Aquaponics Curriculum

Student's Manual

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Aquaponics Curriculum
Table of Contents

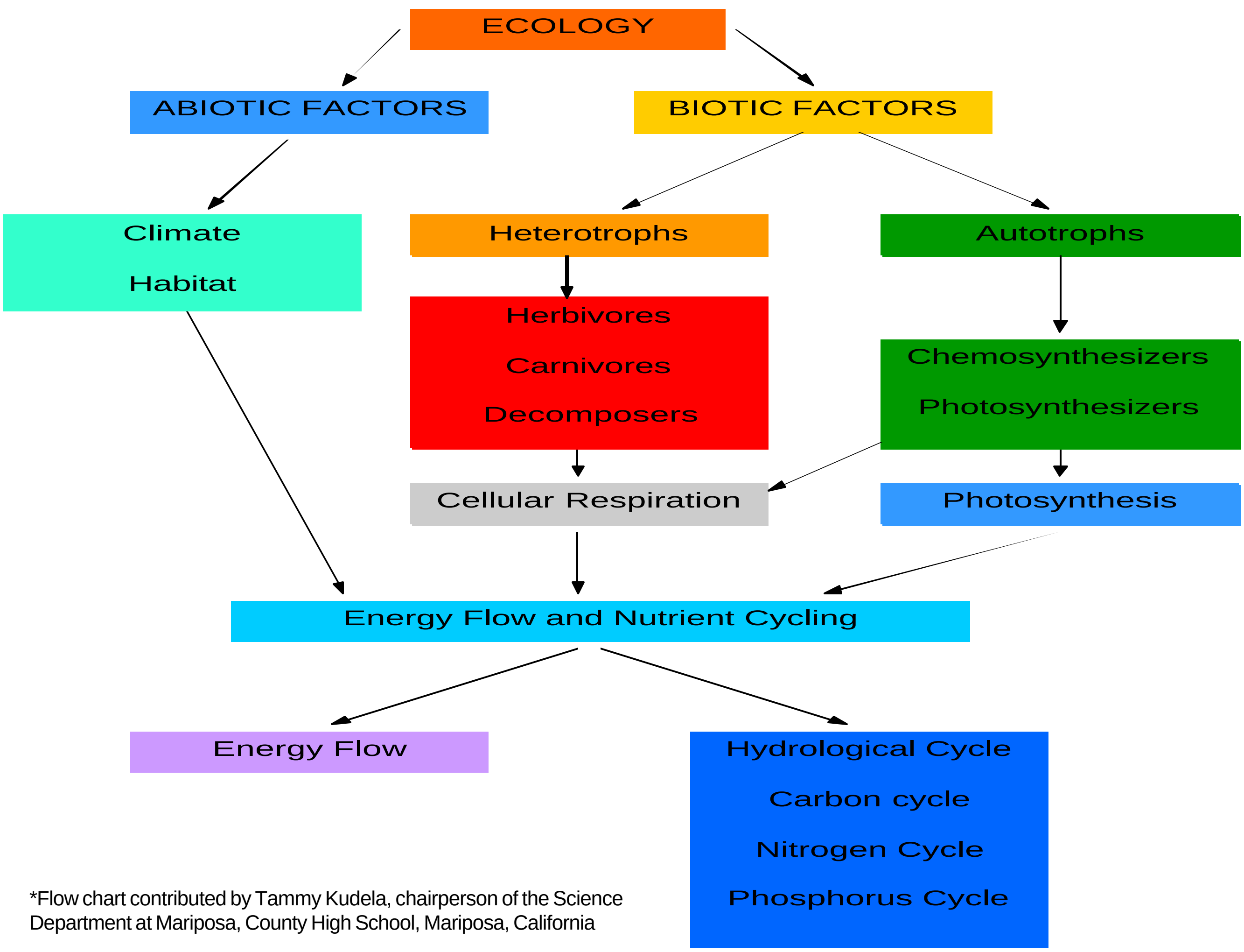
Chapter One	Introduction and System Design	4
Chapter Two	Establishing and Maintaining the Fish Tank	16
Chapter Three	Seed Germination and Planting	28
Chapter Four	Plant Selection and Care	36
Chapter Five	Plant Nutrient Requirements	44
Chapter Six	Photosynthesis, Transpiration and Light	53
Chapter Seven	Fish Anatomy	62
Chapter Eight	Fish Nutrition and Health	70
Appendix A	Additional Information Sources and Pertinent Web Sites	78
Appendix B	Project and Experiment Ideas	79
Appendix C	Other Products from Nelson/Pade Multimedia	80

Preface

Aquaponics is an ideal means of teaching students plant science, nutrition, physiology and care, nutrient and pH testing, pH relationships, nitrification, biology, fish anatomy and nutrition and high-tech agriculture. A unit in aquaponics enforces practical uses of chemistry, mathematics, physics, economics and engineering. The monitoring and care of an aquaponic system by students helps instill a sense of responsibility, inspires creativity and creates excitement in the learning environment. A unit on aquaponics can be started at the beginning of a semester and run through the entire semester, allowing the educator to present the individual concepts and lessons as the plants and fish develop and grow.

The skills used by students during this unit on aquaponics include observation, measuring, testing, experimenting, recording data, problem solving and critical thinking. The activities and lessons in this curriculum are aimed at students in grades 7-10 but they can be easily adapted for advanced grade school students or can be the basis of a more extensive unit for high school science.

From a science point of view, the applications of aquaponics are only limited by ones imagination. Below is a flow chart* that profiles some of the many disciplines that can be incorporated into a program involving an aquaponic system.



*Flow chart contributed by Tammy Kudela, chairperson of the Science Department at Mariposa, County High School, Mariposa, California

Chapter One

Introduction to Aquaponics

Notes

Aquaponics is simply the combination of aquaculture (fish farming) and hydroponics (growing plants without soil).

Koi and lettuce in an aquaponic

Hydroponics is growing plants in a water and nutrient solution, without soil. The solution is created by adding the elements a plants needs to water, which is fed directly to the plant's roots. In some hydroponic systems the roots are in a growing medium which keeps them moist, aerated and helps to support the plant. Hydroponics provides the plant with the ideal water and nutrient ratios and optimum conditions for growth.

In aquaculture, the water quickly becomes nutrient rich due to the fish digesting their food and excreting waste. The waste water is usually filtered and/or disposed of to keep the tank water free of toxic buildups.

In aquaponics, the fish waste provides a food source for the growing plants and the plants provide a natural filter for the fish. This creates a mini ecosystem where both plants and fish can thrive. Aquaponics is the ideal answer to a fish farmers problem of disposing of nutrient rich water and a hydroponic growers need for nutrient rich water.

Applications of Aquaponics

Commercially, aquaponics is in its infancy but, as the technology develops and is refined, it has the potential to be a more efficient and space saving method of growing fish, vegetables and herbs. By incorporating aquaponics, hydroponic growers can eliminate the cost and labor involved in mixing a fertilizer solution and commercial aquaculturists may be able to drastically reduce the amount of filtration needed in recirculating fish culture. Although there is currently a limited number of commercial aquaponic operations, many people are expressing a strong interest in this intensive method of food production.

As we approach the new millennium, it is more important than ever to find means of cultivating food that do not have a negative effect on our planet and it's inhabitants. Aquaponics, aquaculture and hydroponics all can be used to produce large quantities of food in very small spaces in an environmentally friendly way.

Notes

Students of all ages can learn from an aquaponic system in which plants and fish live in a recirculating aquatic environment. A small aquaponic system can be set up in any classroom to encourage individual responsibility while demonstrating the principles of the nitrification cycle, plant usage of nutrients, pH relationships, botany, plant growth, biology, fish health. In addition to classroom setups, an aquaponic system makes an ideal science or agriculture project for students.

The variables in design and construction materials are determined by the location and purpose of your system. If you are building a classroom unit and are on a strict budget, you may choose to use a plastic tub that you have on hand for the fish tank rather than investing in a new glass tank. If the unit will be on display, a new glass tank and a plexi-glass grow bed will cost more but, aesthetically, is more attractive.

Although the practices of fish farming and soilless plant culture have been traced to ancient times, the combination of the two is quite new. Research in aquaponics began in the 1970's and continues today. Several Universities worldwide are dedicating resources to further the technology. At the University of the Virgin Islands, Dr. James Rakocy and his associates have developed a commercially viable aquaponics system designed for use in the tropics where natural fish populations have been depleted and most agricultural products must be imported.

On a hobby scale, aquaponics has the potential to catch on quickly. A home aquarium, with ornamental or food fish, can be combined with a mini garden, growing herbs, vegetables or flowers. A hobby system can serve as a beautiful show piece or a food production system, depending on the size. Many backyard gardeners are setting up systems to grow hundreds of pounds of fish and all the fresh vegetables a family needs.

