water. They can also help stabilize the dissolved oxygen levels in the canals if the air pump fails. See the further reading section at the end of this manual for more sources of information on venturis.

- Finally, **do not add any fish into the canals** as they will eat the plant roots. However the presence of some fish species in the canals like guppies in tropical and temperate areas (who will not eat plant roots) can get rid of the innumerable mosquito larvae which can become a huge nuisance to workers and neighbours.

**Plant techniques for DWC units:**

The polystyrene sheets should have a certain number of drilled holes to fit the net cups used for supporting each plant. The amount and location of the holes is dictated by the vegetable type and the distance desired between the plants (i.e 20-30 holes per square meter for lettuce at 300 grams harvest weight). See step by step annex for further details on how to drill the holes.

**Fig. 4.83 Polystyrene Sheets in a Small (1m x 1m) DWC Trough (12 holes for fruiting vegetables)**

Take one seedling and place it into a net cup allowing the end of the roots to dangle below the bottom of the cup. Gently fill the remaining space in the net cup with 8mm gravel giving support to the seedling.

Fig. 4.84 & 4.85 Planting Seedlings into Net Cups with Gravel Support

Fig. 4.84

Fig. 4.85

Afterwards, place the filled net cup into one of the holes drilled into the polystyrene making sure it fits tight with no threat of it falling into the trough. It is also possible to simply plant a seed straight into the net cups on top of the gravel. This method is recommended if vegetable seeds are accessible as it avoids the transplant shock seedlings experience when replanting. When harvesting, make sure you remove the whole plant (including roots) from the trough.

Note: It is recommended to sterilize the next cups and polystyrene sheets by soaking them with weak bleach for a couple of hours every 6 months.

Fig. 4.86 Planting the Seedling into the Polystyrene Raft

Fig. 4.87 Removing all the Roots When Harvesting

### Low Fish Density DWC Aquaponic Systems

As previously mentioned in chapter 2, some aquaponic units can also be designed to carry a very low stocking density of fish. These units rely mainly on the plant root space as the surface area to house the nitrifying bacteria required thus removing the need for separate mechanical separators and bio-filters. This is advantageous as it will reduce the overall unit capital costs and it removes the need to buy certain filtration materials that maybe difficult or expensive locally. The obvious trade off is less fish production (roughly 1/4 the capacity of the methods previously described in this chapter) yet this may be ideal if vegetables are far more cost effective to grow than fish based on local market prices as the unit design mainly concentrates on plant production; this method is effectively organic hydroponics with a small fish culture component as the organic nutrient source.

### Unit Design

This low fish density method is only really applicable for DWC units as for NFT units, if filtration (solids removal) is not employed then the NFT pipes and the plant roots will clog with waste leading to very poor plant growth. It is also not really applicable for Media Bed units as this method can hold up to 15kgs per cubic meter without any extra separate filtration containers anyway, yet above 15kgs extra filtration in the media beds is necessary (see *filtration* section for Media Bed units above)

The actual design and water flow dynamic is very similar to the DWC unit described above, the main difference is the removal of the two filtration containers (see fig. 4.87-4.88). Water flows by gravity from the fish tank straight into DWC canals (or one large canal made from PVC liner with a wooden frame) that are aerated using an air pump. The fish waste is broken down by heterotrophic and nitrifying bacteria living on the plant root surface and the canal walls. The submersible water pump is then placed into the final canal (or at the end of a much longer canal) which pumps the water back into the fish tank. As there is much less fish than the other methods explained in this chapter, the flow rate entering the fish tank can also be less (at least half of the total fish tank volume/hr) which in turn means a smaller capacity pump (1500-2500 litres/hr for every 1 cubic meter of fish tank space). The recommendations for fish tanks and DWC canals given above are also applicable for this low stocking density method.

**Fig.4.87 & 4.88 Low Fish Density DWC Aquaponic Systems**

**Low stocking density unit management**:

The major difference to the management of the other units (which is discussed in more detail in chapter 8) is the maximum stocking density low stocking density units can handle which is:

Optimal stocking density: 150gram – 1.5kg of fish/square meter of vegetable production

It is simply **not possible** to stock more than this optimal ratio without any mechanical and/or bio-filtration component before the water enters the DWC canals, otherwise fish solid waste will accumulate in the fish tanks and canals leading to sub-optimal growing conditions, diseases and eventual fish and plant death

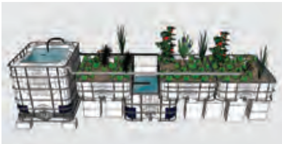
For fish feeding, the management is relatively easy. It's possible to follow the feed rate ratio of **10-50 grams/per square meter of vegetable production/ per day** or to feed what the fish will eat in 30 minutes, 2-3 times per day. If using the latter strategy, make sure to test the ammonia levels in the water to relgulate the amount of feed given each day. If ammonia levels increase has 1 mg/L, reduce the feed amount given per day.

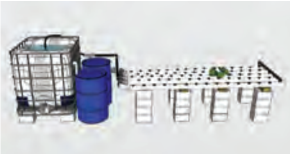
**Disadvantages**:

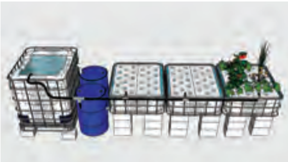
Some of the major advantages have been already mentioned including: cheaper unit capital costs, simpler unit design, less risk of fish stress, yet some there are some disadvantages to this approach that are listed below:

- Fish production limitations: only 150 – 1.5 kgs per square meter of grow space can be grown safely, as outlined above
- Plants **must** be in the canals at all times: plant roots are relied upon for bacteria growth yet if it's necessary to harvest all the plants at once (disease, end of season or major climate event i.e. storm or monsoon season) this may cause a large increase in ammonia.
- Fish production cannot function independently: if for whatever reason the hydroponic component needs to be temporarily shut off, a unit with extra mechanical and bio-filtration components can function perfectly (with intermittent water replacement) as a small scale recirculating aquaculture unit as nitrate is not toxic to fish even at high concentrations (above 400 mg/L). With a low density unit design (no separate filtration) this is not possible for time-period longer than 24 hours.

## 5) Comparing Media Bed, NFT and DWC units:

| System type: | Strengths: | Weaknesses: |
|---|---|---|
| <br>**a) Media Bed Units** | • Very simple and forgiving design making it ideal for beginners<br>• Alternative materials for components are easy to find and substitute (i.e. bathtubs as media beds)<br>• Large fruiting vegetables can be grown with relative ease as well as all types of leaf and some root plants<br>• Water can be delivered through flood and drain, drip irrigation or surface irrigation<br>• Different choices of grow media can be used according to local availability<br>• Excellent for aeration when using bell siphons<br>• Relatively low electrical energy demand as only as water pump is mandatory<br>• Growing media help capture fine-solids from fish waste, which can mineralize at their surface and increase nutrient availability for plants | • Potentially very heavy unit needing bed support , depending on type of grow media which can also be expensive (i.e. limestone gravel)<br>• Not an applicable method for commercial ventures as it is very expensive to scale up compared to NFT and DWC units.<br>• More evaporation of water per day than NFT and DWC as larger surface area exposed to the sun<br>• Labour intensive to start up<br>• Design should carefully consider the water volumes moved from fish tank to media beds during the flooding<br>• The system must include a solids capture device (per grow bed, or a separate container) if the stocking density is above 10 kgs to avoid washing out the gravel.<br>• Plant transplanting is more labour intensive due as the media needs to be moved<br>• If water delivery is not uniform, plant performance may differ in the one bed |

| | | |
|---|---|---|
| <br>**b) NFT Units** | • Cost effective method for commercial ventures<br>• Ideal for herbs and leafy green vegetables<br>• Minimal water loss by evaporation, as the water in the pipes is fully protected from the sun<br>• Light weight system, thus the most applicable method for rooftop production<br>• Very simple harvesting methods<br>• Pipes can be moved closer together for further apart according to plant growth in order to host the maximum plant density<br>• As this method is very popular for commercial hydroponics, there are plenty of resources available.<br>• Smallest water volume required<br>• Minimual labour with grow media | • More complex filtration method compared to media bed units<br>• NFT units must have a water pump and an air pump on at all times for aeration and water flow into the grow pipes, thus electricity security is essential<br>• Plants can only be grown from seedlings in grow pipes<br>• Smaller volume of water may be subject to ammonia peaks, thus raising the need for increased biofiltration into the system<br>• Grow pipes are subject to temperature changes during the day and night which heat up and cool down the water which can lead to unfavourable fish and plant growing conditions<br>• In hot seasons, plants can be prone to diseases due to higher water temperatures.<br>• The water inlet pipes (8 mm pipe) can easily clog (more daily management required) |

