3) Enhancing Other Household Vegetable Production Activities Using Aquaponics

Irrigating vegetables:

Aquaponic units are a source of nutrient rich water for vegetable production. Although designed to grow plants within hydroponic component of the unit, aquaponic water can also be used as an excellent organic fertilizer for other soil based production activities within the household.

• Raised beds: For vegetables growing in raised beds or patches, aquaponic water can be periodically taken from the unit and irrigated onto the growing space, giving the soil a boost of essential nutrients for the vegetables.

• Satellite pots: If growing larger fruiting vegetables (i.e. tomatoes) using satellite pots in the garden or in any space with good access to sunlight, aquaponic water can also be used as a nitrate rich fertilizer partially during the early stages of leaf and stem development.

Fig. 9.13 Satellite Pots

Fig. 9.12 Raised Vegetable Beds

Irrigating Wicking beds:

• Wicking beds are another form of raised bed that has a water reservoir below the plant roots. The water is drawn upward into the root zone by capillary action meaning that there is no need for overhead watering and a lot less water is lost through evaporation.Roots growing in the moist soil have a continuous supply of water, oxygen and nutrients.

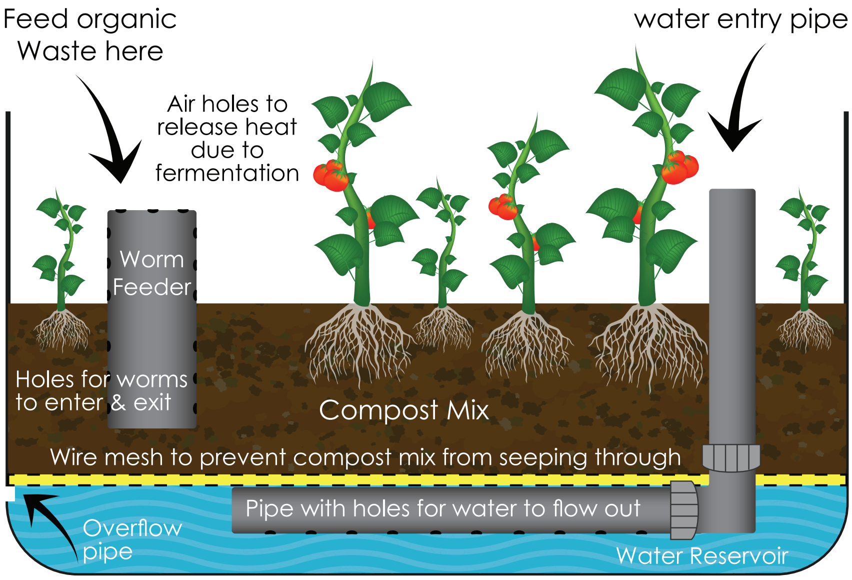


Fig. 9.14 Diagram of the Wicking Bed Production System

• Wicking beds are an excellent method of growing vegetables in arid, water scare regions as up to half of the water is needed compared with standard top down irrigation methods. Wicking beds can made our of water sealed containers or dug into the ground and sealed with PTDE liner that stores the water, making them ideal methods to produce food in arid- semi arid urban areas with little or no access to soil.

Fig. 9.15 Example of a Plastic Wicking Bed Container; **Fig. 9.16 Example of a Wood Wicking Bed Container**

Wicking beds can also be irrigated using aquaponic water. You can either periodically add new aquaponic water to the bed or integrate the wicking bed into the aquaponic unit allowing water to constantly flow through the bed.

For further information on the wicking bed concept please see the sources in the further reading section.

Further Reading:

Below is a list of useful publications and external links divided into specific topics discussed in this manual:

Aquaculture

• Timmons, M.B & Ebeling, J. (2010) Recirculating Aquaculture 2nd Ed. Northeastern Regional Aquaculture Centre, Cayuga Aqua Ventures

Bacteria & Microbes

• Lowenfells, J. & Lewis, W. (2010) Teaming with Microbes: 'The Organic Gardeners' Guide to the Soil Food Web', Timer Press Inc.

Bell Siphon Design & Construction

Below is an external for further information on the construction of automatic bell siphons for small-scale aquaponic systems by Bradley K. Fox (et al)2010:

http://www.ctahr.hawaii.edu/oc/freepubs/pdf/BIO-10.pdf

Black soldier Fly Larve

Below is an external link for further information on the construction of black solder fly Larae pods.

http://www.ie.unc.edu/for_students/courses/capstone/13/bsfl_how-to_guide.pdf

Compost Tea:

• Ingham, E. R. (2005) The compost tea brewing manual, 5th Ed Soil Food Web Incorporated

External Link: http://washington.osu.edu/cuyahoga/topics/agriculture-and-natural-resources/cuyahoga-composts/ Compost%20Tea%20Brewing%20Manual.pdf

DIY Aquaponic System manuals

Below are external links for two recommended aquaponics DIY (Do It Yourself) manuals:

• Barrel ponics: http://www.aces.edu/dept/fisheries/education/documents/barrel-ponics.pdf
• The IBC of Aquaponics: http://www.backyardaquaponics.com/Travis/IBCofAquaponics1.pdf

Greenhouses & net houses

• FAO (2013) 'Good Agriculture Practices for Greenhouse Vegetable Production: Principles for the Mediterranean Climate Areas', Plant Production & Protection Paper 217
• FAO (1999) 'Greenhouses and shelter structures for the tropics', Plant Production & Protection Paper 154

Plant Deficiencies and Diseases

External links for plant deficiencies:

http://landresources.montana.edu/nm/Modules/NM%209%20mt44499.pdf
http://5e.plantphys.net/article.php?ch=t&id=289

External links for plant diseases

http://plantdiseasehandbook.tamu.edu/
http://plantclinic.cornell.edu/factsheets.html

Soilless Culture

• Raviv, M. & Lieth, J.H. (2008) Soilless Culture: ‘Theory and Practice’ 1st Ed. Elsevier publishing

Wicking Beds

External links for wicking bed

http://www.waterright.com.au/wicking_bed_technology.pdf
http://www.waterright.com.au/Wicking%20worm%20beds.pdf

About the Authors:

Mr. Chris Somerville is an Irish national and an honors graduate from Trinity College Dublin and Dublin City University, with a BSc. in Natural Sciences and MA. In Development Studies. Since completing his education, he co-directed a 9-month urban aquaponics research project based in East Jerusalem (2010). This project focused on the feasibility of small-scale aquaponic systems for household/domestic food production in density populated urban areas.

Following this research project, Chris started working with the UN-FAO (January, 2012) where he led a pilot aquaponics project within a larger emergency food security project based in the Gaza Strip. 16 small-scale systems were installed on rooftops in Gaza City. Following on from the success of the initial pilot, he is now employed by FAO (July, 2012) to lead another urban agriculture project designed to expand the initial pilot of aquaponic systems and introduce other applicable soilless culture and sustainable agriculture interventions, such as small-scale hydroponic & wicking bed units.

He has also worked on projects with Applied Research Institute Jerusalem (ARIJ) in the West Bank (May, 2012). Here, he was working on a similar aquaponics pilot project based in the Bethlehem Governate of the West Bank. Along with small-scale systems installed at individual family homes, units were installed in the local agricultural college, Al Arroub, in Hebron. Within this project he advised on system design, monitoring and all aspects of beneficiary training and for the staff and students at Al Arroub College.

Mr. Moti Cohen is an Israeli national with an honours degree in Marine Biology from the Ruppin Academic Center in Michmoret Israel. He has worked on many innovative projects in the Aquaculture, Hydroponics and Water treatment industury.

Currently Mr Cohen is the owner/director of Livingreen Urban Eco-Systems, a private company that provides sustainable agriculture technologies and water treatment solutions at the household level.Aquaponics is the cornerstone of his company and he has established himself as the leading expert on small-scale & semi-commercial aquaponic units in Israel. He has designed and installed hundreds of units and has taught and led workshops on aquaponic food production every month for the past three years.

Moreover, Mr Cohen is providing technical support for a number of aquaponics project run by NGOs in the Middle East region. He is in consultation with professionals who are integrating aquaponics and hydroponics into emergency urban food security projects in Gaza and in the West Bank. He is also the lead designer for a commercial aquaponic and hydroponic system in Israel, while managing a technical forum for domestic hydroponic and aquaponic units.