Aquaponic System Components

Following is a list of basic components you'll need for a healthy desktop aquaponic garden. One could argue the need for some of the items suggested but it is better to cover all the bases and be successful the first time rather than skimp on equipment and potentially kill fish or plants. Once you operate any of the three care free systems described and see aquaponics in action, you'll be hooked. That may lead you to other desktop systems, home-aquaponic-food production or even aquaponics on a commercial scale. So, here is what you'll need:

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A Tank for the Fish
The tank can be a glass or plexi-glass aquarium or, if on a budget, you can use any other clean container that holds water, i.e. a plastic tub, bucket, barrel, etc. Do not use any container that was previously used to hold chemicals or cleaning agents. Commercially, you can have fish tanks of 5,000 or more gallons but, if this is a classroom/desktop unit, I recommend anything between 5 - 100 gallons. If you have the space and budget, larger systems can be set up. The larger the tank, the larger grow bed area you can support. As a general rule, you can support 2 square feet of growing area for every 10 gallons of fish tank water.

Under-gravel or other type of aquarium bio-filter
An under-gravel filter or other aquarium bio-filter should be used to assist in the nitrification process. Fish excrete ammonia in their wastes and through their gills. In its raw form ammonia is toxic to plants. A bio-filter is simply a place for bacteria, which exist naturally in water, air and soil, to convert the ammonia to nitrite and then to nitrate. The plants can readily use the nitrate in the water and, in consuming it, help to purify the water.

Gravel for the tank bottom
If you are using an under-gravel filter, the gravel serves as the home to the nitrifying bacteria. If you are using a bio-filter that mounts on the side of the fish tank, the gravel is used mostly to anchor aquatic plants and give the system a more natural appearance.

Aquarium heater (for tropical fish)
Most gardeners or aquarists setting up an aquaponic system choose ornamental fish for the tank and most ornamental fish originate in tropical waters. A tank temperature of 78^{o} F will need to be maintained for tropical fish. Two kinds of aquarium heaters are available: submerged and tank-side mounted. Either will work but be sure the heater you choose is sized for the number of gallons of water in your fish tank. If you choose to grow cool-water fish, an aquarium will not be necessary.

Water pump and tubing
A small water pump is needed to move the water from the tank to the grow bed in two of the systems shown (Flood and Drain and NFT). Your grow bed in any of these systems should be higher than the tank so the water pumped into the grow bed can gravity-feed back to the fish tank. You'll need enough tubing to go from the outlet on the pump to the top of your grow bed.

Air pump and tubing
If you have an under-gravel filter, an air pump is essential to pass air through the vertical filter stems and down to the gravel.

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expanded clay pebbles

If you are using another type of bio-filter, it may or may not use air in the filtration process. With either type of filter, your plants will do best if you use an air pump to blow additional air into the tank water. Run tubing from the air pump to an air-stone at the bottom of the tank. This will ensure that the oxygen levels are always adequate for both the fish and the plants.

Grow bed

Later in this booklet, directions are given for building three systems: Float, Flood-and-Drain and NFT. In a Float system plants are grown in net pots that rest on a floating raft on the surface of the tank water. In the Flood and Drain system, a grow bed slightly larger than the diameter of the tank rests on top of the tank. This grow bed is filled with a growing medium in which the plants grow. In the NFT system the plants are grown in channels. The plant roots rest on the bottom of the channel where a thin film of water flows, keeping the roots moist, aerated and healthy.

Growing medium

A growing medium is used in hydroponics and aquaponics in place of soil. It should be porous and chemically inert and able to hold the plant roots and maintain moisture. Examples include perlite, expanded clay pebbles, gravel and rockwool. In the float system the net pots are filled with a coarse growing medium like gravel or clay pebbles. In the Flood-and-Drain system the grow bed is filled with a growing medium. In the NFT system no growing medium is used.

Fish and plants

In any aquaponic system the fish provide the nutrients the plants need and the plants purify the water by consuming those nutrients. In selecting your fish, choose hardy species like goldfish, guppies, angelfish and other common varieties. A desktop aquaponic garden will support most varieties of house plants, lettuce, spinach and herbs. You can also plant aquatic plants in the fish tank. They will provide a more natural habitat for the fish and aid in purifying the water. In larger systems, food fish such as tilapia, bass and sunfish can be grown.

Optional Components:

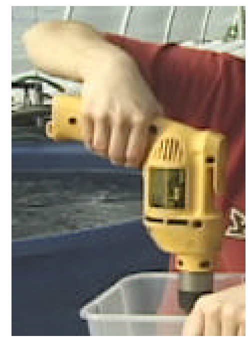
Fluorescent light for fish tank

Most aquariums have a florescent light so you can see the fish and monitor their health. If you have aquatic plants, an aquarium light is essential for their growth.

Notes

Grow light for the plants
If you establish your system in an area with low light levels, you may need to add artificial light for healthy plant growth. Keep in mind the light levels a plant likes will quickly encourage algae growth in the fish tank. You should try to point an artificial light in a way that it does not directly penetrate the tank. If you do have rapid algae growth, merely scrape the interior walls of the fish tank or buy a plecostomus, a fish that eats algae. They are available at most aquarium stores.

Tools Required



Depending on the system you choose and if it is manufactured or you build it, you may need the following:
- Drill with 1/4” or 3/16” bit and 1/2” bit
- Scissors
- Electrical tape
- Razor knife

Once your aquaponic system is operating, you need:
- a siphon hose
- bucket
- pH test kit
- fish food

Grow Bed Designs

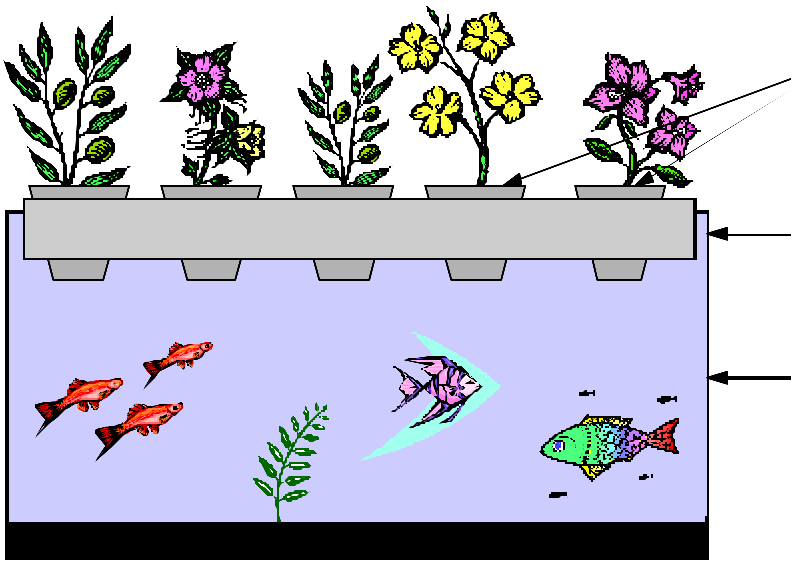
In this booklet, three types of grow beds are shown: Float, Flood and Drain and NFT. Each system has advantages and disadvantages, varying cost of materials and space required.

The Float system is the simplest and least costly of the three, with its grow bed floating directly on the surface of the fish tank.

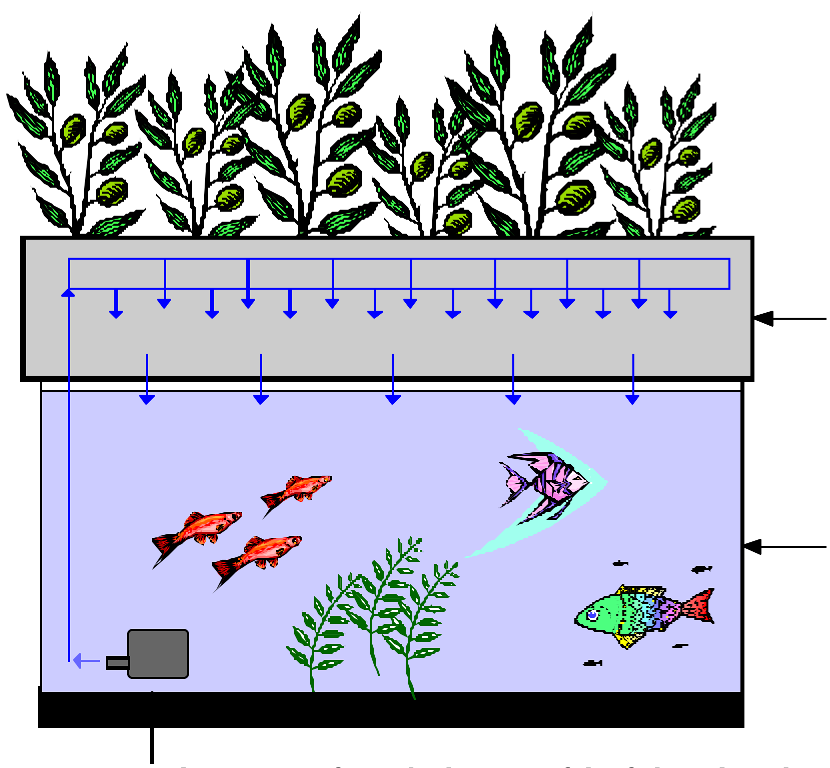
The Flood and Drain system is compact, the grow bed sits on the top of the fish tank. The deeper grow bed allows for larger and long-term plants to be grown. In a larger system, the grow bed can be separate from the tank, sitting nearby.