| | | |
|---|---|---|
| **C) DWC Units**<br> | • Cost effective method for commercial<br><br>ventures<br><br>• Much larger body of water compared with<br><br>NFT and media bed units meaning much less susceptible to pH and nutrient concentration swings or changes<br><br>• Suitable method if short electric cuts are<br><br>prone to happen as large body of water for plants (although fish stocking density must<br><br>be low at all times to fully survive power cuts)<br><br>• Minimal water loss by evaporation, as water<br><br>is fully protected from the sun<br><br>• DWC method is very popular for commercial aquaponics thus, plenty of resources are available<br><br>• Polystyrene rafts have an insulating effect on<br><br>the water and provide additional surface for<br><br>biofiltration<br><br>• Polystyrene rafts can be moved along the troughs allowing harvest on just one side of the system (conveyor method)<br><br>• DWC canals can be fixed with plastic liners using almost every kind of wall (wood, steel frames, metal profiles)<br><br>The DWC System more suitable for higher densities of fish into the system The higher volume of water buffers the ammonia peaks and reduce temperature fluctuations | • More complex filtration method<br><br>compared to media bed units<br><br>• Very heavy unit therefore not<br><br>applicable for rooftop production<br><br>More sophisticated air pump<br><br>requirements than NFT units as each trough must have sufficient oxygen for plants<br><br>• Plastic liners must be food-grade and<br><br>have a long lifespan<br><br>• Although harvesting is simple,<br><br>polystyrene sheets are easily broken<br><br>• Although DWC units traditionally grow leafy greens and herbs only;fruiting vegetables are possible but they will<br><br>need support and cannot be harvested<br><br>by removing the whole polystyrene<br><br>sheet<br><br>• Large volumes of water in the canals can increase relative humidity in a<br><br>greenhouses leading to greater risks of fungal diseases if crops are not<br><br>ventilated |

## Chapter Summary

- The main factors when deciding where to place your unit are: stability of ground; access to sunlight and shading; exposure to wind and rain, option of placing your unit inside a greenhouse, nethouse or shading structure.

- The essential components for all aquaponic units are as follows: fish tanks (which must be white and inert), filtration (mechanical & biological), the hydroponics component (grow beds, grow pipes or troughs) and water pumps.

- For grow bed units, there are 6 key things to remember about grow beds: 1) they must be made of strong inert material; 2) they must have a depth of roughly 30 cm; 3) they must be filled with media containing a high surface area (volcanic gravel is preferable); 4) within the grow beds mechanical and biological filtration occurs; 5) there are 3 separate zones in the grow bed: the dry zone, the wet and dry zone and the wet zone; 6) grow beds must flood and drain to ensure good filtration.

- For NFT and DWC units, mechanical and bio-filtration components are necessary to remove and treat the 3 different types of fish waste (dissolved, suspended and seattable solid). For NFTs: the flow rate for each grow pipe should be no more or no less than 1-2 litre per minute to ensure good plant growth. For DWC units: each trough should have a retention time of 2-4 hours.

- Securing optimal oxygen concentrations: for grow bed units, bell siphons or timer switches are essential for replenishing oxygen levels in the grow beds; for NFT units, air pumps must be placed in the biofilter and fish tank to stabilise oxygen; for DWC units, air pumps must be placed in the bio-filter and along the troughs (1 air stone per 2-4 square meter).

# Chapter 5) Bacteria

## Chapter Introduction:

By now it's hopefully clear that bacteria are pivotal to aquaponics. They are the engine of the system. They are facilitator of the whole aquaponics process, as they produce the accessible fertilizer for plants and at the same time remove toxic levels of waste that would otherwise damage the fish. In chapter 2, we discussed the role of nitrifying bacteria and essential parameters for keeping a healthy colony, while in chapter 4 we learned what materials are used in different aquaponic systems to host the bacteria. In this brief chapter, before we move on to learn about growing fish and vegetables, we will conclude on everything we need to know about bacteria in aquaponics. Let us first recap on what we know about the nitrifying bacteria. Following this, we will discuss other important bacteria groups and their involvement with securing all nutrients for plants. Finally we will explain the bacteria processes during the initial 3 weeks of starting a unit, so we can learn how and when to safely stock the fish.

## 1) Recap: What We Know of Bacteria So Far.....

In chapter 2, we discussed the vital role of nitrifying bacteria in the overall aquaponics process. It is the nitrifying bacteria that convert the fish waste (which is mostly in ammonia form), into nitrate for the vegetables. We mentioned two major groups of nitrifying bacteria that are involved: the **nitrosomonas group** and **nitrobacter group**, which consume the ammonia in the following order:

The Nitrification process:

1)**Nitrosomonas bacteria** converts ammonia ($NH_3$) into nitrite ($NO_2$)

2) **Nitrobacter bacteria** then converts nitrite ($NO_2$) into nitrate ($NO_3$)

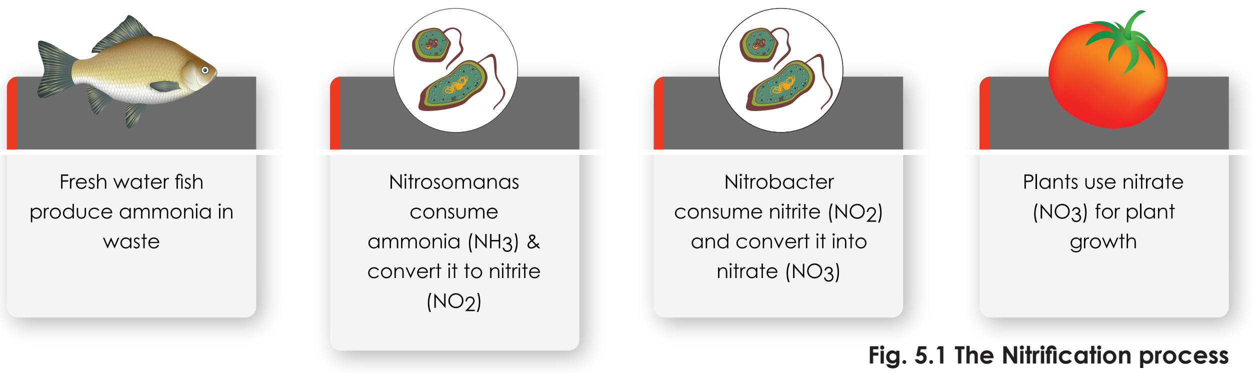



**Fig. 5.1 The Nitrification process**

We also discussed how we maintain a healthy bacteria colony in our unit by keeping within the optimal levels of certainkey parameters. These include:

1) **High Surface Area**: Biofiltration material with  a high surface area (≥300m²/m³) (such as volcanic gravel, expanded clay, bioballs, or plant roots), will enable bacteria to thrive.

2) **Water pH**:  The optimum levels for each nitrifying bacteria group are as follows: Nitrosomanas SP:

pH of 7.2-7.8 and Nitrobacter SP: pH of 7.2-8.2 Yet, we've learned in chapter 2 & 3 that the compromise pH level for aquaponics is 6-7 which will satisfy the optimal Ph levels for vegetables without having a major impact on the nitrification requirements.

3) **Water Temperature**: The optimal temperatures for bacteria growth and productivity are between 17-34 ° Celsius. Once the water temperature drops below this range the productivity of the bacteria begins to decrease. In particular, the nitrobacter group is less tolerant to low temperatures than the Nitrosomanas group. As such, during colder periods of the year, care must be taken to monitor the potential accumulation of nitrites which are harmful to fish.

4) **Dissolved Oxygen:** Nitrifying bacteria need good levels of Dissolved Oxygen (DO) in the water at all times to growth healthily and maintain high levels of productivity. Optimum levels are between 4-8 milligrams per litre (mg/L) of DO. Nitrification will not occur if DO concentrations drop to 2.0 mg/L or less.

5) **UV Light:** Nitrifying bacteria are photo-sensitive until they fully form a colony, meaning that UV light from the sun will cause considerable harm within the first 3-5 days if the unit is not properly protected from the sun.

In chapter 4 (Unit Design), we discussed all the different types of grow media that can be used for hosting bacteria colonies in aquaponics, including: expanded clay, river bed gravel and volcanic gravel (which is the preferred media due to its high surface area, light weight and low cost).

Finally we learned about the key processes involved in maintaining a thriving bacteria colony for the three methods of aquaponics explained in depth in this manual: 1) Flood & Drain method and 2) DWC and NFT method. Bell siphons for media bed units are essential for replenishing oxygen levels in the media beds while bioballs and aerators in DWC and NFT units (small plastic pieces with high surface area) are used to grow bacteria.