Annexes

Small-scale Aquaponic systems

Annex 1: Companion planting chart

Table 1. COMPANION PLANTING CHART FOR HOME & MARKET GARDENING		
CROP	**COMPANIONS**	**INCOMPATIBLE**
Asparagus	Tomato, Parsley, Basil	
Beans	Most Vegetables & Herbs	
Beans, Bush	Irish Potato, Cucumber, Corn, Strawberry, Celery, Summer Savory	Onion
Beans, Pole	Corn, Summer Savory, Radish	Onion, Beets, Kohlrabi, Sunflower
Cabbage Family (Cauliflower, Broccoli)	Aromatic Herbs, Celery, Beets, Onion Family, Chamomile, Spinach, Chard	Dill, Strawberries, Pole Beans, Tomato
Carrots	English Pea, Lettuce, Rosemary, Onion Family, Sage, Tomato	Dill
Celery	Onion & Cabbage Families, Tomato, Bush Beans, Nasturtium	
Corn	Irish Potato, Beans, English Pea, Pumpkin, Cucumber, Squash	Tomato
Cucumber	Beans, Corn, English Pea, Sunflowers, Radish	Irish Potato, Aromatic Herbs
Eggplant	Beans, Marigold	
Lettuce	Carrot, Radish, Strawberry, Cucumber	
Onion Family	Beets, Carrot, Lettuce, Cabbage Family, Summer Savory	Beans, English Peas
Parsley	Tomato, Asparagus	
Pea, English	Carrots, Radish, Turnip, Cucumber, Corn, Beans	Onion Family, Potato
Radish	English Pea, Nasturtium, Lettuce, Cucumber	Hyssop
Spinach	Strawberry, Faba Bean	
Squash	Nasturtium, Corn, Marigold	Potato
Tomato	Onion Family, Nasturtium, Marigold, Asparagus, Carrot, Parsley, Cucumber, Basil	Potato, Fennel, Cabbage Family
Turnip	English Pea	Potato

Source: http://permaculturenews.org/2011/12/02/companion-planting-information-and-chart/

Annex 2: 12 of the most popular Vegetables & herbs Grown in Aquaponic units

The information below gives technical advice on 12 of the most popular vegetables to grow in aquaponics. Included is information on optimal growing conditions, specific growing instructions and harvesting techniques for each vegetable. Most advice comes from 3-4 years experience growing in aquaponics in the Middle East along with vegetable planting advice from Cornell University http://www.vegetables.cornell.edu/

1) Basil

pH: 5.5 - 6.5

Plant Spacing: 20 -25cm (8-14 plants per sq. meter)

Germination Time: 5 -10 days

Growth Time: 5-6 weeks (start harvesting when plant is 15 cm)

Temperature: 18-30° C

Light Exposure: Sunny, but sheltered

Plant height & Width: 30-80cms; 30-80cms

Aquaponic method: Media beds, Grow pipes and Rafts

Growing basil in aquaponic units: Basil is one of the most popular herbs to grow in aquaponic units, particularly in large scale commercial monoculture units due to their high demand and high value in urban or peri-urban zones. Many of the 100+ cultivars of Basil have been tried and tested in aquaponic units including: Italian Large Leaf Basil (Sweet Basil), Lemon Basil, Purple Passion Basil. They are large nitrogen feeders making them ideal for aquaponic production.

Growing conditions: Basil seeds need a reasonably high and stable temperature to initiate germination (20-23°C). Once transplanted in the units, Basil enjoy warm - very warm conditions and near-full exposure to sun. In daily temperatures above 27°C, plants should be covered with 20% sun block shading particularly during the hours of 11:am -3:pm.

Growing instructions: Transplant new seedlings into aquaponics unit once 3-4 true leaves are present.Basil can be subject to various fungal diseases, including Fusarium wilt, gray mold, and black spot particularly if temperature conditions are not optimum. Make sure the unit's water temperature is above 21°C day and night to help avoid these diseases.

Harvesting: Once the plant reaches 15cms in height you can begin harvesting the leaves. Start with the young, tender leaves at the top of the plant leaving the large leaves to help with plant support and stability. Handle the leaves with care when harvesting to avoid leaf bruising and blackening. As the plants continue to grow, remove any flower buds, as they will make the basil leaves taste bitter.

2) Cauliflower:

pH: 6.0 to 7.5.

Plant Spacing: 50- 70 cm (4-6 plants per sq. meter)

Germination Time & Temp.: 4 to 7 days; temperature 8-20° C

Growth Time: 2-3 months

Temperature: 10-23°C (winter crop)

Light Exposure: Full Sun

Plant Height & Width: 40-60cms; 60-90cms

Recommended Aquaponic Method: Media beds, Grow pipes

Growing Cauliflower in Aquaponics: Cauliflower is a great high value, nutritious winter crop to grow and will thrive in media bed units and grow pipe units as long as you provide enough space along the pipes. They can be a difficult crop to grow as they have a large nutrient demand. Also, their heads will not develop properly in hot or very dry weather, therefore selecting the time to plant is crucial. Healthy plants will have a foliage color of medium to dark green.

Growing conditions: Cauliflower will flourish when water and air temperatures are between 14-22° C. They will tolerate colder temperatures as well as other crops in the brassica family including cabbage and broccoli, but mature heads are not resistant to temperatures below 5° C. Cauliflower can tolerate light shade but will grow faster in full sun. Light shade can be beneficial in warm temperatures (above 23°C).

Growing instructions: Germinate seeds in propagation trays in roughly 15° C. Provide direct sun so plants don't get leggy. When plants are 3-5 weeks old and have 4 -5 true leaves begin transplanting into the media beds or grow pipes roughly 50 cms apart. To preserve the white color of the main plant flower, use string or rubber bands to secure outside leaves over the head when it is about 6-10 cms in diameter. At this stage harvest may take less than a week in ideal temperatures or as long as a month in much cooler temperatures. Too much sun, heat or nitrogen up take can cause "ricey" heads where the main flower separates into small, rice-like grains.

Cauliflower is susceptible to some pests including Cabbageworms, Flea beetle, White maggots (larvae) and Cabbage aphids which can be either manually removed or using other pest management techniques (Chapter 6).

Harvesting: Harvest when the heads are compact, white, and firm. Cut the heads off the plant with a large knife and remove the remaining plant and roots from the bed /pipe and place into a compost bin.

3) Lettuce (Mixed Salad leaves):

pH: 6.0 - 7.0

Plant Spacing: 18 - 30 cm (20-25 heads per sq. meter)

Germination Time & temp.: 3 - 7 days; 13-21 °C

Growth Time: 24 - 32 days (longer for some varieties)

Temperature: 15°- 22° C (flowering over 24° C water temp.)

Light Exposure: Full sun (light shade in warm temp)

Plant Height & Width: 20-30cms; 25-35 cms

Recommended aquaponic method: Media bed, grow pipe and floating raft.

Growing Lettuce in Aquaponic units: As with Basil, Lettuce and many other leafy green salad crops are very popular vegetables to grow in aquaponic units as they grow extremely well. At least 40 different cultivars of lettuce and similar plants including arugula and spinach have been highly successful in aquaponics. Lettuce also has a high demand and high value in urban or peri-urban zones making it particularly suited to large scale grow pipe and floating raft aquaponic units.

Growing Conditions: Traditionally speaking Lettuce is a winter crop yet most varieties of lettuce will grow best in aquaponics when the water temperature is between 17-24°C, even if the air temperature is slightly above or below this range. If the water temperature is above 26° degrees each plant will begin to bolt (flower) and will taste bitter when harvested. The ideal pH is between 5.8 and 6.2 but lettuce will still grow well with pH a high as 7 (iron deficiencies may appear if pH increases above 7).

Growing instructions: After germination, transplant them as seedlings after 2-3 weeks making sure each plant has at least 2-3 true leaves. It may be necessary to harden the seedlings (expose them to colder temperatures and stronger sunlight than during germination) for 3-5 days before transplanting to insure high survival rates once moved. When transplanting lettuce in warm weather, place light sun-shade over the plant for 2-3 days. (This hardening process can be done with all other vegetables listed below). To achieve crisp, sweet lettuce grow them at a fast pace by maintaining high nitrate levels in the unit. Moisture stress and high temperatures, particularly at night, encourage bolting. When air and water temperatures increase during a season, plant more bolt-resistant varieties of lettuce. If growing in media beds, plant lettuce where they will be partially shaded by taller nearby plants.

Harvesting: Harvesting can begin as soon as leaves are big enough to eat. For domestic consumption, harvest on demand. If selling to markets, one method is to remove the full plant and roots when harvesting as soon as plant reaches market weight (250-400 grams). Cut the roots and place into a compost bin. Harvest early in the morning when leaves are crisp and full of moisture.