The NFT (Nutrient Film Technique) system is easily expandable and ideal for growing an indoor food garden with leafy crops such as lettuce and herbs.

Float Aquaponic System



Flood and Drain Aquaponic System



Pump circulates water from the bottom of the fish tank to the top of the grow bed. The water trickles through the grow bed keeping the growing medium moist and drains back into the tank.

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Float System Set-Up

Step 1. Measure the inside diameter of the fish tank. Subtract 1" from each side of the diameter measurement and then cut a 1" think piece of styrofoam to these dimensions. Acquire net pots or plastic planting cups with holes in the bottom. Place the cups upside-down on the styrofoam and trace around them. Cut out the cup holes slightly smaller than the circles you traced. This creates a lip that the top of the cup will rest on. (You don't want the cups to fall though!)

Step 2: Set the styrofoam float tray on top of the tank.

Step 3. Fill the net pots or cups with a coarse growing medium. I recommend either expanded clay pebbles or gravel. The growing medium you choose should be larger than the holes in the pots to prevent it from spilling into the fish tank. Plant your seeds or work your plants into the growing medium and set the filled cups into the holes you cut in the Styrofoam tray.

Step 4. Sit back and watch the plants grow.

Flood and Drain System Set-Up

The grow bed for the Flood-and-Drain system can be made from any water-holding container that is slightly larger than the fish-tank diameter and between 3 - 6 inches deep. You can use a plastic tub or, for a very nice looking unit, build one out of plexi-glass and seal with a nontoxic silicone glue. If you build the grow bed, you can accommodate an aquarium light by making a cavity in the grow bed the light can slide into. If you are using some other kind of container, a light can rest just behind it if it's narrow enough.

Step 1: Either acquire or build the actual grow bed. Be sure it is wider than the tank so it rests on top of it without falling in. Drill 1/8" or 3/16" holes in the bottom of the grow bed every 2-3 sq. inches so the water can trickle back into the tank. Drill a hole in the bottom of the grow bed just big enough for the tubing from the water pump to pass through.

Step 2. Set the grow bed on top of the tank.

Step 3. Place the water pump in the fish tank and feed the tubing from the water pump through the hole so it reaches about 3/4 of the way through the grow bed.

Step 4. Fill the grow bed with the growing medium to nearly the top of the tube.

Step 5. Puncture small holes every 2 inches in a piece of tubing (same diameter as the piece coming from the pump) that will easily make a loop around the inside of the grow bed. Attach a Tee to the tubing coming up, connect one end of the punctured tubing to it. Make a loop with the punctured tubing and attach the other end to the Tee.

Step 6. Cover the loop of tubing with an inch or two of growing medium.

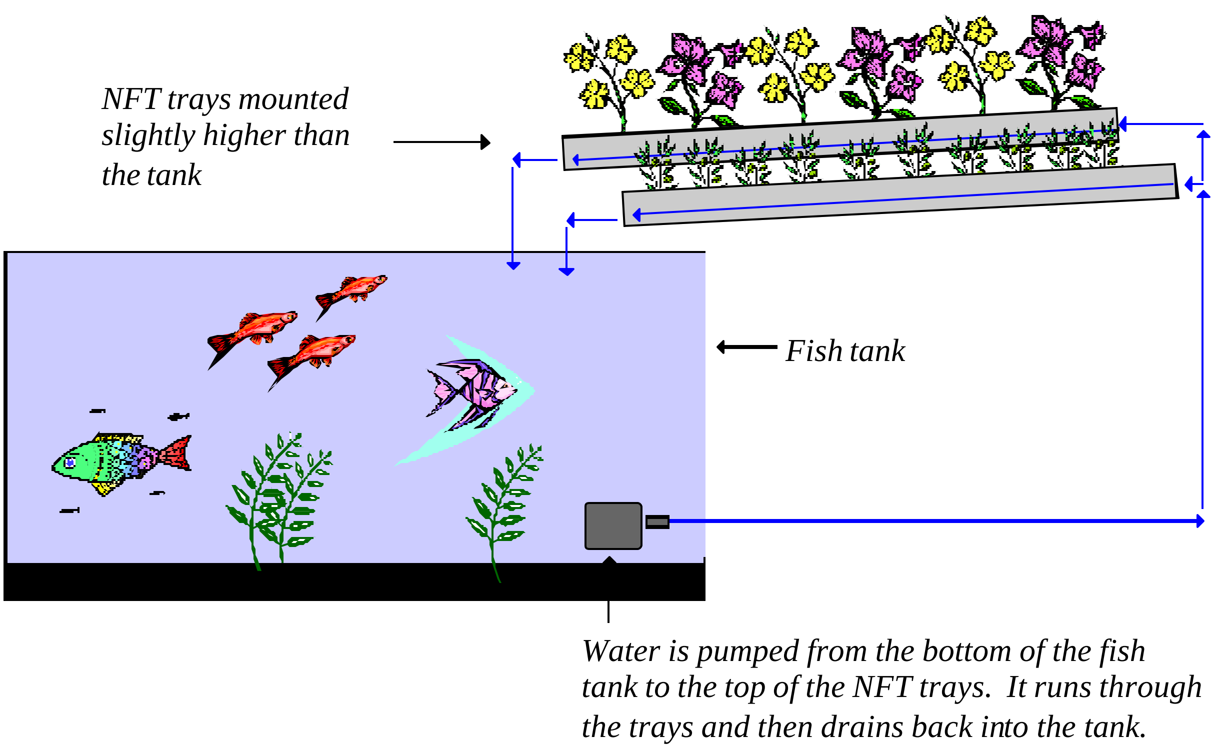
Step 7. Plug in the pump and the water will run through the tubing and will be disbursed evenly through the grow bed, keeping it moist. The water from the grow bed will continuously trickle back to the fish tank.

8. Plant your seeds or plants directly in the moist growing medium or start them elsewhere and transplant them into your grow bed once they've sprouted.

NFT System Set-Up

Rather than resting on top of the tank, the NFT channels can be placed anywhere nearby, as long as they drain back into the tank. The channels can be manufactured NFT channels, rain gutter or any other 2" - 4" deep channel. The advantage of the manufactured channels or gullies is that they are covered and have predrilled holes in which to set plants. This provides

NFT Aquaponic System



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better support for the plant. In addition, the manufactured NFT channels or gullies are designed to provide the plant roots the best combination of water, nutrients and fresh air.

Step 1: Set up a table, rack or wall brackets to support the channel or channels. They should be supported at a slight angle with the far end higher than the tank. The lip of the channel should be just over the tank to allow the water to return.

Step 2. Set the pump into the tank. Run tubing from the pump outlet to the far end of the channel. Plug in the pump, check for leaks and adjust if necessary so a thin film of water continually flows through the bottom of the channel.

Step 3. You can place seeds in small rockwool grow cubes or horticubes to keep them from washing away and then set them into the channel. With manufactured NFT channels you can plant seed in cubes or transplant small plants by setting them into the predrilled holes.

Lesson One - Introduction to Aquaponics
Activity Worksheet

Water Holding Abilities of Growing Mediums

Students: ______________________ ______________________

______________________ ______________________

Date: ______________________

	Growing Medium	**Amount of water absorbed by the growing medium**
# 1	____________	____________
# 2	____________	____________
# 3	____________	____________
# 4	____________	____________
# 5	____________	____________
# 6	____________	____________
# 7	____________	____________
# 8	____________	____________

Lesson One - Introduction to Aquaponics - Quiz

Student:________________________________ Date:______________ Period:_________________

1. Aquaponics is the combination of ______________________ and ______________________.

2. Aquaculture is defined as growing plants without soil. True or False

3. In aquaponics, fish waste provides a food source for the plants and the plants help to purify the water for the fish. True or False

4. Aquaponics is important to the future of food production because it allows a grower to produce a large quantity of food in a small space using minimal resources. True or False

5. List 4 areas of science an aquaponic system demonstrates:

1. ___________________________________

2. ___________________________________

3. ___________________________________

4. ___________________________________

6. In a __________________ nitrifying bacteria convert ammonia to nitrite and then to nitrate, which the plants consume.

7. What is a growing medium?

____

____

____

8: List the three primary aquaponic system designs:

1. ___________________________________

2. ___________________________________

3. ___________________________________

9. List four things you will need once your aquaponic system is operating:

1. ___________________________________ 2. ___________________________________

3. ___________________________________ 4. ___________________________________

Chapter Two

Establishing the Fish Tank

Notes

Stocking your Tank with Fish

For each of the three system designs, establishing the fish tank is the same.