Although nitrifying bacteria groups are central to aquaponics, there is a whole workshop of other bacteria groups and micro-organisms involved in aquaponics. These other bacteria groups are mainly involved in the decomposition of solid fish and plant waste. It is not essential to understand every micro-organism involved, but it is important to discuss one other bacteria group – the heterotrophic bacteria group, who secure all other nutrients for plants in aquaponics.

## 2) Other Bacteria and Micro-organisms Involved in Aquaponics and Their Importance

### Heterotrophic Bacteria and the Mineralisation Process

As previously explained, nitrifying bacteria convert ammonia found in fish waste into nitrate for plants, but what about all other essential nutrients for plants like potassium, phosphorus or sulphur? How is it possible to secure enough concentrations of all these nutrients for vegetables as well?

The answer again lies in the fish waste. Most fish only use 25-30% of the food they eat meaning 70-75% of what they eat is released as waste containing a mix of proteins, carbohydrates, fats, vitamins and minerals. Also, fish release 2 major types of waste:

**Dissolved waste** (50-70%): which is essentially pure ammonia released in the urine.

**Solid waste**: Organic matter containing all other essential nutrients.

Now, the nitrifying bacteria consume the dissolved waste (ammonia) but other bacteria such as **heterotrophic bacteria** and fungi (which will also naturally live in aquaponic units once organic waste is present) help decompose the solid waste, releasing all the other nutrients locked in the solid waste into the water. This process is called **the mineralisation process** and it is essential as plants cannot take up nutrients in solid waste form. They must be broken into simple elements to be absorbed by plants' roots.

Heterotrophic bacteria feed on any form of organic material such as solid fish waste, uneaten fish food, dying plants, dying plant leaves and even dead bacteria, so there are many sources available for food in an aquaponics unit. As with the nitrifying group, heterotrophic bacteria will colonise in all components of the unit. Yet there will be a concentrated group at the wet and dry (middle zone) & wet zone (bottom zone) of the media beds in the Flood and Drain units as most of the solid waste and uneaten food will settle there.

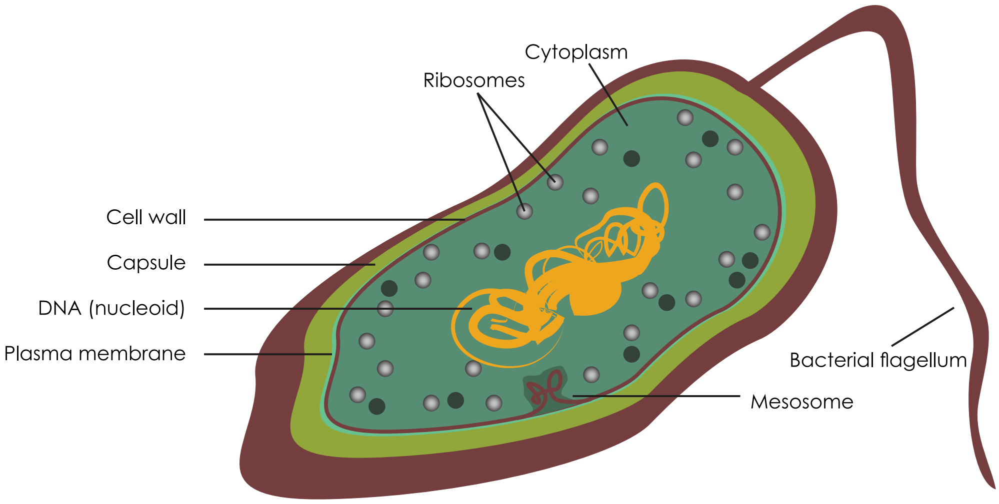


**Fig. 5.2 Diagram of Heterotrophic Bacteria**

So, although nitrifying bacteria are vital for securing nitrate for plants, heterotrophic bacteria groups and other micro-organisms involved in the decomposition of fish waste all play a pivotal role in securing all other nutrients locked up in the fish solid waste.

## 3) Starting an Aquaponics Unit: 'System Cycling'

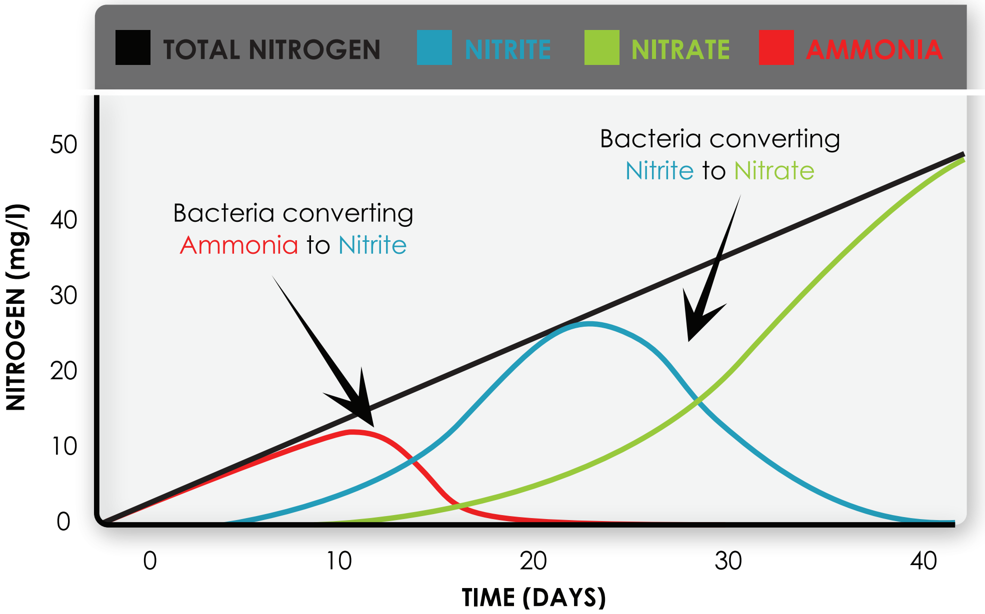
System cycling is a term that describes the initial process of building a bacteria colony when you first start an aquaponics unit. Normally, this is a 3-4 week process that involves soaking an ammonia source in your unit to attract and grow sufficient colonies of nitrifying bacteria. In aquaponics it is a one-off process, that takes place at the very beginning. It is important to understand the biological processes that occur during the first 3-4 weeks, as these temporarily involve high levels of ammonia and nitrite, which could be harmful to fish if they are placed into the system too early.

**The 3-4 Week Process**

Once the pump has been switched on and the water begins to circulate through the unit, an ammonia source is then added to the system water. Once integrated into the unit, the ammonia sets off a series of processes starting with the attraction of the first nitrifying bacteria group, the Nitrosomonas, which is naturally living in all the environments (land, water and air). Within 5-7 days from the start of the process, following the raising ammonia concentrations from continuous addition of $NH_3$, the Nitrosomanas bacteria start forming a colony and begin to oxidize (or consume) the ammonia into nitrite.

After another 5-7 days the nitrite levels in the water will have started to rise, which in turn attracts the second bacteria group, the Nitrobacter. As the Nitrobacter populations increase, the nitrite levels in the water begin to decline due to the active oxidation to nitrate carried out by this second bacteria group. The full process is illustrated in the diagram below that shows the trends of ammonia, nitrite and nitrate in the water over the first 20-25 days.

Fig 5.3 Graph Depicting the Ammonia, Nitrite and Nitrate Levels Over the First 3-4 Weeks




After a period of about 25-40 days (when the nitrite levels begin to decline to zero and the ammonia levels are virtially at zero) the aquaponic systems is at the end of its 'cycling' process (If the water temperature is below 17°C during this process it may take up to two months to finish). This means that a sufficient bacteria colony has formed and is actively converting the ammonia to nitrate. The reason for this long process is due to the slow growth of the nitrifying bacteria: both Nitrosomonas and Nitrobacter may take up to 10-15 hours to double their population, given optimum growth conditions, while heterotrophic bacteria can double in number as short as 20 minutes time as in the same water conditions.

## Using an ammonia source:

There are some ammonia sources that you can use to start the 'cycling process' including:

1) Decaying fish food

2) Decaying dead fish

3) Sterilised Animal waste (Chicken or Fish faeces)

4) Common fertilizers sold at shops (ammonium nitrate)

5) Household Ammonia (not containing detergents, colorants or other chemicals)

Fig. 5.4 Fish Food (Ammonia Source)

This list is by no means exhaustive as virtually any nitrogenous organic material or synthetic ammonia material can be used as an ammonia source. However, some sources are far better/safer to use than others. Stocking live fish can also be used as the source but it is **not** recommended unless under very low stocking densities (1kg/m3) with minimal feeding, as the brief spikes in ammonia and nitrite will negatively affect the fish, even leading to fish death.