4) Cucumbers

pH: 5.5 - 6.5

Plant Spacing: 30 - 60 cm (depending on variety; 4-8 plants per sq. meter)

Germination Time& temp: 3 -7 days; 20-30°C

Growth Time: 55 -65 days

Temperature: 18°-25° C (highly susceptible to frost)

Light Exposure: Full sun

Plant height & Width: 20-150cms; 20-150 cms

Recommended aquaponic method: Media Beds; Grow pipes

Growing Cucumbers in Aquaponic units: Cucumbers, along with other members of the Cucurbitaceae family including Squash, Zucchini and Melons, are excellent high value summer vegetables to grow. They are ideal plants to grow in media bed units as they have a large root structure. They can also be grown in pipes and in rafts but plants can go in excess of 5 meters so it's vital to support them when using these growing methods.

Growing conditions: Cucumbers prefer relatively high temperature between 24-27° C during the day and night. Cucumbers grow best with long, hot, humid days with maximum sunshine and warm nights. Plants are extremely susceptible to frost.

Growing instructions: Cucumbers grow quickly and are at their best if picked before they get too big (2 meters in height/length). Encourage new fruit development by picking regularly. Cucumbers grow like other vine crops so they'll need staking or a trellis to support the plant. Cucumbers require large quantities of nitrogen and this should be taken into consideration when planning the number of plants to grow in a unit to insure it's balanced. Their root systems are delicate and are very susceptible to fungal infections such as powdery mildew if damaged. Thus, take great care when transplanting.

Cucumbers may also need help with pollination as the male and female flowers can be some distance apart. Female flower are also sensitive to high temperatures (above 27°C). The addition of bees in the surrounding area of the unit and shading in temperatures above 27°C will insure higher pollution rates.

Cucumbers are highly susceptible to pests like aphid, whitefly and grasshoppers so it is vital that integrated pest management techniques are applied (see chapter six).

Harvesting: Once transplanted, Cucumbers can be ready to harvest after 65-75 days assuming plants are grown in optimal conditions. Once cucumbers reach pickling or slicing size, harvest every couple of days to prevent the fruit from getting overly large or yellow.

5) Eggplant

pH: 6.0 - 7.0

Plant Spacing: 40 - 60 cm (4-6 plants per square meter)

Germination Time & Temp.: 10 - 15 days; 26-32 ° C

Growth Time: 55 – 70 days

Temperature: 20 – 32 ° C (highly susceptible to frost)

Light Exposure: full sun

Plant height & width: 60-120cms; 60-120cms

Recommended aquaponic method: Media beds &grow pipes

Growing eggplant in aquaponic units: Eggplant is another summer fruiting vegetable that grows well in aquaponics, particularly in media beds &grow pipes. Mature plants can have between 10-15 fruits growing at once meaning that each plant can weigh at least 3-7kgs. This weight shouldn't be a problem for media bed units but extra support for grow pipes may be necessary if you have a lot of eggplants growing in one pipe.

Growing conditions: Eggplants enjoy warm to very warm temperatures with full sun exposure. They are also highly sensitive to frost. They are moderately tolerant to high water salinity levels making them an excellent choice for regions with hard water or reality poor water quality. Eggplants are large nutrient feeders thus consideration regarding the number of eggplants per sq. meter must be taken to insure unit is balanced. If nitrate levels are too high (above 200 mg/l) over a number of weeks this will encourage lush foliage growth at the expense of fruit development.

Growing instructions: Eggplants can grow to 40 - 140cm s in height with large lobed leaves than can be up to 20cms long and 10cms wide. Germinate seeds in warm temperatures (26-30° C) and transplant into the units when seedling has 3-4 true leaves. Plants are often started indoors six to eight weeks before the final frost and transplanted when temperatures rise in spring.

Towards the end of the summer season, begin pinching off new blossoms so that plants channel energy into ripening existing fruit, not producing new ones. Eggplants are susceptible to pests and diseases such as aphids, whitefly and spider mites. Also, as they are part of the Solanaceae family (along with tomatoes and peppers) they have complete flowers meaning they have both male and female organs, therefore they self-pollinate.

Harvesting: Start harvesting when the eggplants are 10 -15cms long. The skin should be shiny; dull skin is a sign that the eggplant is overripe. Use a sharp knife and cut the eggplant from the plant leaving at least 3csm of the fruits' stem attached to the fruit.

6) Peppers

pH: 5.5 - 6.5

Plant Spacing: 30 - 40 cm (6-8 plants per square meter)

Germination Time & Temp.: 8 -12 days; 22-34 ° C (seeds will not germinate below 13°)

Growth Time: 60 - 95 days

Temperature: 16° C -26° C

Light Exposure: Full sun

Plant height & width: 30-90cms; 30-90cms

Recommended aquaponics method: Media beds & Grow pipes

Growing Peppers in aquaponic units: There are many varieties of peppers, all varying in colour and degree of spice, yet from the sweet bell pepper to the hot chilli peppers (Jalapeño or Cayenne peppers), all possible to grow using aquaponics. They are more suited to the media bed method but they'll also grow well in 11cm diameter grow pipes once given extra support.

Growing conditions: Peppers are a summer fruiting vegetable. They enjoy warm to very warm air and water temperatures and full sun exposure. The top leaves of the plant protect the fruit hanging below from sun exposure. Seed germination temperatures are high: 22-34°C. Seeds will struggle to germinate in temperatures below 15°C.

Peppers can be temperamental when it comes to setting fruit particularly if temperatures are too hot or too cold. Nighttime temperatures below 15°C or above 25° C and lower humidity can reduce fruit set. Also, as with Eggplants, too much nitrate may promote lush vegetative growth but fewer fruit. Due to this, when the plant begins blossoming make sure nitrate levels are within the optimum range (20-120 mg/l) and other key nutrients for fruit growth (Potassium and Phosphorus) are high. Very dark green leaves are a sign of excessive nitrate up take.

Growing Instructions: Transplant seedlings to the unit at start of summer season when plants have 6-8 true leaves. Support bushy, heavy-yielding plants with 60cm stakes. For sweet red peppers, leave green peppers on the vine until they ripen and turn red. Pick the first few flowers that appear on the plant in order to encourage further plant growth.Other than Aphids and borers, pests are not a serious concern. Aphids can be removed with a strong stream of water.

Harvesting: Begin harvesting when peppers reach a usable size. Leave some peppers on the plant to ripen fully. The peppers will change color and develop greater levels of vitamin C. Harvest continually through the summer to avoid having all peppers stay on the plant as this will inhibit further blossoming and fruit set.

7) Tomatoes

pH: 6.0 - 6.8

Plant Spacing: 20-35 cm for indeterminate varieties (4-8 plants per square meter)

Germination Time & temp.: 5- 7 days; 23- 32° C

Growth Time: 65 -85 days till first harvest

Temperature: 21° C - 35° C

Light exposure: Full sun

Plant height & width: 60-180 cms; 60-180cms

Recommended aquaponic method: Media beds, grow pipes and floating raft

Growing tomatoes in aquaponics: Tomatoes are an excellent summer fruiting vegetable to grow in all methods of aquaponics, although plant support is mandatory. There are two major types of tomato plant: determinate (produce all fruit at once) and indeterminate (continually produce fruit over a season). Indeterminate varieties are recommended as they use less horizontal space (determinate varieties grow as bushes therefore need alot of horizontal space). Indeterminates also need a constant amount of the major nutrients (Phosphorus, Sulphur Potassium) during their fruiting period which is easier to manage in aaquaponic unit than the requirements for determinate plants. They need very high concentrations of the same nutrients during their short fruiting period.

Growing conditions: Tomatoes prefer warm summer temperatures with full sun exposure (except in very hot conditions, where some shading is needed to prevent poor fruit set). Tomatoes have a moderate tolerance to high salinity levels making them ideal crops to grow in aquaponic units using hard - very hard water to replenish unit. As with peppers and eggplants, excess nitrate will promote lush vegetative growth but fewer fruit. Thus, recording and managing nitrate levels is highly recommended as tomatoes begin to blossom. Tomatoes also require high levels of Potassium and phosphorus while blooming.

Planting instructions: Set stakes or plant support structure before transplanting to prevent root damage. Transplant seedlings into units 6-8 weeks after germination when seedling is 10-15cms and when nighttime temps are at least 8°C. Once the tomato plants are about 90 cm tall, remove the leaves from the bottom 30 cm of the stem as these are usually the first leaves to develop fungus problems. For best results, prune suckers (stems growing from where leaf stems meet the main stem) to allow 2-3 central stems to grow. Also, pinch and remove new flowers that develop in the crotch joint of two branches. These will not bear fruit and will take energy away from the rest of the plant. Tomatoes are susceptible to insect pests such whitefly or hornworms and also to fungal diseases. See chapter 6 on plant pest control. Also spraying weekly with compost teas will ward off fungal diseases.