Step 1. Set up the aquarium with the under-gravel or bio-filter as per manufacturers instructions. Fill the tank with water, set heater in place and adjust to the desired temperature. If you are using water that has been purified with chlorine or a similar agent, let the water stand 24 hours to allow the chlorine to dissipate or use a dechlorination product (available at aquarium stores).

Step 2. Stock your aquarium with fish. Start with a few and gradually add fish every couple of weeks until you reach the maximum stocking rate of 1 - 2 inches of fish per gallon of water. When introducing fish from an aquarium store into your system, it is important that you allow them to slowly acclimate to the water. Initially float the fish in a bag of water to allow the temperature in the bag to match to temperature of the water in the fish tank. This should take about 30-40 minutes. Then open the bag and dip some of the water from your tank in it, close the bag and allow it to float for about 10 minutes. Do this 2 or 3 times and then gently pour the fish and water from the bag into your tank.

Once your tank has been setup with fish in it for several weeks you can add the grow bed. Yes, it is possible to add it sooner if you just can't wait but the plants will initially be stressed because of the minimal amounts of nutrients in a newly established tank.

Fish Selection

When selecting fish for a small aquaponic system, choose hardy species like goldfish, guppies, angelfish and other common varieties available from your local aquarium store. Most desktop aquaponic gardens do not include food fish because there isn't enough space to grow them to maturity. If you do want to raise food fish and have a large enough tank, be sure to provide adequate feed and environmental conditions. Following is a list of common tropical fish and some food fish that will do well in an aquaponic system. Information about is species is provided.

Fancy Guppy (Poecilia reticulata)
Origin: Central to South America
Size: 5 cm pH: 7.3
Temp: 27°C/80°F
The Fancy Guppy is probably the

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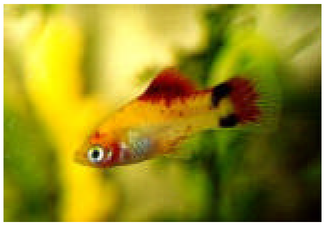
most popular aquarium species in the world. Small, beautiful, peaceful, lively and hardy, there's a myriad of colorful variants that can be collected and easily bred. The Guppy is one of the best choices for beginners in the hobby. Guppies are live-bearers that will easily breed in a home aquarium or aquaponic system.

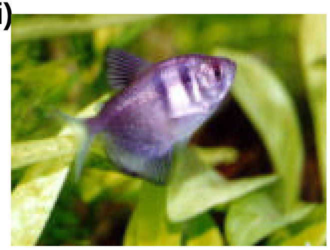
Platy (Xiphophorus maculatus)
Origin: Central America
Size: 5 cm pH: 7.3 Temp: 25ºC/77ºF
Small, hardy, active and pretty, the Platy is one an excellent choice for a beginner. A prolific live-bearer, platies can be found in several different color varieties which have been developed through decades of selective breeding. Platies will eat just about anything including algae, making it a handy cleaner fish as well.



Swordtail (Xiphophorus helleri)
Origin: Central America
Size: 13 cm pH: 7.3 Temp: 25ºC/77ºF
The swordtail is a peaceful species, desirable in the community tank. The wild swordtails are all a pale green color but the domesticated hybrids you'll find in your local pet store will be a brighter green, red, painted, pine-apple (yellowish). Swordtails, like all live-bearers, are very easy to breed and raise.

Serpae Tetra (Hyphessobrycon callistus)
Origin: Paraguay, Central Brazil
Size: 4 cm pH: 6.6 Temp: 26ºC/78ºF
Serpae Tetras are small, hardy and very popular. They're usually quite peaceful towards other species but will sometimes fight among themselves. During these disputes, they boost their beautiful colors and open their fins wide. Tetras are egg layers.

Black Tetra (Gymnocorymbus ternetzi)
Origin: Central America
Size: 7 cm pH: 7.0
Temp: 23ºC/73ºF
The Black Tetra grows a little larger than most other tetra species but



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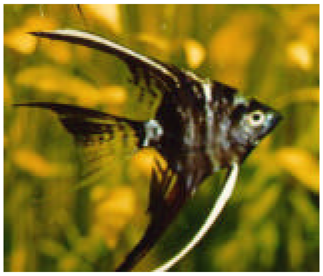
they're just as peaceful and hardy as the others. They exhibit the typical tetra behavior of picking on each other, although it never seems to get serious. Their colors vary according to health, mood and lighting levels, only occasionally reaching a solid black tone. Tetras are egg layers

Pleco (Hypostomus plecostomus)
Origin: Amazon
Size: 60 cm pH: 7.2 Temp: 25ºC/77ºF

The Common Pleco is a hardy fish that can reach lengths of 60 cm. It is widely available and a nice addition to larger tanks. It is often thought of as only an algae eater but, while it eats algae very effectively, its diet should be supplemented with other foods including sinking pellets and romaine lettuce.

Angelfish (Pterophyllum scalare)
Origin: Amazon Basin
Size: 15 cm pH: 7.0 Temp: 26ºC/78ºF



The Amazon Angelfish has always been an all-time favorite among many aquarists. A member of the cichlid family, the angels' lack of bright coloration is compensated by their unique, beautiful fins and by the variety of patterns which have been achieved through many decades of selective breeding. Angelfish are egg layers.

Tilapia
Origin: Africa
Size: Harvest at 1 - 2 lbs. pH 6 - 8 Temp: 64º - 90ºF

Tilapia, a member of the cichild family, is the most widely cultured fish in tropical and sub-tropical regions of the world because they are easily bred, survive in a wide range of water conditions and gain weight rapidly on a low protein diet. Tilapia is commonly grown in aquaponic systems in which the tank population is very dense, often over 1/2 lb. of fish per gallon of water. Tilapia are egg-laying mouth-brooders.

Bass
Origin: North America
Size: Harvest at 1 - 3 lbs. pH 7 - 8.5 Temp: 68º - 85º F

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Hybrid Striped Bass, a popular food fish, have been a grown in recirculating tank culture for many years. In recent years, largemouth bass, a sought after game fish and tasty food fish, have been converted to pelletized feed and tank culture. Either species can be grown in an aquaponic system although the hybrid striped bass will grow 2-3 times faster than the largemouth bass. All bass are egg-layers.

Catfish
Origin: North America
Size: Harvest at 1 - 1.5 lbs. pH 6 - 8 Temp: 70º - 90º F

Most of the catfish farmed in the United States are Channel Catfish and are raised in ponds but they can be raised in aquaponics also. Other catfish compatible with aquaponic culture include the white catfish, the black bullhead, the brown bullhead and the flathead catfish. Catfish are popular in fish farming due to their fast growth and marketability. The nutritional and biological requirements of catfish have been precisely determined by scientists. Catfish are egg-layers.

Australian Red Claw Lobster
Origin: Australia
Size: Harvest at 8 - 12 in pH 6 - 9 Temp: 70º - 86º F
The Australian Red Claw Lobster is the second largest crayfish in the world. This freshwater creature grows rapidly and can reach maturity in one year. In tank or pond culture, the Red Claw need small structures to provide shelter and protection from other crayfish and fish. Red Claw Lobster can be grown in polyculture (with other aquatic species) with non-aggressive fish such as tilapia. Red Claw are becoming popular world wide as an alternative to wild-caught marine shrimp and lobster. Red Claw are egg-layers.

Feeding Your Fish

With the wide variety of fish foods available to the aquarist, it may seem difficult to determine which are appropriate for your fish. Inferior quality foods may initially cost the less but, in the long run, may cost you more if they have a negative effect on

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the fish's health. Most popular species of aquarium fish will eat flake foods which soften quickly without disintegrating in the water and do not sink to the bottom too rapidly. When they do finally pass through the water over a period of time they are progressively fed upon by top-feeding, middle-feeding and bottom-feeding species of fish. Granules, bits or small pellets have the disadvantage of sinking too quickly for most mid-water and surface fish but are a good choice for bottom-feeding fish. Floating pellets are good for cichlids, goldfish, catfish and other large fish that feed at the surface. Floating pellets do not disintegrate as quickly as most sinking pellets do.

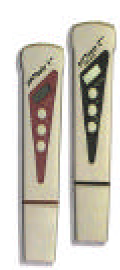
Supplementing a dry food diet with live feeds will make your fish healthier and happier. Plankton, tubiflex worms, micro worms, brine shrimp, earth worms and white worms are all good choices. Some or all of these can be cultured or might be available from your local aquarium store.