**Fig. 5.5 Chicken Waste (Ammonia Source)**

The least problematic ammonia source to be used during the cycling period is decaying fish food (that is new and disease free) as it is a biologically safe product and it is relatively easy to control the amount of ammonia being added. Chicken waste, despite being an excellent ammonia source, can be **very risky** as harmful bacteria such as E Coli and Salmonella naturally present in every warm blooded animal, can be introduced into the system. Therefore it must be sterilised before use. Household ammonia products can be used but harmful chemicals may be included in the product solution such as detergents, colorants or other heavy metals. So make sure to use a solution that **only** contains ammonia, and **no** other ingredients.

Once you have selected your ammonia source, there are some important management considerations to follow: (The below example uses decaying fish food)

- Once you have added decaying fish food to the system, begin testing the water for ammonia, nitrite and nitrate every 2-3 days so you can track the process along the graph above.

- **It is very important not to over-soak your unit with ammonia**. High levels of ammonia (1-2 mg/litre), negatively impact the bacteria and will inhibit bacteria at levels above 6 mg/litre. Start by adding 20-40grams and continue adding more fish feed as the ammonia levels are recorded. It's better if it's a bit low than a bit high.

- If very high concentrations of ammonia (above 3 mg/litre) are recorded during the initial 5-10 days of cycling, it is suggested to remove up to 1/3 of the water and replenish with fresh water in order to dilute the concentrations and avoid harming the newly forming colony. Do this everytime ammonia is above 3 during the cycle.

- Although staying vigilant regarding the ammonia concentration, make sure you are still continually adding small amounts of ammonia most day so the newly forming colony continues to grow

- Finally, if the temperature and pH are not ideal for bacteria, system cycling could take longer than explained above, as the bacteria grow at a slower rate.

**Adding Fish and Planting During the 'Cycling' Process:**

**Fig. 5.6 Adding Plants into the Bed**

**Vegetables** can be planted once the nitrite levels drop to roughly 1 mg/L during the cycling process (as high nitrite levels, >2mg/L are toxic to plants) but expect some deficiencies to occur during this period, as other nutrients will take time to reach optimal concentrations.

**Fish**: Obviously it is problematic to add fish during the first two weeks as ammonia and nitrite levels will temporarily spike, which may lead to toxic levels for fish. Only when ammonia and nitrite levels are below 1mg/liter it is safe to start stocking your fish. This will normally take 20-25 days and can be easily tracked using the water test kits.

Once fish have been stocked it is not uncommon to see a secondary and smaller ammonia and nitrite spike. This will happen if the ammonia created from the newly stocked fish is much greater than the daily ammonia amounts added during the cycling process.

*****There are several products containing living nitrifying bacteria in a bottle available to buy at aquarium or aquaculture retailers. Once added to the unit they will immediately colonise in a system thus avoiding the cycling process explained above. However these products may be expensive or unavailable and ultimately unnecessary and the cycling process can be achieved using organic means.

## 4) How Do We Know the Bacteria are Working Well?

Seeing as how important bacteria are to aquaponics, it is vital to know the overall health of the bacteria at any given time. As bacteria are microscopic organisms, it is impossible to see them without a microscope, (although a bio-film full of bacteria can be seen on the surface of bioballs a couple of months after a unit is started). However, there are simple methods to make sure the bacteria are present and functioning well.

The most basic and obvious approach is to make sure all 5 factors for optimum bacterial growth are accounted for (i.e. pH at roughly 7, water temperature between 17 & 30 °C etc., surface area, Dissolved Oxygen and a constant ammonia source). If so, then it is safe to say that the bacteria alive and present in the unit.

**Fig. 5.7 Ammonia Test Kit Showing a Small Increase in Ammonia Levels (0.25-0.5 mg.l)**

Another more accurate method is to test the water for ammonia and nitrite**.** In chapter 2 (Water Quality), we learned how simple water test-kits are an essential management practice for aquaponics. Ammonia and nitrite, two of the four mandatory water tests, are also excellent indictors for bacteria health. Ammonia and nitrite will always read 0-1 mg/L in a functioning and balanced aquaponics unit as they are both being constantly converted by the nitrifying bacteria. If they're not in this range, but higher and increasing over time, then something is wrong with the bacteria.

There are two major reasons for this: 1) **there is too much fish waste being produced,** and conversely there are not enough bacteria established in the biofilter to convert ammonia to nitrate. This suggests an unbalance between fish, plants and bacteria, which is most likely caused by overfeeding the fish, having too much fish in the unit, or both.

If the unit is balanced, then: 2) **the bacteria are not functioning properly**. If this is the case, then go through each water parameter to make sure they are all within the optimum levels. The most probable cause can be ascribed to the fall of water temperatures in fall-winter, which slows down the bacteria efficiency in converting the waste to nitrate. Remember, nitrobacter reproduce slowly in colder temperature.

## Chapter Summary

- The nitrification process occurs as follows:
  - Nitrosomanas bacteria convert ammonia into nitrite
  - nitrobacter bacteria convert nitrite into nitrate.

- The 5 most important factors for good nitrifying bacteria are as follows: high surface area media for bacteria to grow and colonise; pH (6-7); water temperature (17-34°C); dissolved oxygen (4-8 mg/L); cover from direct exposure to sunlight
- While the nitrifying bacteria consume the dissolved waste (ammonia) other bacteria strains, such as heterotrophic bacteria, (naturally present in aquaponic systems once organic waste is accumulated) help the system to build up the plant nutrients pool through the miner alization of the fish waste
- 'System cycling' describes the initial process of building a bacteria colony when a new aquaponic system is set up. Normally, this is a 3-4 week process that involves soaking an ammonia source in the system to favour the colonization by nitrifying bacteria. Decomposing fish food or plain household ammonia (with no added chemicals) can be used as a source of ammonia but attention should be paid to avoid water concentrations above 5 mg/l. It is not reccommended to add fish until the unit is fully cycled.
- Ammonia and nitrite tests can be used to check that your bacteria are functioning properly. If they are, ammonia and nitrite levels should be close to zero mg/L. If either ammonia or nitrite is high it is suggested to change, 1/3 of the water immediately and figure out the source of the problem. In many cases the reduction in nitrification is due to sub optimum water temperatures, DO levels or pH levels.

# Chapter 6) Growing Vegetables in Aquaponic Systems

## Chapter Introduction:

In this chapter we will be discussing all the theory and most of the practice needed to insure successful plant production in aquaponic systems. We will first begin by highlighting some of the major differences between ground-grown crop production and soilless crop production. This section will give the reader a good framework on this relatively new method of crop production to build on. Following this, there will be a discussion on some essential plant biology and plant nutrition concepts all-the-time focusing on the most important aspects for aquaponics. After, there is a brief section on recommendations for selecting vegetables to grow in the units. The final two sections will cover plant health, methods to maintain plant health and some advice on how to make the most of your plant growing space.

Other essential information on aquaponic plant production will be covered in Chapter 8 and in the annexes at the end of this manual. Chapter 8 will cover all plant management practices essential to grow over a season(s) including planting methods for each hydroponic method mentioned in chapter 4 (Media Bed, NFT & DWC). Attached in the annexes is a 12-page technical description of the 12 most popular vegetables to grow in aquaponics along with a table on companion planting advice.

### 1) Initial Remarks on Growing Plants:

- Vegetable production in aquaponics will more than likely be the most profitable part of your system, unless you choose to grow a particularly valuable fish. Estimates from commercial aquaponics units suggest that up to 90% of the financial gains come from the plant production.

- It is important to follow the local seasonal planting practices in the area where your unit is placed. To a certain extent, aquaponic food production methods enable you to extend past soil grown planting seasons, particularly if the system is housed inside a greenhouse (as this allows for better control of the water temperature, which can be set to optimal ranges for plants and fish). Despite this being the case it is still recommended to generally follow local seasonal crops and practices to avoid plant stress and ensure successful plant production..

- It is **not** possible to use standard chemical pesticides on plants growing in an aquaponics unit as they can be fatal for fish. Furthermore some of the organic insecticides available are not applicable in aquaponics because they can equally harm the fish. In this chapter we will discuss safer methods to protect your plants by using organic means. Also, It is important to highlight now that when growing plants in aquaponics units or in any other organic production set up, there needs to be a different mindset to plant production and protection. Rather than assuming plants need outside help to grow, it is better to adopt a more 'pro plant' mentality, meaning a great way an aquaponic farmer can protect his plants is to secure all the essential nutrients in their optimum quantity, so the plants can protect themselves using their own biological defense systems.