Harvesting: For best flavor, harvest tomatoes when firm and fully colored. Fruits will continue to ripen if picked half ripe and brought indoors.

8) Beans (Or Peas)

pH: 6.0 – 6.8

Plant Spacing: dependent on variety (pole beans: 5-10 cms; bush beans: 30-40 cms)

Germination Time & temp.: 8- 10 days; 21- 26° C

Growth Time: 50-110 days to reach maturity depending on variety

Temperature: 15-26° C

Light exposure: Full sun

Plant height & width: 60-250 cms (Pole); 60-180cms (Bush)

Recommended aquaponic method: Media bed, grow pipes

Growing Beans in aquaponic units: Both pole & bush bean varieties grow well in aquaponic units but pole varieties are recommended as they can be trained to use far less space than the bush varieties thus maximising the limited growing space available. Their yield can also be 2-3 times greater than bush varieties. Beans are medium nitrate feeders with a moderate demand of the other macro nutrients (phosphorus & potassium) making them ideal for aquaponic production althoughexcess nitrate will delay flowering. Beans are recommended for newly established units as they can fix atmospheric nitrogen on their own.

Growing Conditions for Pole Beans: Pole beans enjoy full sun but will tolerate partial shade in warm conditions. Beans will thrive in mild to warm water and air temperatures (15-26°C) but will struggle to produce in conditions above 28°C. Pod set is if very poor when temperatures exceed 32°C.

Growing instructions for Pole Beans: For media bed units, seed directly into the bed 3-4cms deep (making sure the bell siphon is out so the water level is high during germination) as beans do not like to be transplanted (unfortunately transplanting is a must if growing in pipes). If using a trellis or vertical support poles for each plant, set them up before you seed to avoid root damage. Make sure seeds are placed so they will not shade other vegetables from their shadow. Rotate the location of your bean crops from year to year to discourage disease. Beans are susceptible to aphids and spider mites which can both be washed off using a hard stream of water. Other larger pest including bean beetles and maggots can be manually removed.

Harvesting: Snap bean varieties (Green or Yellow Wax Beans): Pods should be firm and crisp at harvest; the seeds inside should be undeveloped or small. Hold stem with one hand and pod with other to avoid pulling off branches that will produce later pickings. Pick all pods to keep plants productive.

Shell beans (Black, Broad or Fava Beans): Pick these varieties when the pods change color and the beans inside are fully formed but not dried out. Pods should be plump, firm. Quality declines if you leave them on the plant too long.

Dried beans (Kidney & Soy beans): Let the pods get as dry as possible before cooler weather sets in or when plants have turned brown and lost most of their leaves. Pods will easily split when very dry making seed removal an process.

9) Cabbage:

pH: 6 – 7.5

Plant Spacing: 60-80 cms (4-6 per sq. meter)

Germination Time & temp.: 4-7 days; 8-29°C

Growth Time: 45-85 days (depending on when planted during the winter season

Ideal Temperature: 15-20°C (Growth will stop above 25°C)

Light exposure: Full Sun

Plant height & width: 30-60 cms; 50-100 cms

Recommended aquaponic method: Media beds (not suitable for aquaponic units less than 4 months old)

Growing Cabbage in aquaponics: Cabbage is a highly nutritious winter crop to grow in aquaponic units although media beds are the recommended method as plants are very large and heavy at harvest. Cabbage is a very large nutrient feeder making them relatively difficult to grow in aquaponics particularly in newly established units (not recommended for units less than 4 months old due to an insufficient nutrient base). Due to the large space required for cabbage, they are far less beneficial per square meter than other winter crops such leafy greens (lettuce, spinach, rocket etc).

Growing Conditions: Cabbage is a winter crop with ideal growing temperatures of 15-20°C; Cabbage can tolerate temperatures also low a 5°C but aquaponics is not possible at this temperature. Cabbage grows best when the heads mature in cooler temperatures, so plan to harvest before daytime temperatures reach 23-25 degrees.

High concentrations of Phosphorus and Potassium are vital when the head begins to grow. Organic fertilizers either used as a foliar spray on leaves or in liquid form, such as compost tea (see chapter 9), may be necessary to boost the level of nutrients.

Growing Instructions: If day time temperatures rise above 25°C cover cabbage using 20-30% sun-block shading to prevent the plant for bolting (growing to produce seeds). Common cabbage pests include aphids, root maggots, cabbageworms, and cabbage loopers therefore organic (aquaponic safe) pesticides must be applied (see chapter 6).

Harvesting:

Start harvesting when cabbage heads are firm with a diameter of roughly 10-15 centimeters (depending on variety grown). Cut the head from the stem with a sharp knife and place the outer leaves into the compost bin. If Cabbage heads split then it's past its maturity

10) Broccoli

pH: 6 - 7.5

Plant Spacing: 30-50 cms (6-10 per sq. meter)

Germination Time & temp.: 5-7 days; 7-29°C

Growth Time: 65-95 days

Average daily temperature: 13-18°C

Light exposure: Full sun; can tolerate partial shade but will mature slower

Plant height & width: 30-60 cms; 30-60 cms

Recommended aquaponic method: Media beds

Growing Broccoli in Aquaponics: Broccoli is a nutritious winter vegetable to grow in aquaponics although the media bed method is the recommended option as Broccoli is a large, heavy crop at harvest. Broccoli is moderately difficult to go with aquaponics as it is a large nutrient feeder. It is also highly susceptible to warm - very warm temperatures therefore it is recommended to select a variety that is bolt resistant as the water temperature in aquaponics should always be above 18°C.

Growing Conditions: Broccoli grows best when daytime temperatures are in between 14-17°C. Therefore, growth in Autumn, Winter and Spring are all possible but avoid growing during the mid-summer as hot weather will cause premature bolting.

Growing Instructions: Transplant seedlings into media beds once 3-4 true leaves are present. Transplant each seedling 30-50 cms apparent. The larger the space between each seedling the larger the central heads will be at harvest. Closer spacing's will produce smaller central heads, yet if you harvest secondary heads you will get a greater total yield from the closer spacing's.

Broccoli is susceptible to aphids and spider mites which can both be washed off using a hard stream of water. Other larger pests including Cabbageworms, Cabbage root maggot and flea beatles can be manually removed. If larger pests are persistent you can use any of the aquaponics-safe pesticides (Garlic Spray, Molasses Spray) to deter them. For best results apply generously making sure you cover the entire plant.

Harvesting: For best quality, begin harvesting Broccoli when the buds of the head are firm and tight. Harvest immediately if the buds start to separate and begin flowering (yellow flowers).

11) Swiss Chard/mangold:

pH: 6-7.5

Plant Spacing: 15- 20 cms (15-20 per sq. unit)

Germination Time & temp.: 5-35°C (27-35°C optimal); 5-7 days

Growth Time: 25-35 days

Temperature: 10-30°C

Light exposure: Full sun (partial shade in temperatures above 26°C)

Plant height & width: 30-90 cms; 30-60 cms

Recommended aquaponic method: Media beds, grow pipes and floating raft

Growing Swiss Chard in Aquaponic units: Swiss Chard is an extremely popular leafy green vegetable to grow using aquaponics as it thrives in all three aquaponic methods. It is a relatively large nitrate feeder, requiring less concentrations of potassium and phosphorus than other fruiting vegetables, making it prefect for aquaponic production. Due to its high market value, its fast growth rate and nutritional content, Swiss Chard is frequently grown on commercial aquaponic systems. They are also relatively easy to grow and create very few pest problems for commercial growers. Foliage is green to dark green but the stems can be yellow, purple or red depending on the variety.

Growing conditions: Although traditionally a late-winter/spring crop (tolerating moderate frosts), Swiss chard will also grow well in full sun during mild summer seasons, yet partial shade is required above 26°C.

Swiss Chard has a moderate tolerance to salt making therefore ideal to grow in hard water conditions.

Growing Instructions: Swiss chard seeds produce more than one seedling therefore thinning is required as the seedlings begin to grow. As plants age during the season, older leaves begin to get tough. If so, cut plants back to about 10-15 cms tall to encourage new growth.

Harvesting: You can begin harvesting when leaves reach usable size. Remove a leaf or two from each plant, or cut plants an inch or two above the soil for cut-and-come-again harvest. Avoid damaging the growing point in the center of the plant at harve

12) Parsley:

pH: 6-7

Plant Spacing: 15-30 cms

Germination Time & temp.:2-5 weeks; 8-25°C

Growth Time: 20-30 days after transplant

Temperature: 15-25°C

Light exposure: Full sun; partial shad above 25°C

Plant height & width: 30-60cms; 30-60 cms

Recommended aquaponic method: Media Beds, NFT & floating rafts

Growing Parsley in aquaponic units: Parsley is a very common herb grown in both domestic and commercial aquaponic units due to its nutritional content (rich in vitamins A & C, calcium, and iron) and its high market value. Parsley is a relatively easy herb to grow as the nutrient requirements are relatively low compared to the vegetables crops listed above.