Proper feeding of fish requires patience & consideration. It is important to understand the fish and to appreciate differences among species and different stages of their life cycles. The amount of food required depends upon the type of food, the culture conditions and the individual fish. One to two feedings a day are best for most aquarium fish; more for newly hatched fish and food fish and less often for larger fish. Single species, breeding and hospital tanks will require a more careful approach, based on the specific requirements of their inhabitants. As a general rule of thumb, do not feed your fish more than can be consumed in 5 minutes. The problems with overfeeding result when wasted food spoils in the fish tank. Ammonia & other products of decay will degrade water quality & stimulate disease organisms.

System Maintenance

Monthly Water Changes

Every 3-4 weeks you should do a 20-25% water change to refresh the water in the system and remove any ammonia buildup. For example, if you have a 20 gallon aquarium, draw 4-5 gallons out and replace it with fresh, non-chlorinated water. To complete the water change, you'll need a siphon hose or aquarium vacuum, a bucket and an algae pad for scraping unsightly algae off of the tank walls. Before beginning the water change, remove anything from near the aquarium that you don't want to get wet and make sure the electrical outlets are outside of the splash-range. Unplug & remove the grow bed, pump, aquarium light and heater if you have one.



pH pens

Notes

When ready, begin to siphon the water from the bottom of the tank into the bucket. You can start the suction one of two ways. The first is by placing one end of the siphon hose in the tank and sucking on the other end (it works but, more often than not, you'll get the dirty aquarium water in your mouth). The second way is to submerge the entire siphon hose in the tank to allow it to fill completely with water. While still submerged, cover both ends of the tube and then lift one end out and into the bucket. Once one end is in the bucket, uncover both ends and the water will begin to flow. If you have an outside filter box, remove and clean it and replace any cartridges or filter pads that are fouled. To refill the tank, you must use water that is the same temperature of the aquarium water. If your tap water is chlorinated you must remove the chlorine. Chlorine removers are available from most aquarium stores. Chlorine will completely dissipate from water that sits for 24 hours so, if you plan ahead, you can also use this method for dechlorinating your water. When the tank is full, plug in the pump, heater and light and replace your grow bed.

Water Quality Dynamics

Your desktop aquaponic system is easy to maintain and the only daily input is fish food. Water quality dynamics are quite complex and vary dramatically with different sized fish and stocking rates. The most important water quality parameter you can monitor is the pH because when pH is in-line (7.0), most of the other factors fall into place. If you have an ammonia/nitrite/nitrate test kit, you should monitor these factors as well.

pH

The term pH stands for the Power of Hydrogen and is defined as the negative logarithm of the hydrogen ion (H^-) concentration. In other words, pH is a measure of the amount of hydrogen ions in your water. The pH scale runs from 0.0 to 14.0. Values less then 7.0 are acidic, 7.0 is neutral and values greater than 7.0 are basic. Basic is sometimes referred to as alkalinity but, in fact, alkalinity is a measure of the buffering capacity of water. Because pH is a logarithmic function, a change in pH from 6.0 to 7.0 would represent a tenfold decrease in the hydrogen ion concentration; 6.0 to 8.0 would be a 100-fold decrease. In other words a pH of 6.0 is 100 times more acidic than a pH of 8.0.

PH in an aquaponic system is an important factor. Not only do fish require a certain "safe" range to survive, but pH is an important controlling factor for many chemical balances, including the ratio of nontoxic ammonium ion (NH_4^+) to toxic ammonia (NH_3) and between the toxic nitrite ion (NO_2^-) and very toxic nitrous acid (HNO_2).

Notes

You can check the pH of your water using litmus paper, a pH test kit or pH meter. Litmus paper and inexpensive pH test kits are available in most aquarium, hardware and pool supply stores. The ideal pH of an aquaponic system is 7.0, which is a compromise between the plant and fish needs. If the pH is higher than 7.2 the plants in your system will probably not be able to absorb all of the nutrients they need for proper growth and development. You can lower the pH with a "pH down" product. If the pH is lower than 6.5 you should raise it with a "pH up" product. A pH lower than 7.0 will slow down the nitrification process and a pH of 5 or lower will cause nitrification to stop completely. pH Up and pH Down are products that can be purchased at most aquarium and growing supply stores. All water will react differently to additions of pH-correcting substances. Prior to correcting the pH of your tank water be sure to practice with a container of your tap water. The easiest method is to start with a gallon of tap water and test the pH. Add a given amount (i.e.: one drop) of the correction agent and then test the pH again, keeping track of the amount you add. Do this until you see a change in pH and then determine the amount of correction it took to alter the pH.

Nitrification Cycle

More than 50% of the waste produced by fish is in the form of ammonia, secreted through the gills and in the urine. The remainder of the waste, excreted as fecal matter, undergoes a process called mineralization which occurs when Heterotrophic bacteria consume fish waste, decaying plant matter and uneaten food, converting all three to ammonia & other compounds. In sufficient quantities ammonia is toxic to plants and fish. Nitrifying bacteria, which naturally live in the soil, water and air, convert ammonia first to nitrite and then to nitrate which plants consume. In your aquaponic system the nitrifying bacteria will thrive in the bio-filter, in the gravel, and in the growing medium. The plants readily uptake the nitrate in the water and, in consuming it, help to improve the water quality for the fish.

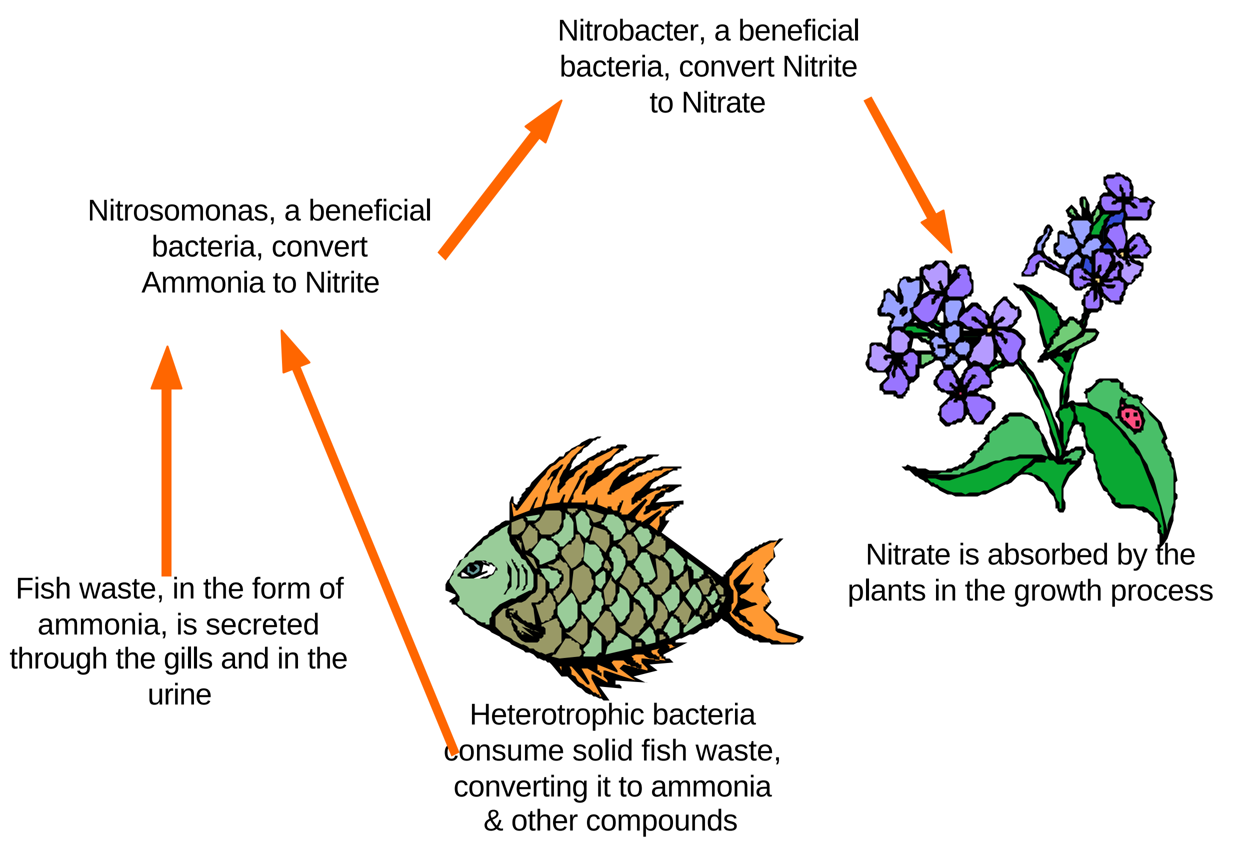
Ammonia

The majority of fish waste produced in an aquaponic system is ammonia or converted to ammonia. Ammonia exists in water in two forms: as toxic molecular ammonia (NH_3) and as the nontoxic ammonium ion (NH4+). At any given time, the amount presence in each form is primarily dependent upon pH and, to a lesser extent, temperature. As the pH and temperature increase, so does the amount of ammonia in the toxic form.