  Having said this, there still some disease and pest threats that plants can't remove on their own regardless of how well their fed, thus prevention is still paramount. (e.g. netting, ventilation, temperature and humidity control). It is also important to use all the physical and biological tools that help the plant to grow healthy and vigorous (e.g. insect predators, insect traps, repellents, some organic insecticides, micro organisms against fungal diseases or pests).

## 2) Major Differences between Ground-Grown (Soil) and Soilless Crop Production:

Fig 6.1 Tomatoes Growing in Soil; Fig 6.2 Swiss Chard Growing in NFT Pipes (Soilless Culture)

Before beginning to explain how to grow plants in aquaponics, we need to explain the major differences between soil and soilless production, in order to bridge the gap between traditional ground-grown practices and new soilless techniques.

### 4 major Differences:

1) **Fertilization approach:** Despite the possibility to top up the soil with fertilizers, farmers cannot fully control the delivery of nutrients to plants, as in soil the process of nutrient availability at the root zone is regulated by complex biotic (living creatures) and abiotic (non living factors: water, oxygen particle size) interactions. Yet, for soilless culture, nutrients are dissolved in a solution that is delivered according to plant needs. Plants in soilless culture grow in contained inert media that physically supports the plants and keeps the roots wet and aerated; this inert media does not interfere with the delivery of nutrients, which occur in soil. This tailored management for soilless has two main advantages:

A. Optimized use of water/nutrients as minimal loss of nutrient solution due to leakages, percolation or evaporation.

B Nutrient concentrations can be adjusted at a given rate and time according to the growth stage of the plants which will improve productivity and increase the quality of the products (firmer and bigger fruits, longer shelf-life, reduced content of residues, higher content of vitamins in fruits)

2) **Water use:** Water use in hydroponics and aquaponics is much lower than soil production. Water loss in soil through evapo-transpiration, percolation, runoff and weed growth can render soil-based fertilizers highly inefficient with up to 50-80% nutrient loss. Thus, soilless cultivation has great potential to allow production wherever water is scarce.

3) **Productivity/yield:** Soilless culture can achieve 20-25% higher yields than intensive soil-based greenhouse management using expensive inputs to sterilize and fertilize the plants. Yet, in standard outdoor soil farming conditions hydroponics can be 2-10 times more produc-

tive than soil. This is due to the fact that in soilless culture, optimal conditions for plant roots (Ph, temperature and nutrient concentration) can easily be achieved.

Also, in soilless culture higher plant production densities can be achieved compared with soil. Speaking generally, all cultivated plants are spaced apart from each other as they compete with one another for light, growing space, water and nutrients. Yet in soilless culture, as there is no competition for water or nutrients, and no weeds to use available nutrients, plants can be spaced much closer together (roughly half the space) than the space required for soil grown production.

4) **Utilization of non-arable land:** Soilless culture methods and be used in urban and peri-urban areas on the ground floor or on rooftops and in areas where traditional agriculture cannot be employed due to aridity, salinity, poor soil quality or land unavailability. Urban based agriculture can also reduce the production footprint as transport needs are greatly reduced.

### Other minor differences

**Workload ease:** Soilless culture removes the need for ploughing, tillage and mulching to control weeds which also means less reliance on fossil fuels to power traditional agriculture machinery. Harvesting is also a simple procedure compared with soil based agriculture. Yet the cost of set-up and the relative initial workload required to prepare the plants may discourage farmers from adopting this method

**Sustainable monoculture:** For soilless culture production, it is entirely possible to grow crops in monoculture year after year avoiding the issue of soil tiredness and the need to set crop rotations to restore soil fertility and control the levels of pests and pathogens.

The “Pros and Cons For Soilless Vegetable Production” table below shows some of the other minor differences between soilless culture and ground-grown crop production.

**Table 6.1 Summary Table Comparing Soil and Soilless Plant Production**

| | Soil | Soilless |
|---|---|---|
| **Production** | | |
| 1. Yield | Variable, depending on soil characteristics and management | Very high, 2-10 times more & high density crop productio |
| 2. 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 factors that impair root growth in soil: (soil compaction, shortage of water, insufficient soil aeration). |
| 3. 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** | | |
| 1. 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 & accurate supply of nutrients according to plants’ growth stages. Needs monitoring and expertise. |
| 2. Nutrient use efficiency | Fertilizers widely distributed with min. control of nutrients according to growth stage. High nutrient loss due to leaching and runoff | Minimal amount used. Uniform distribution and real time adjustable flow of nutrients. No leaching. |
| **Water use** | | |
| 1. System efficiency | Very sensitive to soil characteristics, possible water stress in plants, high dispersal of nutrients | Maximized, all water loss can be avoided. Supply of water can be fully controlled by sensors. No labour costs for watering. |
| 2. Salinity | Depends on soil and water characteristics. Can use saline water, but needs salt flush out that needs alot of water. | Can use moderately saline water.<br><br>Concentrations in nutrient solution (hydroponics) can be adjusted to provide salt flushing out |
| **Management/costs** | Standard, but machines are needed for soil treatment (ploughing) and harvesting which rely on fossil fuels. More manpower needed for operations. | Simple harvesting methods as plants can be waist height. Expertise and daily monitoring using relatively expensive equipment are both essential.<br><br>High initial set up cost due to setting up of protected environment, nutrient delivery and monitoring equipment. |

## 3) Basic Plant Biology

It is not within the scope of this manual to go into huge detail regarding plant biology. Instead, we will briefly comment on the major parts of the plant and then focus on plant nutrition, as well as providing information on how to grow plants using just water and media.

### i) Basic Anatomy and Function:

**Roots:** Roots act like straws, absorbing water and minerals from the soil. Tiny root hairs stick out of the root, helping the absorption process. Roots help to anchor the plant in the soil, preventing it from falling over. Roots also store extra food for future use. *N.B. Root adaptation in soilless culture: As water and nutrients are constantly available to the plants in soilless culture, there is little need for plants to send out large tap roots in search of these. Instead, plant roots adapt to their environments and begin to grow shorter and more fibrous roots.*

**Stem:** Stems do many things. They support the plant. They act like the plant's plumbing system, conducting water and nutrients from the roots to other parts of the plant, while also transporting glucose from the leaves to other areas. Stems can be "herbaceous", like the bendable stem of a daisy, or "woody" like the trunk of an oak tree.

**Leaves:** Most of the food for plants is produced in their leaves. Leaves are designed to capture sunlight, which the plant then uses to make food through a process called *photosynthesis*.

**Flowers:** Flowers are the reproductive part of most plants. Flowers contain pollen and tiny eggs called ovules. After the pollination of the flower and fertilization of the ovule, the ovule develops into a fruit.

**Fruit/Seeds:** Fruit provides a protective covering for seeds, and allow the seeds to form. Fruit can be fleshy like an apple or hard like a nut. The seeds found in the fruit contain the building blocks for new plants.

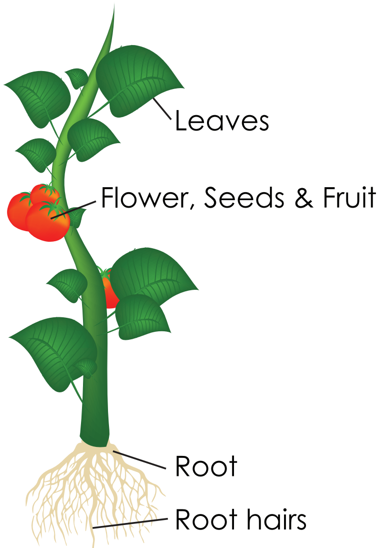



**Fig 6.3 Basic Plant Anatomy**

### ii) Sourcing Nutrients: Photosynthesis

Plants are organisms that need oxygen, carbon dioxide, water and light to grow. All green plants are designed to generate their own food using the process of photosynthesis. This process employs the combination of water ($H_2O$), carbon dioxide ($CO_2$) and sunlight (energy), in order to create simple sugars (glucose) that will be transported throughout the plant.

So, as explained in the section on site selection in Chapter 4, it is vital to locate your unit in a place where each plant will have access to either full or shaded sunlight for at least 8 hours per day. This will ensure good plant production.

Along with the energy produced by photosynthesis, plants need a number of nutrients (inorganic salts), that are normally sourced from the soil. Therefore, in soilless culture (aquaponics), we need to supply these additional essential nutrients using fish waste.

During the night, plants use the sugars created during the day through photosynthesis and oxygen to generate the energy needed for growth. This process is called respiration.