Growing Conditions: Parsley is a biennial herb but it's traditionally grown as an annual; most varieties will grow over a 2 year period if the winter season is mild with minimal to moderate frost. In the first year the plant produces leaves while in the second the plant will begin sending up flower stalks to seed. Parsley enjoys full sun for up to 8 hours of the day. Partial shading is required in temperatures about 25°C.

Growing Instructions: The main difficulty when growing parsley is the initial germination which can take anything up two 5 weeks depending on how fresh the seeds are. To speed up the process, you can soak the seeds in warm water (20-23°C) for 24-48 hours to soften the seed husks. Afterwards, drain the water and seed into propagations trays. Emerging seedlings will have the appearance of grass with two narrow seed leaves opposite each other. After 5-6 weeks, transplant the seedlings into the aquaponic unit during early spring

Harvesting: Harvesting can begin once the individual stalks of the plant are at least 15cms long. Harvest the outer stems from the plant first as this will encourage growth throughout the season. If only the top leaves are cut the stalks will remain and the plant will be less productive. Parsley dries and freezes well. If you dry it, crush it by hand after it's completely dry and store it in an airtight container.

ANNEX 3: Calculating The Amount of Biofilter Media Required to Convert a Given Amount of Ammonia

The calculations, discussion and rules of thumb (See chapter 8: aquaponic calculations) given belowprovides a more detailed explanation on deciding how much filtration media is required per a given amount of fish feed. Thus, this explanation will help when deciding to build or expand an existing aquaponics system. Along with the information provided in the manual chapter we will also need introduce two new important biological rates in the equations: Total Ammonia Nitrogen (TAN) production from fish food and a conversion rate of pure ammonia to nitrate by bacteria.

Determining the amount of bio-filtration needed for aquaponic units:

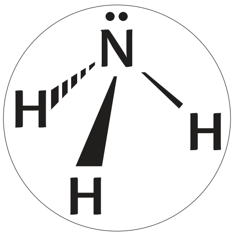
To determine the appropriate bio-filtration capacity we need to introduce two new rates. The first is the amount of pure ammonia (TAN) produced by certain amount of fish food. The rule of thumb for this is as follows: 100 grams of fish food (32% protein) will produce 3 grams of pure ammonia. This means that for every 200 grams (which is the max. feed amount for a 20kg fish density unit, a typical small scale unit size) of fish consumed, 6 grams of pure ammonia will be released into the water by their waste.

Ammonia (NH_3) Production

3 grams of NH_3 is produced from 100 grams of food

Calculation:

200 grams of daily feeding: 3gm x 2 = 6 grams of pure ammonia per day



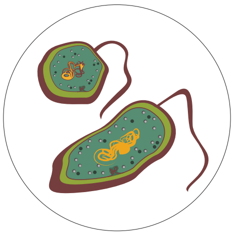
The second rate is as follows: bacteria will convert TAN (or pure ammonia) at a minimum rate of 0.1 grams per square meter of surface area per day (given the optimal environments for bacteria to grow, i.e. temperate 18-30). When using these two rates together we observe that for every 200 grams fed to fish per day - 6 grams of pure ammonia is produced, and if bacteria convert a min. of 0.1 grams of pure ammonia per day using 1 m² of surface are then we'll need 60 m² (6 grams divided by 0.2 grams).

Nitrifying bacteria

1 sq.meter of media with bacteria will convert 0.45 grams of ammonia into nitrate per day

Calculation:

6 gram of ammonia / 0.45= 13.3 sq.m of media we need to convert 6 grams of pure ammonia



So, how many litres (cm³) of media do we need to secure

60 m² of surface area? Well, if we use volcanic gravel,

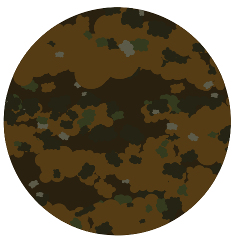
which has a surface area of 300 m²/m³, we can work it out using the same ratio as follows:

Media Bio filter

Specific Surface Area (SSA) of tuff: 300 m²/m³

Calculation:

(1000 x 13.3 m²) / 300 = 43.3 litres of tuff



If the tuff ratio is: 300 m^2 / 1000 dm^3 (1 dm^3 = 1 litre) and we need to work out the cm^3 for 60 m^2/?? dm^3, we multiply 1000 x 13.3 and divide the product by 300, which equals to 200 dm^3 or litres of tuff.

So for Media Bed units we need at least 200 litres of tuff to convert the 6 grams of pure ammonia produced from 200 grams of fish food fed to roughly 10- 20 kgs of fish (1 litre for every 1 gram of feed). Yet we know from chapter 4 that for media bed units the bio-filtration media (tuff) also acts as the plant growing space and plants require a 30cm depth of media inside the each bed. This means that, once the 30cm depth rule is kept, any small scale media bed unit will have more than enough gravel to convert the ammonia.

Take the example of the media bed unit in the step by step guide in the final annex of the manual:

1 x 1000 litre fish tank with a max. fish capacity of 20 kgs, connected to 3 grow beds, each containing 300 liters of media (900 litres in total). Even with a max. feed rate per day of 240 grams (3 square meters of fruiting vegetables (3x 80 grams)) this unit has almost 4 times (900/240 = 3.75) the gravel needed to convert the pure ammonia produced .

Filtration for NFT & Deep Water Culture units:

As discussed in Chapter 4, NFT and DWC units can have a different method of filtration using two separate containers for mechanical and bio-filtration. Yet for NFT and DWC bio-filtration, the exact same calculations used above apply. The only difference is the surface area of the media used to host the bacteria. Instead of tuff, Bioballs are used and they have a surface area of roughly 500-700m^2/m^3.

Fig. 8.2 Bioballs (with Surface Area of 500 -700 m^2/m^3)

Taking the same example as above, 200 grams of fish food will produce 6 grams of ammonia and 60m^2 of any media is needed to convert the 6 grams into nitrate.

The ratio for bioballs is: 600m^2 / 1000 dm^3 and we need to work out the dm^3 for 60 m^2 / ?? dm^3, so we multiply 1000 x 60 and divide the product by 600, which equals to 100 litres of bioballs

So for NFT and DWC units using bioballs with a surface area of 600 m^2/m^3, we need at least 100 litres of bioballs to convert the 6 grams of pure ammonia produced from 200 grams of fish food fed to roughly 20 kg of fish. (1 litre for every 2 grams of feed)

Take the example of the DWC unit in the step by step guide in the final annex of the manual:

1 x 1000 litre fish tank with a max. fish capacity of 20 kgs, connected to a mechanical separator and biofilter container (200 litres each) and 3 DWC canals. With a max. feed rate per day of 240 grams (3 square meters of fruiting vegetables (3x 80 grams)) this unit will need 120 litres of bioballs (1 litre of bioballs for every 2 grams of feed: 240)) to convert the pure ammonia.

Simple filtration rules of thumb for small scale units:

Specific Surface Area (m^2/m^3)	Media (Litres)
300 (Volcanic tuff, pumice)	1 litre for every 1 gram of feed
600 (Bioballs)	1 litre for every 2 gram of feed

Annex 4: Making Homemade fish feed for Common Carp and Nile tilapia

Introduction:

Fish feed will be the most expensive input when maintaining a small scale aquaponics unit (see Annex 6, cost/benefit analysis of aquaponics unit, Table 2). It is also one of the most important aspects of the whole aquaponics eco-system as it not only sustains the fish but also the vegetables as their food comes from fish waste which is the by-product of fish food. Therefore it is necessary that farmers/ practitioners understand its composition and methods to produce it on their own.

1) Why make your own feed?

- If fish feed is not available: Fish farmers around the world feed their fish with industrial pellet feed and usually there are no doubts as to its composition and nutritional value. Yet, in other areas where an aquaculture industry is non-existent, pelleted fish feed of good quality is difficult, if not impossible, to obtain. Under these circumstances, a grower may have no choice but to produce his own feed.

- Reduce production costs: In certain contexts it may be more cost effective to produce your own feed rather than buying ready-made feed.

- Sustainability and Reliability: Producing your own feed is another step towards sustain ability; it also allows you to control the exact nutritional composition of the feed and there fore your nutrition.