Notes

Nitrite and Nitrate

Nitrite results from the bacteria, Nitrosomonas, converting ammonia. Nitrite is toxic to fish because it interferes with the fish's ability to use oxygen. Levels above 1.0 ppm for freshwater are considered unsafe for most fish. Nitrite is also pH dependent. In a system with a good beneficial bacteria culture, nitrite is converted to nitrate (NO_3^-) (which is relatively nontoxic to fish) by the bacteria Nitrobacter. Nitrate is the primary source of nutrition for the plants in the grow bed and aquatic plants in the tank. If your bacteria culture isn't yet established or is unhealthy and the nitrite levels are too high, partial water changes can be done daily to bring the nitrite level to an expectable level. Highly concentrated beneficial bacteria is sold by most aquaculture suppliers and aquarium store. Although it is not essential, it can provide a quick start to an aquaponic system.



Nitrification Cycle

Notes

Water Quality Test Kits

The serious aquarist should invest in water test kits which will enable you to measure and keep track of pH, ammonia, nitrite, nitrate and water hardness. Most kits sold are easy to use and are based on color changes in the sample being tested, then compared to a color standard. Some kits are supplied with liquid reagents, others with powdered ones.

Chapter Two - Establishing the Fish Tank
Activity Worksheet

pH Testing

Origin of Sample (tap, lake, rain, well)	pH	Acidic or (Check one)	Alkaline
Sample one, well water	7.2		☑

pH of water to be used in class' aquaponic garden:_______________

Is it alkaline, acidic or neutral ?______________

Do you need it alter it ?_________________

If so, how much baking soda (to raise it) or vinegar (to lower it) did you have to add to the gallon of water to achieve the desired pH level ? _________________

Chapter Two - Establishing the Fish Tank - Quiz

Student:______________________________ Date:_____________ Period:________________

1. What is the desired stocking density of fish per volume of water in an aquaponic system?

____

2. List four species of fish that will do well in an aquaponic system:

1. _______________________________

2. _______________________________

3. _______________________________

4. _______________________________

3. Once or twice/day, you should feed your fish as much as they can eat in

a. 1 minute
b. 5 minutes
c. 30 minutes
d. 1 hour

4. You should change 75% of the water in your system every 3-4 weeks. True or False

5. What is the ideal pH in an aquaponic system? __________________

6. At a pH of 4.5, nitrification will stop completely. True or False

7. What do heterotrophic bacteria do?

____

8. Nitrosomonas convert ammonia to nitrite and Nitrobacter convert nitrite to nitrate.
True or False

9. Nitrosomonas and Nitrobacter are harmful bacteria. True or False

10. Explain the role of beneficial bacteria in an aquaponic system:

____

____

____

Chapter Three

Seed Germination: Planting Your Garden

Notes

Planting Your Seeds

When your aquaponic system is built, your pumps and bio-filter are functioning properly and the fish tank is stocked with healthy fish, you are ready to plant your grow bed.

Plants that have been raised in soil can be transplanted in an aquaponic grow bed if the roots are thoroughly rinsed of all soil and organic material but there is always a risk of introducing pests and disease from the nursery where the plants were propagated. Transplanting and cuttings are explored in Chapter Four.

By starting your plants from seed, you have the most control over the initial development of your crop. As a general rule, seeds are free of pests and disease. If you start your seeds in an aquaponic system, there is no transplant stress or shock.

A seed needs moisture and warm temperatures to germinate, which you can provide in your aquaponic grow bed or in a separate system designed for propagation.

Direct seeding into the growing medium is a common method of propagation. Direct seeding works well in perlite, rockwool or any other medium that is fine enough not to loose the seed in. It is important to thoroughly moisten your growing medium prior to seeding and then be sure you've plugged in the water pump to circulate your fish tank water through the grow bed.

To seed directly into perlite (or a similar medium) sprinkle the seeds on the moistened perlite and cover with a layer of perlite. Follow the directions on the seed packet for planting depth.

Rockwool is often used in the form of cubes for seed propagation. To plant seeds in rockwool, soak the cube in water from your fish tank and drop the seeds into the hole in the center of each rockwool cube.

Lettuce plant emerging from a rockwool cube.

Many growers seed into rockwool cubes set in a tray that is flushed with water every few hours. Once the seedling develops and is 2-3 inches tall, move the whole cube with the plant in it into the aquaponic grow bed. A seedling in a rockwool cube can easily be transplanted into a Float, Flood and Drain or NFT system.

Notes

Once seeded, the growing medium will need to be kept moist and warm in order for the seed to germinate. You can initially use water for germination, right up to the point that the seed coat cracks open and the radical root is exposed. At that point, you have a seedling, rather than a seed, which will need water, nutrients, light and warmth.

Controlling temperature is important for good seed germination. Some growers will start their seeds in an incubator, a propagation table or similar device to maintain the ideal temperature throughout the germination process. If proper temperatures are not maintained germination will be delayed or may not happen at all.

When you plant seeds for your aquaponic garden, you should over-seed by 25 % - 50 %. Once your seeds have developed into seedlings, you can select the strongest plants and keep them. The weaker plants should be removed by pinching the plant off at the base. Pulling the plant out will disturb the roots of the plants that you are keeping.

The Germination Process:

(see diagram on the next page)

The initial stages of plant growth happen within the seed coat. As the seed absorbs water, growth begins with cell enlargement. In the presence of water, the stored reserves within the seed are converted chemically to substances that can be readily used in the growing process.

Once the seed coat breaks and the radical root comes out, the seedling will need to draw moisture and nutrition from the medium surrounding it.

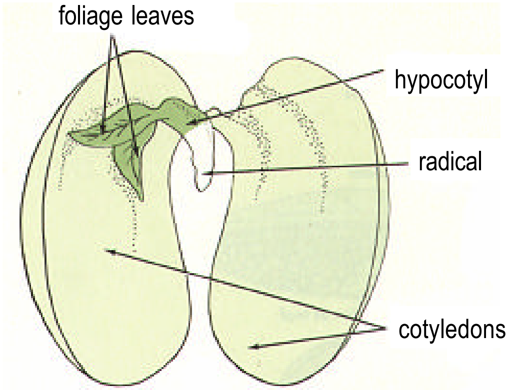
Several days after the root has emerged, the shoot begins to grow. In the presence of light, the seed leaves (cotyledons) open. The opening of the first foliage leaves follows.

Germination Requirements:

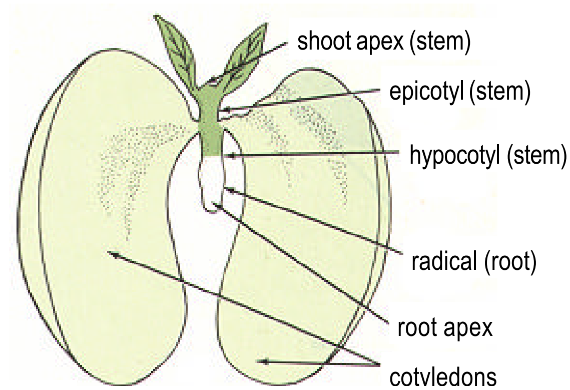
Moisture and Temperature
Saturate your growing medium with water from your fish tank. Be sure to keep the growing medium moist throughout germination. Ideally, the water should be kept about 75 - 80^{o} F. This temperature can be easily maintained with a submersible aquarium heater.

Bottom heat is advantageous for propagation. Heated propaga-

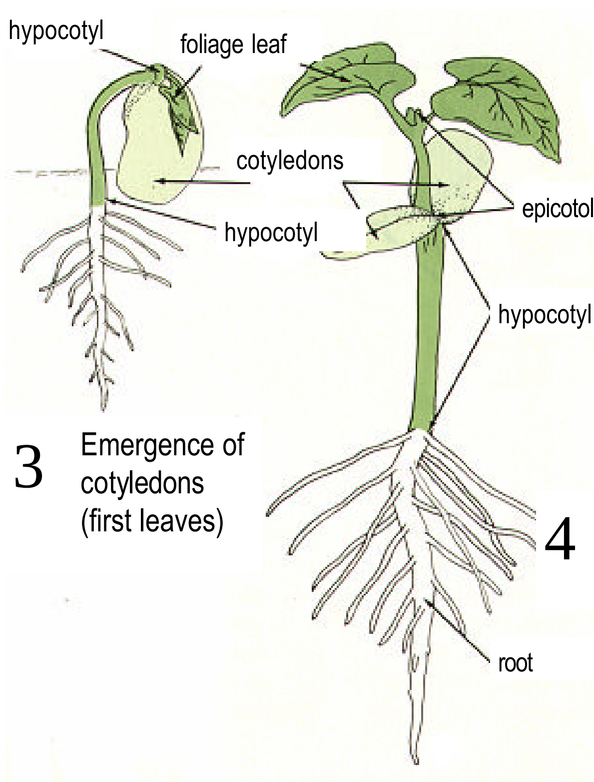
Germination Process
Sample of a Bean Seed



1 Dormant seed showing natural position of seed parts



2 Emergence of shoot



3 Emergence of cotyledons (first leaves)

4 Seedling with first foliage leaves

Notes

tion mats are made for this purpose and are often incorporated into incubation chambers and propagation tables.