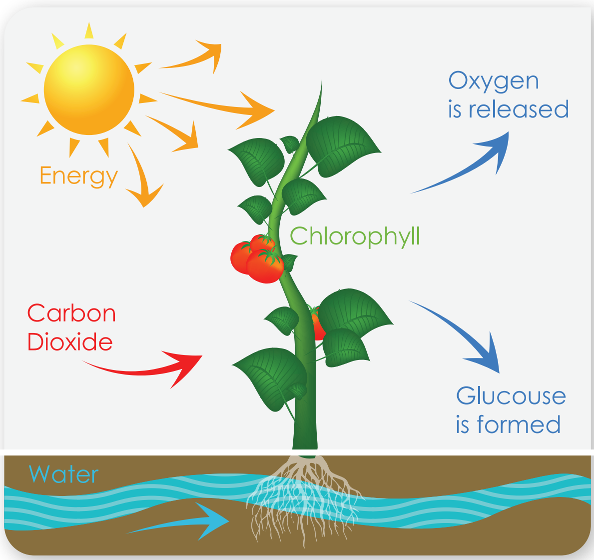



**Fig 6.4 The Photosynthesis Process**

**iii) Other Nutrient Requirements:**

There are two major categories of nutrients: **macronutrients** and **micronutrients.** Each of these types of nutrient are essential for plants, but in differing amounts. Much larger quantities of the 6 macronutrients are needed compared to the micronutrients (micronutrients are only needed in trace amounts). All of these nutrients exist in solid fish waste, although some element may be limited in quantity such as potassium, calcium and iron. As we learned in Chapter 5, fish waste is either dissolved or broken down by heterotrophic bacteria into simple elements, that the plant roots can then absorb from the water.

It is important to gain a very basic understanding of each nutrient, in particular the macronutrients, and to understand how they will impact plant growth. As **nutrient deficiencies** occur, you will then be able to identify which element is absent or lacking in the system.

**Major/Macro Nutrients:** Below is a list of the 6 macronutrients with brief notes on their function. We have also listed indicators/signs to help you spot when a plant may be deficient in a particular macronutrient.

- **Nitrogen (N):**Essential for plant cell growth, photosynthesis, metabolic processes and the production of chlorophyll (the green pigment of the plant responsible for photo synthesis). It also helps leaf and stem growth.

  **Deficiency:** Yellowing of old leaves; new leaves and stem may be a pale green co lour.

- **Potassium (K):** Helps build plant protein. It is involved in the production and transpor tation of sugars, water uptake, disease resistance and the ripening of fruits.

  **Deficiency:** Plant will stop growing. Floral abortion or limited fruit setting. Fruit will not develop.Older leaves may wilt and look scorched. Interveinalchlorosis begins at the base, scorching inward from leaf margins

- **Phosphorus (P):** Essential part of the photosynthesis process and formation of oils and sugars. It encourages germination and growth of seedlings and roots. It also aids fixing light energy in plants.

  **Deficiency:**Slow growth rates and production of smaller leaves that will wilt. Leaf tips appear burnt, older leaves begin turning dark green or reddish-purple.

- **Calcium (Ca):** Essential for nutrient transport and plant strength. Involved in the pro duction of plant cell walls. Strengthens stems/stalks/branches and contributes to root development/growth. Ca is required for the absorption of nitrogen.

  **Deficiency:** New leaves at the top of plant are distorted with either hooked tips or are irregularly shaped. Tip burn in leaves or tip rot in fruits (tomato).

- **Magnesium (Mg)**: Used in the production of chlorophyll and the photosynthesis pro cess. Contributes to healthy leaf structure through activation of plant enzymes.

**Deficiency**: Older leaves turn yellow between the leaf veins. The rest of the leaves remain green.

- **Sulphur (S):** Essential for the production of proteins, chlorophyll, enzymes and vitamins. Improves root and vegetative growth.

  **Deficiency:**Stunted growth-rates. Leaves will become yellow, stiff and brittle, and will fall off.

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

- **Iron (Fe):** Is critical for chlorophyll formation and photosynthesis.
- **Manganese (Mg):** Enzyme catalyst that aids photosynthesis/chlorophyll production.
- **Boron (B)**: Helps movement of sugars, reproduction and water intake by cells. Also contributes to leaf-production, colouring, and structure.
- **Zinc (Zn)**: Affects plant-size and maturation, as well as the production of leaves and stalks/stems/branches.
- **Copper (Cu)**: Strengthens stalks/stem/branches and is crucial for reproduction.

  **Molybdenum (Mo):** Helps in the use of nitrogen

**Below are pictures of 4 common nutrient deficiencies seen in aquaponics: nitrogen, potassium, sulphur and iron.**

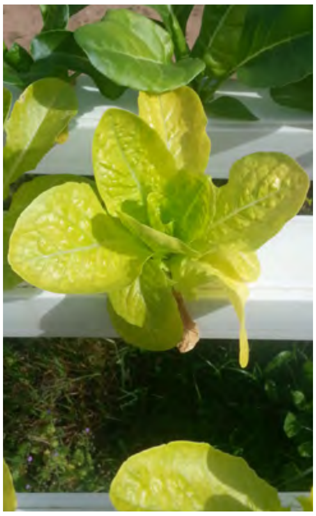



**Fig. 6.5 Nitrogen Deficiency; Fig. 6.6 Potassium Deficiency; Fig. 6.7 Sulphur Deficiency; Fig. 6.8 Iron Deficiency**

It is not in the scope of this manual to go into further detail on plant deficiencies. For further illustrated details on them including methods on how to detect them please the further reading section at the end of this manual

### iv) Providing All Necessary Nutrients through Aquaponics

As we described in Chapter 5 (Bacteria), the nitrifying bacteria convert most of dissolved fish waste (mostly ammonia). The solid fish waste, on the other hand, is broken down by heterotrophic bacteria, and this releases all the other essential nutrients found in solid waste into the water.

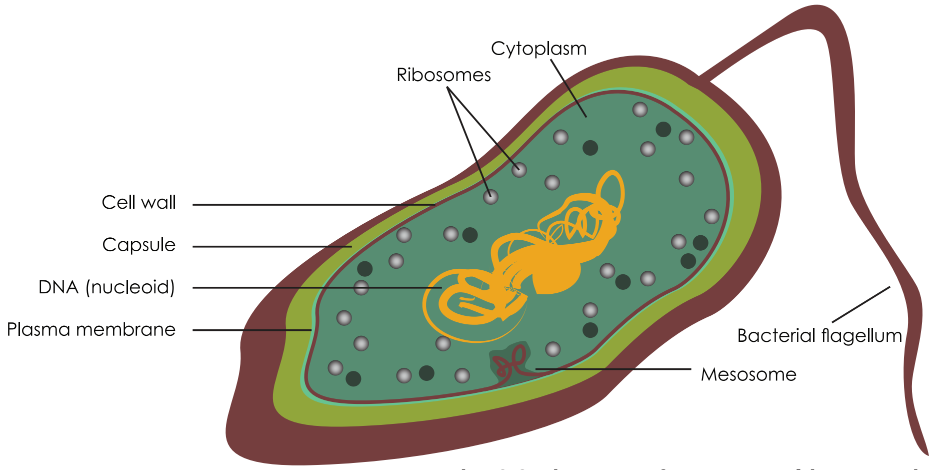



**Fig. 6.9 Diagram of Heterotrophic Bacteria**

The best way to ensure that plants do not suffer from deficiencies is to maintain the optimum water pH (6-7) and feed the fish a balanced and complete diet. However, over time, even a high capacity aquaponics system that is perfectly balanced in terms the amount of the daily amount of fish feed relative to the growing space, may become deficient in certain nutrients – generally, iron (Fe) potassium (K), calcium (Ca). Deficiencies in these nutrients are due to the composition of the fish feed. As we will learn in Chapter 7, fish food pellets are a **whole food,** meaning they provide everything that a fish needs to grow, but not necessarily everything needed for plant growth. Fish simply do not need the same amounts of iron, potassium and calcium that plants require. As such, deficiencies in these nutrients may occur in units.

Although this can be problematic for plant production, there are sustainable solutions available. In Chapter 9 we will discuss how to produce simple organic fertilizers from compost to use as supplements to the fish waste, ensuring that your plants are receiving the right amount of nutrients.

## 4) Water Quality for Vegetables

We discussed optimal water quality parameters for all 3 organisms in Chapter 3. Here we will briefly summarize these and expand on some of the parameters that refer specifically to plants:

### A) Water Quality Needs for Plants

- **pH**: **pH** is probably the most important parameter for plants, as it controls a plant's access to nutrients (see diagram on right). In general, the tolerance range for most plants is between pH 5.5-7.5; this is lower than the tolerance ranges for fish and bacteria. If the pH goes above 7.5 or below 5.5, plants will experience "nutrient lock out" as they will no longer be able to absorb some essential nutrients. The diagram to the left describes this relationship between pH level and the ability for plants to "take up" certain nutrients.

- **Dissolved Oxygen (DO):** Plants need high levels of DO (>3 mg/L.) Plants can take in oxygen from both water and air.