2) Food groups in fish feed

As with food for humans, fish feed must consist of all the nutrients that are required for growth, energy and reproduction. Details of each nutrient for fish of 50 grams and above are given below with a final summary table identifying widely available sources of each:

Protein

Protein is the main component for building fish mass. It is also a major source of energy for fish and it's vital for many biological processes within the fish's body. The building blocks of protein are amino acids. There are 20 common amino acids, 10 of which are essential for fish growth yet none of these 10 can be synthesized (produced) internally so they must be included in fish feed.

Protein should constitute 25-35% of the food when growing tilapia and other herbivore fish; for carnivorous fish like barramundi or trout,it is common to use (but not for all carnivore species) 38-45% protein. For aquaponics this increase of protein directly affects the amount of vegetables that can be grown as protein released in fish waste controls the amount of the nitrogen (nitrate) available for plant growth. Thus, the higher the volume of protein in fish food the greater amount of plants can be grown. Finally, it is worth noting that protein is the most expensive ingredient for any feed production, either industrial or home-made.

Carbohydrate

Carbohydrate is the most important energy source for mammals and some herbivorous and omnivorous fish species like tilapia and carp. Up to 40% of fish feed for omnivorous fish can be composed of carbohydrates. This is due to the fact that carbohydrates are a far cheaper energy source than protein, leaving the protein to be used for building fish mass instead. Carbohydrates are also used as a binding agent to insure the feed keeps its structure in water.

Fat

Fats are made up of different fatty acids which are a group of organic compounds used as another energy source for fish. Fats are also used in many physiological processes including the absorption of vitamins and the production of hormones. Speaking generally, the most suitable fatty acid groups for fish are omega 3 & omega 6 and need to be supplied in the diet to optimize growth. Health problems will occur for fish if the total percentage of fat in fish feed increases past the recommended range(-less than 10%).

Vitamins & Minerals

Vitamins are organic compounds necessary for fish growth and many other physiological processes. They are not produced internally so they must be included in their diet. There are many indicators for deficiencies of specific vitamins however the most noticeable is a slowdown in growth rate.

Fish require 20 inorganic elements for several reasons including healthy growth, the regulation of salt and for building bones. As with plants, the essential minerals can be split up into two categories: macro-nutrients (phosphorus, calcium, potassium etc.) and micro-nutrients (iron, manganese, zinc etc.) Fish can absorb essential minerals from food or minerals suspended in the water via their gills.

Food Groups for Fish Feed	Widely Available Sources for Each Food Group
Protein	**Plant based sources:** algae, soybean meal, cottonseed meal, peanuts, sunflower, rapeseed/canola, other oil seed cakes **Animal based sources:** fishery byproducts (fishmeal or offal), poultry by-products (poultry meal or offal) meat meal, meat & bone meal, blood meal
Carbohydrates	Wheat flour, wheat bran, corn flour, corn bran, rice bran, potatoes, cassava root meal
Fats	Fish oil, vegetable oil (soya, canola, sunflower), animal fat
Vitamins	Vitaminpremix package, chopped liver, milk
Minerals	Mineral premix package, crushed bone

4) Initial comments on domestic fish feed production

- Producing fish feed domestically requires a fine balance of all of the components mentioned above (Protein, fats, vitamins etc). An unbalanced feed will eventually lead to illness and fish growth problems.

- Because of its balanced amino acid profile, fish meal is regarded as the best protein source for fish feed. However, it is very expensive and not always available. A plant protein source to partially or fully replace the fish meal protein is possible however plant protein sources must be pre-processed (dehulled, grinded, cooked etc) beforehand. This is to remove the anti-nutritional factors associated with plant protein sources which would otherwise result in decreased digestibility and poor fish growth and performance (Recipes with both animal & plant based proteins will be given below).

- The final pellet size should be roughly 20-30% of the fish's mouth you're feeding. If fish are below 50 grams the recommended pellet size is 2mm; for fish above 50 grams the recommended size is 4mm. If the pellets are too small, fish exert more energy to consume it; if too big, fish will be unable to eat.

- If using fish offal as the protein source, it should be heat treated to remove the threat of harmful microbes. The heat treatment will also remove chemicals that negatively impact the availability of some vitamins in the feed.

5) Homemade fish feed recipes for omnivorous/herbivorous fish (Roughly 30% Crude protein)

As previously indicated, below are two simple recipes for making fish feed. The first is a plant based protein recipe using soyabean meal as the main protein source. The second is an animal based protein recipe using fish meal. Following the recipes and the table of preparation utensils below is a simple step by step guide to prepare both recipes:

A) Plant based protein recipe (for 10kg of fish feed,
if only 5kgs is necessary simply divide the ingredients by 2)

Ingredients	Weight	Percentage of total feed (%)
Corn grain	1 kg	10
Wheat grain	1 kg	10
Soybean meal	6.7 kg	67.24
soybean oil	0.2 kg	2
Wheat bran	0.7 kg	7.76
Vitamin & mineral premix packet	0.3 kg	3
Total amount	10kg	100%

Approx. composition (as % of total feed)	%
Dry Matter	91.2
Crude Protein	30
Crude Fat	14.2
Crude Fiber	4.8
Ash	4.6
Nitrogen Free Extract (NFE)	28.29

B) Animal based protein Recipe (for 10 kg of fish feed)

Ingredients	Weight	Percentage of total feed (%)
Corn grain	1.0 kg	10
Wheatgrain	4 kg	40
Soybean meal	1.5 kg	15
soybean oil	0.2 kg	2
Fish meal	3 kg	30.
Vitamin & mineral premix packet	0.3 kg	3
Total amount	10kg	100%

Approx. composition (as % of total feed)	%
Dry Matter	90.9
Crude Protein	30
Crude Fat	10.5
Crude Fiber	2.1
Ash	8.3
Nitrogen Free Extract (NFE)	34.5

List of essential preparation utensils	
weighing scales	To weigh each ingredient
Metal Sieve	0.2 – 0.4 cm mesh
10 litre mixing bole	To mix ingredients
3 x 2 litre bowls	To handle the ingredients
Meat grinder / Pasta maker	Automatic or manual
Large mixing spoon	Mixing spoon
Aluminum try	40cm x 40cm

Step by step preparation method:

1. Gather all the utensils required and weigh each ingredient according to the two formulas above using the weighing scales
2. Take the soybean and toast or heat treat them (in an oven for 1-2 minutes,@ 120° C) Alternatively, you can germinate the beans to have their seed coats removed (this must be done before grinding)
3. **Plant protein formula only:** Take the treated Soybean, corn flour, wheat grain and wheat bran and separately dry and finely ground them. Mix the ingredients thoroughly for 5-10 minutes until the mix becomes homogeneous.
4. **Animal protein formula only:** Take the fish meal, treated Soybean, corn grain, and wheat grainand separately dry and finely ground them. Mix the ingredients thoroughly for 5-10 minutes until the mix becomes homogeneous.
5. For both formulas (and for all other steps): Add the vitamin and mineral premix into the bowl and continue mixing for another 5 minutes to be sure that the vitamins and minerals are distributed throughout the whole mixture.
6. Once the premix is thoroughly spread, begin slowly adding all of the soybean oil, a few drops at a time, while continuing to mix over a period of 3-5 minutes
7. If necessary, add a few drops of distilled water to the mixture until you get a paste-like texture.
8. Once all ingredients have been thoroughly mixed, divide the feed paste intosmaller mixing balls and pass all of the paste through a meat grinder/pasta maker to form spaghetti–like strips, which should be then gathered on an aluminium tray (or similar hard surface).
9. Dry the feed strips in an electric oven at a temperature of about 60oC for20-30 minutes or in a shaded and well ventilated area for up to 24 hours.
10. Chop (using a serrated knife)or blend the dried feed strips (in a small electric blender)intosmall pellets (according the fish size). Pellets can be sieved through small metal sieves with different mesh sizes to separate them into the appropriate size required for the fish (2-4mms).
11. Place the chopped feed pellets into plastic containers and label the pellet size and date of production.

6) Storing homemade food:

- Once prepared, the best way to store fish feed is in a plastic container with a lit removed in a freezer with a minimum temperature of at least minus 3 degrees. Feed can be stored for anything up to 2 years using this method

- Another method is to store feed in a cool, dark place; that is well ventilated and away from pests (vermin, insects). Feed should last up to 2 months with this method.

- Feed should be used on a first in first out basis. Also, throw out food at the first sign of de cay or mould as this could be fatal for fish.

7) Supplementary feeding with live feeds

It is highly recommended to supplement any process fish feed diet with a live fish food source as it will boost the fish's nutritional intake.Examples of live fish feed include: duckweed, earth worms, black solider fly larvae, small fish, crabs, zooplankton, mollusk and live algae (Spirulina or Astaxan-thin).