Providing the ideal ambient temperature for your seeds will encourage quick germination. The chart below shows optimum germination temperatures for a variety of seeds.

Crop	Optimum temperature for germination
Carrots	86º F
Cucumbers	76º F
Lettuce	76º F
Melons	90º F
Parsley	77º F
Peas	76º F
Radishes	86º F
Tomatoes	78º F

Relative humidity:
The higher the relative humidity, the greater the absorption of water by the seed. Ideally, relative humidity should be 70 % - 80 % in the air around the media and near 100 % right around the seed.

Light
During the first few days of seed germination (the time prior to the radical root emerging) light is not required. After that time, light must be provided. If proper light is not provided, a plant will grow tall and spindly as it searches for light. This is often referred to as “stretching”. Young plants will quickly do this if sufficient light is not available. For seedling growth, having at least 500 foot candles of light is required. This can be either natural or artificial light. If artificial light is used, set a timer that turns the light on for 16 hours and off for 8 hours of each day. Plants do need darkness as part of their daily cycle so do not leave the light on all of the time.

(see Chapter Six, Photosynthesis and Light, for more information).

Seed Selection

The following list of crops can be planted from seed and will do well in any of the three aquaponic systems profiled here. In a well established system with a heavy fish stocking rate, you might also be successful with fruiting crops such as tomatoes, peppers and cucumbers.

Notes

Leaf Lettuce

There is a myriad of lettuce varieties available and most have great taste and texture. Lettuce grows best in a temperature range of 60º - 80º F and pH of 6.0 - 7.0 making it perfect for a desktop aquaponic system.

Basil

Basil is a culinary herb popular for its a pungent fragrance and sharp taste. It is a great companion to fresh tomatoes and a nice addition to sauces, salads, soups and pasta. Basil can survive in a wide range of temperatures but does best between 68º - 75º F. The ideal pH for basil is 5.5 - 6.5 but it handles 7.0 well enough to grow in an aquaponic system.

Beans

Beans do moderately well in an aquaponic garden. Some nutrients may be lacking for proper development. Beans will grow well in an Flood and Drain system with a loose growing medium such as perlite or expanded clay pebbles.

If climbing beans are planted, you will need a trellis for support. Beans will generally produce in about 6-8 weeks, with total time in the garden about 3-4 months.
Days to germinate: 3 - 8

Chives

Chives will thrive in a aquaponic system and, once planted, will continue to grow as long as you take periodic cuttings. Chives make a nice toppings for potatoes, salads and sauces and can be used in place of onions for a milder taste. A temperature range of 60º - 80º F and pH of 6.5 - 7.0 are suitable.

Mint

Mint grows well in a moist rooting environment making it an excellent choice for an aquaponic garden. There are many types of mint, two of the most common being peppermint, spearmint and applemint. A temperature of 60º - 70º F and pH of 7.0 are ideal for healthy growth.

Watercress

Water cress is basically an aquatic plant and will do well in an aquaponic system with a moist grow bed. Fresh watercress is an excellent addition to any salad or sandwich and also makes

Notes

a delicious soup. Watercress does best in a temperature range of 65º - 75º F and pH of 6.5 - 7.0.

Pak Choi

Pak choi, resembling Swiss chard, is a common ingredient in stir fry dishes and Asian cookery. Both the tender stalks and green leaves are edible.   Pok choi does very well in aquaponics.

Chapter Three - Seed Germination - Quiz

Student:_______________________________ Date:_____________ Period:________________

1. A seed needs __________________ and _________________ for germination to occur.
2. Once the seed coat cracks, the ________________________ emerges.
3. The first leaves to emerge are called the _________________________.
4. The second leaves to emerge are called the _________________________.
5. List four things the plant needs once germination has occurred:
    1. ___________________________
    2. ___________________________
    3. ___________________________
    4. ___________________________
6. When seeding your aquaponic garden, you should over-seed by 25% - 50%. True or False
7. For optimum germination, the relative humidity around the seed should be 10%.
True or False
8. Light is required during the first two days of germination. True or False
9. List four edible crops that will do well in an aquaponic system:
    1. ___________________________
    2. ___________________________
    3. ___________________________
    4. ___________________________

Chapter Four

Plant Care

Notes

Ornamental Plants

When choosing ornamental plants to add to your aquaponic grow bed, select only plants which appear to be insect and disease free. Check the undersides of the foliage and the axils of leaves for signs of insects or disease. Select plants that look sturdy, clean, well potted, shapely and well-covered with leaves. Avoid plants which have yellow or chlorotic leaves, brown leaf margins, wilted or water soaked foliage, spots or blotches and spindly growth. Plants which have new flowers and leaf buds along with young growth are usually healthy and a good choice.

Transplanting

If you select a plant that is growing in soil, be sure to thoroughly wash all of the dirt from the roots prior to transplanting the plant into your grow bed. Once the plant roots are clean and free of soil and organic debris, gently work the root base into your growing medium until it is completely covered.

Cuttings

Many common house plants and herbs will readily produce new roots from a cutting, making this an easy means of starting a new plant. To take a cutting, use a clean scissors or pruning shears and snip a branch at the base of a leaf axil. Place the cut end in a small container of water and allow time for new roots to grow. Most garden centers sell rooting compounds which enhance the production of new roots from a cutting. Once your cutting has new root shoots, gently work it into your growing medium.

Following are several common house plants that will do well in aquaponics.

Dieffenbachia
Dieffenbachia is a large plant with colored leaves. Leaf coloration varies depending on the variety. This plant tolerates low light but will do best in medium to bright light. Keep temperatures above 55ºF and, ideally, 60ºF to 75ºF during the day and 60ºF to 65ºF at night. As the plant ages, the lower leaves fall off. Dieffenbachia propagation is by cane cuttings or stem tip cuttings.

Notes

Ivy

Ivy are elegant, rich looking, easy to grow and they age gracefully. They like medium to high light levels and a slightly dry growing medium. Ivy can be trained to cover shapes with their vines but they need constant clipping and directing.

Neanthebella

Neanthebella will do well in low to medium light and likes a slightly dry growing medium. This plant is also called a parlor palm. It stays thick and green with little light and attention. Over watering is evident with yellowing and brown tips on the fronds. Pruning to maintain the shape is not needed with this low growing compact palm.

Dracaena

The name dracaena includes a broad variety of plants which usually have a lot of woody stalk showing and are grown upright with the foliage or head just at the top. They can resemble a candelabra. The leaves are dark green with a dark red margin around the outer edge. Dracaena like medium light levels and a slightly dry growing medium.

Philadendron

Philodendrons are a diverse group of plan that boast more than 200 varieties. The most common philodendron has tall, climbing vines with deep, green leaves that are heart-shaped and glossy. This fast-growing plant can quickly climb a pole. Philodendrons grow in any moist medium that has sufficient air for root growth. Philodendrons grow best in indirect light but will survive low-light conditions if acclimated. A nighttime temperature of 60° F and daytime temperatures between 70° F - 75° F are best for philodendrons.

Aquatic Plants

You can also plant aquatic plants in the fish tank. They will provide a more natural habitat for the fish and aid in purifying the water. Fish & plants compliment each other atheistically and benefit each other in water quality issues. Aquatic plants

Notes

provide shade, shelter and food for some fish. Well lit plants release oxygen which fish need and fish release carbon dioxide which plants need. Aquatic plants are not difficult to keep healthy & beautiful as long as their needs are met. Needs of aquatic plants include adequate light, fertilization, suitable growing mediums, healthy water & the right temperature.

Aquatic plants which do well in a range of water temperatures	*Aquatic plants which do well in warm water with bright light*	*Aquatic plant which do well in warm water with low light*
-Anacharis	-Ceratopterus	-Cryptcoryne
-Cabomba	-Hygrophila	
-Egeria	-Ludwigia	
-Myriophyllum	-Microsorium	
-Sagittaria	-Sagittaria	
-Vallinsneria	-Vallinsneria	

Caring For Your Plants

All of the plants on our planet have adapted to a specific environment. A tomato plant, for instance, is a tropical plant and thrives in average daytime temperature of 80^o F and nighttime temperature of 60^o F. When grown in temperatures outside these parameters, a tomato plant may survive, but not thrive and, if the temperatures are too extreme, the tomato plant will die.