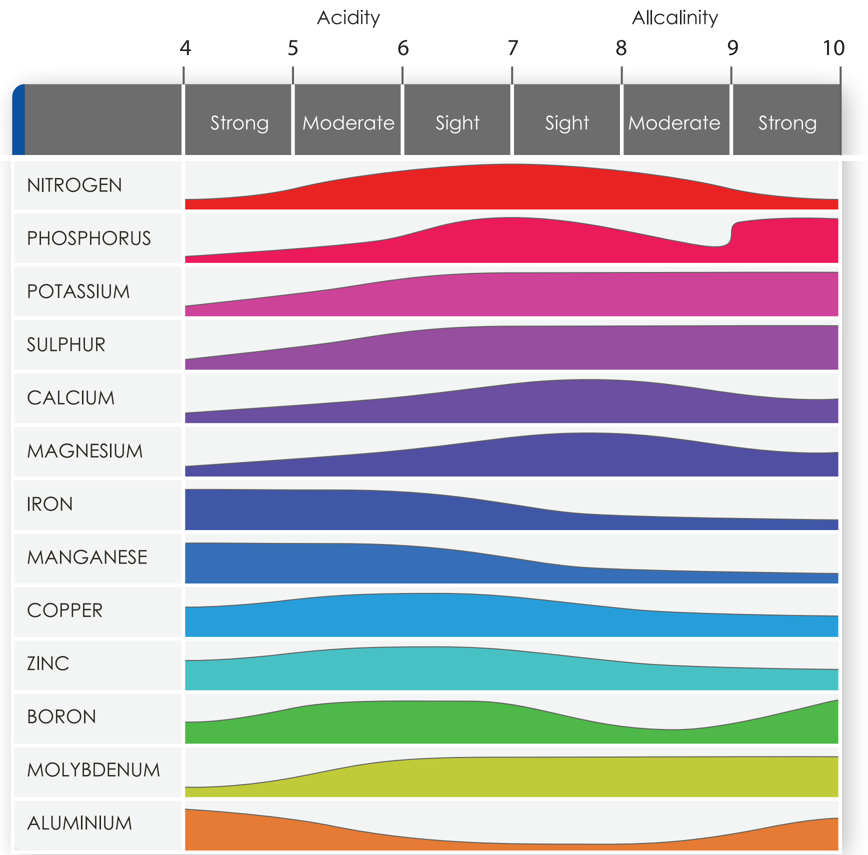



**Fig. 6.10 The Impact of pH on Nutrient Availability in Water**

- **Temperature**: The suitable temperature range for most vegetables is 18-30°C. However, some vegetables are far more suited to growing in particular seasons. Win ter vegetables require temperatures of 8-20°C, and summer vegetables require tem peratures of 17-30°C. For example, leafy green vegetables grow best in cooler condi tions (14-20°C). In higher temperatures of 26°C and above, leafy greens will bolt (begin growing to produce seeds). As such, it is important to follow the local seasonal planting practices for each vegetable you want to grow (see Annex for further details on individual vegetables).

- **Ammonia** ($NH_3$) **Nitrite** ($NO_2$) & **Nitrate** ($NO_3$): As previously explained in Chapter 2, plants are able to take up all 3 forms of nitrogen, but nitrate is the most accessible (although nitrite is toxic to plants above 1gm/L). In a functioning aquaponics unit, ammonia and nitrite will always be 0-1 mg/L.

## 5) Selecting Vegetables for Aquaponics

To date, over 150 different vegetables, herbs, flowers and small trees have been grown successfully in aquaponic systems (both in terms of research and domestic/commercial units). A 12-page technical summary of the 12 most popular herbs and vegetables to go can be found in the annex of this manual. Each page gives details optimum conditions and growing instructions.

In general, leafy green plants do extremely well in aquaponics along with some of the most popular fruiting vegetables: tomatoes, cucumbers and peppers, although best fruiting is achieved when the potassium concentrations equal those of nitrogen (N:K ratio is equal to 1). However, some root crops as well as plants that normally grow poorly in saturated conditions will not grow well in aquaponics.

The major categories of vegetables that are grown repeatedly in aquaponic units are as follows:

- **Leafy Green Vegetables and Herbs**: Lettuce mixes (all types), chards, arugula (rocket), spinach, pak-choy, basil, mint, parsley, coriander and chives.
- **Root and Other Large Vegetables**: Spring onions, bulbing onions, beetroots, kales, cauliflower, broccoli, carrots, fennel, turnip, cabbage, leeks, kohlrabi
- **Fruiting Vegetables**: tomatoes, cucumbers, eggplant, zucchini, okra, strawberries, sweet peppers, chilli peppers.
- **Legumes**: Types of peas (snow pea, sugar snap pea), types of beans (broad, long & Asian beans)

**Recommendations for Vegetable Selection:**

- In media Bed units, it is common practice to grow a polyculture of leafy greens, herbs and fruiting vegetables at the same time. Monoculture practices are more prevalent in commercial NFT and raft units as the grower is restricted by the number of holes in the pipes and rafts in which to plant vegetables.

- Vegetables vary regarding their overall nutrient demand. There are two major cate gories: **Low/medium nutrient demand** (such as lettuce, pak-choy, basil, beans) and **high nutrient demand** (such as tomatoes, eggplants, cucumbers and peppers). It is recommended to plan every square meter of growing space in your unit in order to calculate the necessary feed ratio (based on the fish Feed Rate Ratio discussed in chapter 2 and 8). This will ensure that the plants' nutrient demands are met.

**Fig. 6.11& 6.12 High Nutrient Demand Vegetables Growing in Grow Beds (Eggplants, Tomatoes and Cauliflower)**

Ensure continual harvesting and replanting: Although this will be covered in detail in Chapter 8, it is worth noting now that it is important to stagger the planting in your unit to prevent having to harvest your crop all at once. If this happens, nutrient levels may spike post harvest, which may stress the fish. Staggering the planting will help maintain a balanced water chemistry.

- Provided Media Bed units are the right depth (at least 30 cm), it is possible to grow all the vegetables mentioned in the four categories above.

- Using NFT units, it is possible to grow the larger fruiting vegetables, such as tomatoes, but they will need to be planted over a larger distance than leafy vegetables. This is firstly because fruiting plants grow bigger and need more light to ripen their fruits and secondly because there is limited root space in the pipes. Also, when using NFT units, it is not recommended to grow larger bulb and/or root crops, such as: kohlrabi, carrots and turnips.

## 6) Plant Health & Pest Control

So far in this chapter we have mentioned plant health with regard to securing plant nutrients in aquaponic units. We also highlighted in the introduction of this chapter the 'pro plant' mentality for aquaponic food production, meaning that the best practice for ensuring healthy and protected plants is to secure all the essential nutrients in their optimum amounts – **this will enable the plant's own biological defence mechansims to protect itself**. However, despite this, plant diseases and pests can still occur. The major diseases are either fungal, bacterial or parasites. The common way to deal with these is :

1. prevent disease outbreaks by controlling the environmental conditions (ventilation, humidity, planting density, and by securing a balanced nutrition of plants by avoiding excess of nitrogen)

2. Use (fish-safe) products certified for organic agriculture. They could be ascribed into two main groups:
   a. Inorganic: such as sulphur, potassium carbonate, clay and other extracts, mostly efficient against fungal diseases.

b. Biological: such as Thricoderma, Ampelomicesspp, bacillus subtilis.
They can be used either to leaves or at root level. They can provide an efficient protection against the most common soilborne diseases, the downy mildew, powdery mildew and some bacteria.

3. Provide tools for exclusion by removing infected leaves, branches and if necessary the whole plant as soon as they become infected.

4. Enforce the control on potential sources of viruses such as whiteflies by growing plants in insect-proof structures.



**Fig. 6.13: Pictures of common diseases of vegetables:**

**Mildew (Fungus); Fig 6.14: Canker or Blight (bacteria); Fig 6.15: Leaf Spots (Bacterial or fungus)**

For more detailed information on common vegetable diseases please see the further reading section at the end of this manual.

**Fig. 6.16 & 6.17 Rooftop AquaponicProduction, Gaza City**


## Pest Control

Along with plant disease, pests can also be problematic, particularly in controlled environments such as greenhouses. As aquaponic units maintain an independent eco-system, it is normal for a number of insects and spiders to live within the media beds. However, some of these insects can be parasitic. The common practice to deal with problematic insects (pests) in ground-grown vegetable production is to use chemical pesticides, but this is **impossible** in the case of aquaponics. Any chemical-based pest control could be fatal for fish as well as the beneficial bacteria living in system. Therefore, **chemical pesticides can never be used**. Fortunately, there are other effective methods to remove the threat of pests for aquaponics.