For further information on homemade fish food production please see the links to online recourses below:

- **Aquaculture feed and fertilizer resource information system :**

  http://www.fao.org/fishery/affris/aquaculture-feed-and-fertilizer-resources-informa tion-system-home/en/

- **Nile tilapia feed:**

  http://www.fao.org/fishery/affris/species-profiles/nile-tilapia/nile-tilapia-home/en/

- **Common carp feed:**

  http://www.fao.org/fishery/affris/species-profiles/common-carp/common-carp-home/en/

- **Feed resources database:**

  http://www.fao.org/fishery/affris/feed-resources-database/en/

Annex 5: General guidelines for selecting where to establish and operate small-scale & commercial aquaponic units

A) Aquaponics in different regions of the world:

There are some key considerations when figuring out where aquaponics is most applicable and beneficial. Generally speaking, regions in the world where soil fertility is poor (and particularly where replenishing the soil with nutrients via organic material is difficult and/or expensive) and water is scarce are the most ideal locations. This is due to the fact that aquaponic food production is extremely water efficient and the vegetable growing methods are soil-less. When taking these factors into consideration, semi- arid regions with poor access to water would stand to benefit the most from this new method of food production.

Climate is another major factor as it will determine the extra cost for each unit to maintain the ideal environmental conditions for aquaponic food production. In general, regions where the average daily air temperatures throughout the year are between 20-30°C are the most ideal. Moreover, the closer the unit's water temperature is to 23°C during the day and night without extra environment control the more productive and cost-effective the unit will be. In these conditions, greenhouses used to control the immediate surroundings of a unit, which can be a substantial fixed cost (up to 30% of the entire unit cost), are not essential. Also, regions where air temperatures are within the ideal bracket (20-30°C) but fluctuate dramatically during the day and night (i.e. mountainous regions) will be problematic particularly for fish production as large daily water temperature swings will negatively impact fish growth. Thus, tropical, sub-tropical and arid regions with low altitude around the world are the most ideal for tropical fish.

Attention must also be paid to the seasons of a region. Cold, winter seasons will force an aquaponic farmer to either invest in water heating systems for their unit within a greenhouse or stop production entirely for those months. Extended rainy seasons will force a farmer to protect their unit with a strong canopy or greenhouse as large volumes of rain water entering the unit will cause overflows. Rain water can also dramatically dilute the nutrient concentration of the water therefore negatively impacting vegetable growth. For summer seasons, although methods to keep water temperatures relatively low during hot periods are quite simple (covering the fish and bio-filter containers with UV protective material and making sure no water in the hydroponic component is exposed to the sun) it is possible that water temperatures can rise up to 30-35°C during extremely hot seasons without any extra internal water cooling systems. Although these temperatures are not that problematic for topical fish production or bacteria growth, they will limit a farmer's vegetable growth and selection.

Having stated all the above, there are many fully functional commercial and small-scale aquaponic units in temperate climate zones around the world or in even colder conditions. Commercial systems are actually running in the outskirts of tundra regions of North America and Northern Europe where cold winter seasons can last up to 6 months of the year. These are only possible with the aid of sophisticated greenhouse technology controlling the water and air temperatures of the unit and the surrounding areas along with humidity, CO_2 levels and flow of air. This extra technology, though, will drastically increase the initial and running costs of the unit.

B) Choosing a location within an ideal region:

After considering the factors above related to climate and seasons, the next essential factor to consider is access to or presence of local aquaculture knowledge and experience. Aquaponics is simply not applicable in regions where there are no hatcheries, aquaculture production or other aquaculture extension services unless broodstock, fingerling production and fish feed production is a major component of the initial aquaponic investment. Even then, the investment must be long term (3-5 years minimum) with substantial knowledge transfer and backstopping to new farmers on aquaculture and fish feed production along with comprehensive analysis on potential local and regional markets to sell the produce.

Fish production is the most complicated aspect of aquaponics (particularly for farmers new to aquaculture) which demands daily management as a whole fish crop can die within hours due to power failure. Therefore it is essential for new aquaponic farmers to have easy access to new fingerlings at an affordable price and expertise on locally cultured fish so they have the capacity to fully care for the fish and restock their units when necessary. There must also be a market for key aquaponic components including water test kits, bio-filtration media, submersible water pumps & air pumps which a local aquaculture industry would normally facilitate. Failing that, it must then be possible to import these essential materials at an affordable price otherwise aquaponics, and particularly small scale aquaponics, will struggle to be a cost effective method of producing food.

Educational capacity is also a key factor when selecting specific locations within regions or countries. Aquaponics is a relatively sophisticated method of food production compared with traditional soil-based approaches. The method demands a strong level of understanding of the aquaponics eco-system and the major factors that influence it (i.e. water temperature, pH, water hardness etc). It also demands good individual aquaculture and horticulture knowledge that must either be transferred internationally or gained locally. Therefore it is not applicable for illiterate or even semi-illiterate farmers/end users who don't have a good understanding of at least one of the farming methods (aquaculture or horticulture). Also, if aquaponic food production is virtually non-existent within a specific region it is beneficial to initially partner with local universities or agricultural extension institutes to develop knowledge on best practices for aquaponics with fish and vegetables that are most applicable and profitable in the local and regional markets.

Finally, another major barrier to the development of aquaponics in a region is the initial construction costs. Aquaponic units have much higher installation/fixed costs than soil production even without including the cost of extra materials needed to control the environmental conditions surrounding it (although for small-scale units, it is possible to use re-cycled materials to lower the initial cost). As mentioned in the paragraphs above, new commercial aquaponic farmers must therefore do an extensive feasibility study and market research to know exactly which local and regional markets they'll operate in before installation.

C) Considerations for a specific unit location:

At any unit location, access to electricity and appropriate water is essential. Regarding electricity: access to constant electricity is very important as aquaponics relies on electric pumps to move the water and create oxygen for the fish and plants. It is possible to construct a low yield aquaponics unit that can withstand temporary power cuts using back-up generators or AC/DC air pumps to secure constant oxygen levels in the water for fish. But if power cuts are prevalent and last longer than 4-8 hours then aquaponics will more than likely not succeed unless you have a very profitable market to operate in. Profits can then be used to secure electricity in the long run using generators or sustainable energy solutions (i.e. solar powered pumps).

Regarding water: there must always be access to good quality water to satisfy the unit's daily replenishment requirements. Also, if using water wells for commercial operations make sure the pumping pressure is enough to the cover the daily requirements. Salinity levels of the initial and replenishment water for the units are important to take into consideration. If Electric Conductivity (EC) levels are above a certain amount (2000 Micro-Siemens) then vegetables growing in soilless culture methods will struggle. This will lead to a substantial amount of water dumping to lower the EC levels which will decrease the unit's water efficiency rate and negatively impact bacteria growth.

Finally, prevailing winds: if local prevailing winds are present it is very important to protect the plant production component of the unit using either a greenhouse or wind protection barriers. Plants can use from 15-50% of their energy on plant stability alone due to prevailing winds so plant growth will suffer if this environmental factor in not sufficiently dealt with.

D) Other minor factors to consider:

- The legality of food production with the presence of fecal coliforms from cold and warm blooded animals in the plant growing media in a specific country
- Access to quality seeds/seedlings

- Attitudes to fish production and consumption and soilless culture within the local culture
- Bio-security
- Proximity to a hydroponic solution supply as a backup if fish die

E) Summary of essential requirements for aquaponics at difference scales

Essential requirements:	Small scale (50-500 lettuce heads)	Semi-commercial (500-2500 lettuce heads)	Large scale commercial (+2500 lettuce heads)
Optimal climate and environmental conditions for aquaponics (as discussed above)	X	X	X
Access to good quality fish fry, fingerlings and seeds/ seedlings on demand	X	X	X
Access to other essential inputs including: Water and air pumps, water test kits, bio-filtration media	X	X	X
Access to electricity and appropriate water at the unit site at all times	X	X	X
Feasible methods to control key environmental factors including: Automated greenhouse technology with air ventilation, humidity and carbon dioxide control; water heating systems		X	X
Sophisticated water quality monitoring equipment (i.e. digital oxygen & pH meters)		X	X
Equipment for effective, large-scale fish solid waste capture and bio-filtration (swirl separators, clarifiers.. etc)		X	X
Sludge waste management		X	X
Backup power generators		X	X
Bio-security and integrated pest management protocols		X	X
Good experience with both aquaculture and horticulture methods		X	X
Business plan including extensive market research		X	X
Aquaculture & hydroponic specialists on staff or on call			X
Fry production facility, on-site water quality laboratory and extension services for fish disease identification and treatment			X
Automated methods to integrate pure or dissolved oxygen and remove carbon dioxide in the water			X

Annex 6: Cost-benefit analysis for small scale aquaponic units

Introduction:

The tables below describe all the costs and benefits of a small-scale aquaponics unit. The information in the tables will give the reader an understanding of how much a unit costs to build and run for 1 year along with the expected production valve for the investment over the same period.