- **Rooftop Food Production:** If your unit is placed at least two stories high (on a rooftop), this will remove the vast majority of pests that live at ground level. Essentially, the height difference creates a massive barrier for pests. However, rooftop systems will experience a greater threat from birds.

- **Yellow Stick Traps (Pest Inspection and Removal)**: As seen in the picture (right), coloured adhesive trap cards can be used to trap and kill any pests. They also let you see what types of pests are present.

**Fig. 6.18& Fig, 6.19 Yellow Stick Traps in a Greenhouse**

- **Manual Control:** On inspection of your plants, begin to trim and remove heavily infested leaves and discard completed highly infested plants. Periodically hose small plants with a strong spray and wipe leaves of larger plants with a soft, damp cloth. You can also physically remove large pests and feed them to the fish. Reapply these treatments regularly so that you can keep the pests under control.

**Fig. 6.20 Manual Removal of Pests**

**Fig. 6.21 Garlic Foliar Spray**

- **Bio-chemical Control**: Soft chemical alternatives to industrial pesticides can also be applied to control pests. Organic foliar sprays consisting of crushed garlic, pepper, soap and insecticidal oils can all be used to remove the threat of pests. Once diluted with water these organic alternatives can be applied. Thorough coverage of the plant is necessary for effective pest control. If using soaps make sure to use the most natural soaps, otherwise potentially harmful chemicals - found in synthetic soaps - can make their way into the water.

**Other examples include:**

1. **Lavender tincture foliar** spray made water that is boiled for a short time with lavender leaves. This will be effective against ants and prodania (leaf eating caterpillar.)

2. **Ash** white ash is a great fertilizer and it also re pels pests including ants and snails.

3. **Molasses Spray:** Mix molasses with water and organic soap and spay generously onto plants

**Fig. 6.22 Application of Garlic Foliar Spray on Plant Leaves**

## 7) Making the Most of Your Vegetable Production

In this final section of the chapter we will briefly discuss some tips and methods on how to maximize plant production in the space you have available. **Note**: *There are two sections below. Most of the methods in the first section apply mainly to the Media Bed Units, although not exclusively. The second section on companion planting methods, apply to both Media Bed, NFT and DWC units.*

### A) Media Bed Layout

Before you start planting, choose wisely which plants you want to grow, bearing in mind the space needed for each plant and what the appropriate growing season. A good practice is to design the layout of your beds on some paper in order to have a better understanding of how everything will look before you plant. Make sure to consider “easy access” to plants when you develop your plan. For example, taller crops (i.e. tomatoes) should be placed in the most accessible place within the media bed to make harvesting easier.

As mentioned above in *plant selection*, it is important to stagger your planting and then harvest and replant continually. This will help maintain a balanced level of nitrates in the unit. Keep in mind that some plants produce fruit or leaves that can be harvested continually throughout a season (such as salad leaf varieties, basil, coriander and tomatoes), whereas for some other crops, the whole plant is removed at harvest (kohlrabi, lettuce, carrots).

### *Encouraging Plant Diversity:*

In general more mixing of various crops and varieties provides a degree of security to the grower. All plants are susceptible to some kinds of disease or parasites. If you only grow one crop and this crop happens to develop problems then removing the whole crop will unbalance your unit – as there will be no plants to take up the nutrients. As such, it is encouraged to plant a diverse range of vegetables in small-scale units. This will ensure that in cases of problems, you will never have to remove all the plants in the unit

**Fig. 6.23 Example of 2 Grow Beds Growing Multiple types of Vegetables**

### *Maximizing Space:*

It makes sense to plant vegetables with short grow-out periods (such as salad leafs) between plants with longer-term crops (i.e. eggplants). The benefit of this practice is that you can harvest the salads before the eggplants get big. You can also continue to replant vegetables like lettuce in between large fruiting plants as the will enjoy the naturally shaded conditions created by the larger plants. Be careful that you do not create to much shade or your 'understory' crops may suffer and grow poorly.

Vegetables such as cucumbers are natural climbers who can be trained to grow up or down and away from the beds. Use wooden stakes and/or string to help support the climbing vegetables. This will create more space in the media bed.

**Fig. 6.24 & 6.25 Examples of Maximizing Space in Grow Beds**

## B) Companion Planting:

This final section briefly introduces the concept of 'companion planting'. This is very important to understand when growing intensive polyculture in aquaponics (or anything in soil). Companion planting is the constructive use of plant relationships by growers. For example, all plants produce natural chemicals that they release from their leaves, flowers and roots. These chemicals may attract or repel certain insects and can enhance or limit the growth rate and yield of neighbouring plants.

It is therefore important to be aware of which plants benefit from each other when planted together and which plant combinations are best avoided. Below is list of topics demonstrating how companion planting can be beneficial and the Annex (1) provides you with a companion planting table to use when choosing your crops. **Note:** *when using the companion table, concentrate on avoiding the bad companions rather than planning for good ones.*

**Physical Complementarity**: As previously discussed, many plants have special needs for sunlight or a lack of it. By combining crops like cucumbers (who like heat, moisture and shade) and corn (who enjoy heat and full sun), the cucumbers can enjoy the shade the corn produces, while both enjoy the heat.

**Sacrificial Planting ('catch crop'):** This is the method of planting a specific crop (i.e. Kale) that attracts pests amongst a primary crop. The idea is to intentionally sacrifice the pest-laden crop for the sake of the primary crop. The sacrificial plant can be even a plant growing outside of the aquaponic system (e.g. in a pot and positioned next to the bed. The advantage of is that it can be sprayed with chemicals with a systemic effect. So it will kill insects (especially aphids, leaf hoppers) who will come to drink the sap or eat the leaves.

**Bio-Chemical Pest Suppression**: As explained above, some plants release chemicals from their roots or leaves that either suppress or completely repel pests, which can serve to protect other neighbouring plants.

## Chapter Summary

- The major differences between soil and soilless agriculture are as follows: 1) fertilization approach; 2) water use; 3) productivity/yield; 4) utilization of non-arable land

- Along with the energy produced byphotosynthesis, plants need inorganic nutrients. Macronutrients include: Nitrogen, phosphorus, Potassium, Calcium, Magnesium and Sulphur; micronutrients include iron, zinc, boron, copper.

- pH is probably the most important parameter for plants, as it controls a plant's access to nutrients. If the pH goes above 7.5 or below 6, plants will experience "nutrient lock out" meaning they will no longer be able to absorb some essential nutrients.

- The suitable temperature range for most vegetables is 18-26°C. Some vegetables are far more suited to growing in particular seasons. Winter vegetables require temperatures of 8-20°C, and summer vegetables require temperatures of 17-30°C.

- In general, leafy green herbs and vegetables do extremely well in aquaponics. Other large fruiting vegetables are also applicable including tomatoes, peppers, eggplant, and cucumbers, peas and beans.

- Companion planting techniques should be applied to maximise the production within the grow beds and grow pipes.

- Ensure continual harvesting and replanting. Stagger the planting of your unit to prevent having to harvest your crop all at once. If this happens, nutrient levels will spike and stress the fish

# Chapter 7) Growing Fish in Aquaponic Systems

## Chapter Introduction:

Taking the same approach as chapter 6 on plant production, we will begin by discussing fish in general terms. The first section will include information on their anatomy, how they breathe, digest and release waste, their life cycle and reproduction. Second, we will discuss everything you need to know about caring for fish in aquaponic units. We will cover the following topics in relation to fish health: water quality, oxygen, temperature, light and nutrition. In part 3, we will identify the most applicable types of fish for aquaponics. These include tilapia, carp (including koi), catfish and trout. We will then make some comments on some applicable crustacean species also in aquaponics. The chapter will close with a final section on individual fish heath, diseases and disease prevention methods.

## 1) Initial comments about small scale fish production:

Before we begin learning about fish, we will make 3 introductory comments on growing fish in aquaponics that will help frame all you need to know about successful fish production:

1. Knowing how to maintain a stable and healthy environment for fish will make unit management much easier over a growing season. A healthy environment helps keep fish free from stress (i.e. stable pH, low ammonia and nitrite etc). We will learn more about fish stress as we work through this chapter.

2. Knowing the specific tolerance range & optimum fish growth rate for the type of fish you want to grow will ensure healthy and effective fish production.

3. Maintaining a low Food Conversion Ratio (FCR) is important for growing fish. The FCR is the amount of food needed to produce a given biomass of fish (e.g. kg of feed per kg of body weight gain). For Tilapia, an average FCR is 1.8 kg of food to produce 1 kg of biomass.

**Fig. 7.1 & 7.2 Tilapia Fish Growing in an Aquaponics Unit**