The first table below summarizes the total cost of materials for a small-scale media bed unit (the full list of materials and costs for this unit can be found in Annex 5: The step-by step guide to building aquaponic units). The second table details all the running costs involved for 1 year (details of how each figure is calculated can be found in the notes section directly underneath this table). The third and fourth table details the all benefits. The third focuses on actual production of vegetables and fish in one year while the fourth calculates the total financial value of production. The fifth and final table brings together the costs of tables 1 & 2 and the financial value of production in table 4 showing the overall cost-benefit of a unit.

Finally, it must be made clear that the figures in the tables below and the concluding cost-benefit results in table 5 are only guidelines for new users. It is very difficult to provide accurate figures, particularly regarding production yields and their value, as many factors influence them including: temperature & seasons, fish type, fish feed quality and percentage protein, markets prices.. etc.

Assumptions of the calculations below:

1) All calculations are based on a small-scale Media bed unit with 3 sq. meters of growing space and 1000 litres of fish tank space (the Step-by-Step annex shows how to build this exact unit).

2) The unit is for domestic food consumptiononly and not for small scale income generation by selling the outputs. The financial benefit would actually be larger than reflected in table 5 below if the farmer selected the most profitable crop to grow. Yet, as the focus is on small-scale aquaponics for domestic food consumption, we've included two crops in the calculations: one leafy green (lettuce) and 1 fruiting vegetable (tomatoes), as this better reflects the growing patterns of users growing food for consumption only.

3) Continuous production for 12 months, feeding the fish with quality 32% protein feed daily in unit water temperatures between 23-26°C throughout the 12 month period.

4) The unit will have a constant standing fish mass between 10-20kgs.

5) Tilapia fish are grown and fed 50 grams per sq. meter of growing space (50 grams x 3 sq.meter = 150 grams per day) with expected growth rates of: 20 to 500 gram in 6-8 months.

6) 20 heads of lettuce are grown per sq.meter per month and 3 kgs of tomatoes are grown per sq. meter per month (average production rate for amateur growers).

Table 1: Total Cost for a Grow-Bed Unit (1000 Liters Fish Tank Space & 3 Sq. Meters Growing Space)

#	Item description	Price
1.	Unit containers: IBC tank containers	100
2.	Electrical equipment: Water pump, air pump and connections	120
3.	Media bed support: concrete blocks and wood length	80
4.	Volcanic gravel (Bio-filtration media)	120
5.	Miscellaneous items: fish net, Teflon, shading material etc	100
6.	Plumbing: pipe, pipe fittings and connections	80
	Total cost (US$)	600

Table 2: Total Cost of Maintaining a Unit per Month

#	system inputs	Unit	Average quantity per month	Price per unit (US$)*	Number of aquaponic units	Total cost (US$)
1	Seedlings	Seedlings	35	0.10	1	3.5
2	Fingerlings (20 grams)	Fish	5	1.00	1	5
3	Electricity	Kilowatt hours	25	0.1	1	2.5
4	Water	Liter	450	0.0027	1	1.2
5	Fish food (32% protein)	Kilo	4.5	2.5	1	11.25
6	Miscellaneous: (Acid/ base, test kits, liquid fertilizer)	n/a	1	3	1	3
	Total cost per month					26.45

Notes on Table 2:

*Colum no.5: The figures presented in this column (shaded in light blue) are estimated prices for each input in Israel/Palestine. Simply replace these figures for the prices in whichever region you are to calculate the total management costs.

1) Seedlings : 35 seedlings is the average reseeding rate per month for 3 sq.meters growing space while growing 50% leafy greens (20 plants per square meter) & 50% fruiting vegetables (10 plants per square)

2) Fingerlings: The max yearly production is 30kg which equates to 60 fish per year @ 500grams per fish. Therefore the unit will need 60 fish per year or roughly 6 per month.

3) Electricity: 30 Watts (water pump) + 5 Watts (Air pump) x 24hours x 30 days / 1000 = 25 Kilowatts per month.

4) Water: On average the water replenish rate for a unit growing leafy greens and fruiting vegetables is roughly 1% of the total water volume in the unit (1500 litres) per day; 15 liter x 30 days = 450 litres

5) Fish Food: 50 grams (fish food) x 3 (media beds) x 30 days= 4.5kg per month

6) Miscellaneous: The total figure of $3 per month is an estimated price for the use of acid or base, water test kits and liquid fertilizer if necessary.

Table 3: Expected Yearly Production for Lettuce (heads), Tomatoes (Kg) and Fish (kg) for a Media Bed Aquaponic Unit with 1000 Litres Fish Tank space & 3 Sq. Meters Growing Space

Media bed unit	Max fish mass (kg)	Average Lettuce heads per year	Average tomatoes per year (Kg)	Average fish yield per year(Kg)
1	20	360	54	30

Notes on Table 3:

1)Average lettuce heads per year: 1.5 sq. meters (50% of growing space) x 20 lettuce heads per sq. meter per month (1.5 x 20) = 30 heads per month. Per year: 30 x 12 = 360 lettuce heads

2) Average Tomatoes per year (Kg): 1.5 sq. meters (50% of growing space) x 3 kgs of tomatoes per sq. meter per month (1.5 x 3) = 4.5kg per month. Per year: 4.5 x 12 = 54 Kgs.

3) Average fish yield per year (kg): Fingerling growth rate of 20-500 grams in 8 months with a max fish mass of 20kgs per 1000 litres = 20kgs (8 months) + 10kgs (4 months)= 30 kgs over 12 months.

Table 4: Estimated Value of Fish and Plant Production for 1 Year:

Output	Production Quantity	Unit market Value (US$)	Total (US$)
Lettuce	360 (heads)	1.2 (per head)	432
Tomatoes	54 (kgs)	1.6 (per Kg)	86.4
Fish	30 (kgs)	8 (per Kg)	240
Total Value			758.4

Notes on Table 4:

Unit Market Values (Column 3): These figures are taken from an Israeli market price comparison website: www.zap.co.il and the Israeli Plant production and Marketing Board www.plants.org.il on the 17th of September, 2013.

Table 5: Cost/Benefit Analysis of a Media Bed Unit in 1 Year

Total Costs Per Year	Total (US$) Per Year
Unit Construction Cost	600
Total Management Cost ($26.45 x 12)	322.2
Total Production value	758.4

Taking the final figures for management cost and production value together, we can conclude that the production value of $758.4 just over doubles the management costs at $322.2. This means that in general, once a unit is set up, $2 worth of output is produced for every $1 invested in growing food using a small scale aquaponics unit for domestic consumption.

Step by Step

Guide for Constructing
Small-Scale Aquaponic Systems

Smart Fish

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Annex 7: Step by Step Guide for Constructing Small-Scale Aquaponic Systems

Introduction:

This step by step guide describes how to build the three methods of small scale aquaponic units described in chapter 4 of this manual.

Initial comments on the 3 designs
The actual design theory for the 3 methods is explained in chapter 4 so this annex will only focus on how to set them up using cheap materials that are universally available (although brief explanatory comments will be given for some of the more complicated components for each unit throughout).

The key factors considered for the design of each unit showcased are 1) material cost, 2) material availability and 3) production capacity. Thus, the materials for each design shown in the proceeding diagrams have all been purposely selected as they are all widely accessible. The main material used for fish tanks, grow beds and DWC canals is the Intermediate Bulk Container (IBC) which is roughly a 1000 liter container used to transport different liquids worldwide. Yet, for all components of each unit design, local/cheaper materials can be substituted but the recommendations for alternative materials stated in chapter 4 of the manual must be adhered too.

There are 3 major sections to the manual:
The first section shows how to build the Media Bed Unit using fabricated IBC containers for the fish tank, media beds and sump tank.

The second section describes how to build an NFT Unit. This includes how to set up the fish tank (same as Media Bed unit), how to fabricate and install a mechanical separator and a bio-filter using blue barrel containers and how to install the NFT grow pipes using standard 4” (110cm) PVC drainage pipe.

The third and final section shows how to build the DWC Unit. The same fish tank method for the Media Bed is employed along with same swirl clarifier and bio-filter method given for the NFT unit. The other parts show how to set up the DWC canals and fabricate rafts using polystyrene sheets.

An index of all materials and tools used for each section are given in the following 2 pages which should be referred to for each of the 3 major unit construcion sections.