Individual species of plants have very specific nutritional needs that must be met. These needs may vary throughout the stages of the plant's growth. For instance, a tomato plant needs more nitrogen during the vegetative growth stages and less nitrogen during the fruiting stages.

In an aquaponic system, a compromise is required between the needs of the plant and the needs of the fish. The nutrients available to the plant are directly proportional to the quantity of fish and the amount of food fed. For best results in aquaponics, it is a good idea to plant crops with similar needs together so the compromise in minimal.

In the soil, organic materials are broken down to release minerals and nutrients. They can then be dissolved in water, taken up by the roots and passed into the foliage. In hydroponics the minerals a plant needs are provided in precise quantities in a water-soluble form, ready to be taken up by the plant roots.

Notes

The more precisely a plant's needs are met, the more vigorous it's growth will be. When you observe a lush, healthy plant, you can be sure that most, or all of its environmental and nutritional requirements are being met.

Water

As with all plant needs, the amount of water required depends on the species and the needs of that particular plant. A plant that suffers from lack of water will extend a huge, but not very effective root system and will develop a very small plant above the ground. Many roots are sent out in search of water and, when an inadequate amount is found, the plant will not grow to it's potential.

In the other extreme, if a plant is over watered, the roots can drown because they are not receiving the proper amounts of fresh oxygen. This makes proper drainage of a hydroponic growing medium crucial to your plant's health.

The last consideration concerning the water you feed your plants is purity. In an aquaponic garden, you should use as pure of water as possible. Water that has possible toxic contaminants or salt build ups may stunt or kill your plants and fish.

Temperature

Most house plants tolerate normal temperature fluctuations. In **general, foliage house plants grow best between 70**- 80º F during the day and from 60º - 68º F at night. Most flowering and fruiting plants prefer the same daytime range but grow best at nighttime temperatures from 55º - 60º F. The lower night temperature induces physiological recovery from moisture loss, intensifies flower color and prolongs flower life. Excessively low or high temperatures may cause plant failures, stop growth or cause spindly appearance and foliage damage. A cooler temperature at night is actually more desirable for plant growth than higher temperatures. A good rule of thumb is to keep the night temperature 10 to 15 degrees lower then the day temperature.

Humidity

Atmospheric humidity is expressed as a percentage of the moisture saturation of air. The natural evaporation of water from the fish tank will help to increase humidity around the grow bed area. You can also increase humidity in the area near the aquaponic system by misting the plants, grouping the plants close together or running a humidifier.

Notes

Ventilation

Plants require adequate air circulation around the plants as well as proper aeration in the root zone. Poor ventilation in the growing environment encourages mold, mildew and plant disease. In the Flood and Drain and NFT systems, the root zone has plenty of aeration. In the Float system, the root zone should be monitored to ensure the plants aren't drowning. Additional air might need to be introduced into the tank water to ensure healthy plants and roots in the Float system.

Commercial greenhouse growers use large fans and air movement systems to provide adequate air movement. House plants, especially flowering varieties, are very sensitive to drafts or heat from registers. Forced air dries the plants rapidly, overtaxes their root systems and may cause damage or plant loss. For healthy plant growth, place your aquaponic system in a location free of drafts and rapid air movement.

Plant Pest and Disease Control

If you see any plant pest or disease problems in your aquaponic garden, it is best to remove the plant and treat it outside of the system. Fish are highly sensitive to any chemicals, pesticides and cleaning agents so it is best not to use them near your system. In commercial aquaponics, growers use biological means of pest control. For instance, ladybugs, lacewings and other predator and parasitic insects are used to control common pests such as whiteflies, aphids, mites and thrips.

By providing the proper environment for the plants in your system and by carefully inspecting new plants, you drastically reduce the potential of introducing pathogens, diseases, viruses and molds.

Nutrient Deficiencies and Toxicities

A hydroponic gardener uses minerals that are water soluble, and ready to be taken up by the plant roots. Exactly what minerals and in what quantities a plant needs have been determined by scientists and researchers. A large number of hydroponic nutrient formulas have been developed and, although some have better results than others, there is no one perfect mixture. The success of each nutrient formula depends on the conditions in which it is used and the needs of the specific plants grown.

In an aquaponic system, the nutrients that are available to the plants are directly related to the number of fish and the quantity and quality of the fish food. For a precise analysis, the fish tank water can be sent to a laboratory for a report on the elements in the water..

Notes

Plants use some nutrients in larger quantities than others. As a general rule, most plants use the following macronutrients

-Nitrogen
-Phosphorous
-Calcium
-Potassium
-Sulphur
-Magnesium
-Iron

and the following trace elements (used in minute quantities):

-Manganese
-Boron
-Zinc
-Copper
-Molybdenum

In Chapter Five, plant nutrient requirements will be discussed in greater detail.

pH and Nutrient Availability to Plants

As you learned in lesson two, pH is a measure of the amount of hydrogen ions in your water and the pH scale runs from 0.0 to 14.0. Values less then 7.0 are acidic, 7.0 is neutral and values greater than 7.0 are basic. There are specific relationships between pH, the nutrients a plant uses and their availability to use those nutrients at varying pH levels.

PH is important to plant growth and every species of plant has a preferred pH range. PH ranges beyond the preferred for a given plant may cause stunted growth or even death.

Very low pH (< 4.5) or high pH (> 9.0) can severely damage plant roots and have detrimental effects on plant growth.

As the pH level changes, it directly affects the availability of nutrients. The majority of nutrients are available to a plant at a pH range of 6.0 - 7.5. Somewhere within that range is the ideal pH level for most garden and house plants. When pH levels are extremely high or extremely low, the nutrients become “locked” in solution and unavailable to the plant. At extremely low pH levels some micronutrients, such as manganese, may be released at toxic levels.

The newer and more popular growing mediums, like perlite, rockwool and expanded clay have a neutral pH. Peat moss, saw dust, vermiculite and some of the other materials that have been used for hydroponic growing in the past are often unstable and will alter the pH of your solution.

Chapter Four - Plant Selection and Care - Quiz

Student:_______________________________ Date:_____________ Period:________________

1. What should you do to a plant that was grown in soil prior to transplanting it into your aquaponic grow bed?

____

____

2. List three common house plants that will do well in an aquaponic system:

    1. ___________________________
    2. ___________________________
    3. ___________________________

3. List two reason aquatic plants are good to add to an aquaponic system:

    1. ____
    2. ____

4. If a plant is over watered, the roots can drown because they are not receiving enough oxygen. True or False.

5. Flowering and fruiting plants generally do better with (warmer or cooler) night time temperatures.

6. Humidity is the percentage of ____________________ in the air.

7. Fish are not sensitive to pesticides and chemicals. True or False

8. If a plant in your aquaponic system shows signs of pests or disease, you should treat it in the system. True or False

9. The majority of elements are available to plants at a range of_________________________.

10. A pH of 4.0 is (acidic or basic).

Chapter Five

Plant Nutrient Requirements

Notes:

Concentration of Elements

Many hydroponic formulas have been developed over the past 40 years, with some designed for specific plants, while others are designed for general hydroponic gardening. In an aquaponic system, you have the advantage of a built-in fertilizer source from the fish waste. The disadvantage comes from not having a precisely mixed formula. A well balance aquaponic system will support a variety of leafy vegetables and plants but may lack specific nutrients needed for some fruiting plants.

For healthy plant growth, the average concentration of elements in your tank water should fall within these parameters:

Nitrogen (nitrate form)	70 - 300	PPM
Nitrogen (ammonium form)	0 - 31	PPM
Potassium	200 - 400	PPM
Phosphorous	30 - 90	PPM
Calcium	150 - 400	PPM
Sulfur	60 - 330	PPM
Magnesium	25 - 75	PPM
Iron	.5 - 5.0	PPM
Boron	.1 - 1.0	PPM
Manganese	.1 - 1.0	PPM
Zinc	.02 - .2	PPM
Molybdenum	.01 - .1	PPM
Copper	.02 - .2	PPM

*PPM = parts per million

Plant Uses of Individual Elements:

Typically plants are composed of 80-85% water and the balance is made up of a combination of organic and inorganic matter. When the water is removed from a plant and its dry weight is examined, it is found that organic matter accounts for about 95% of the dry weight and inorganic matter accounts for about 5% of the dry weight. Although all matter is composed of elements, all elements are not absolutely necessary for successful plant growth. Many careful studies using hydroponics have helped determine which of the elements are essential nutrients for plant growth. That is, which elements are required by a plant to complete its life cycle from seed to production of another generation of seeds. By deleting elements one by one in a hydroponic solution and comparing the growth of the two groups of plants, researchers have identified 17 elements as essential nutrients for all plants. There are also some additional elements that are essential to particular groups of plants and not others.

Notes:

These 17 elements are divided into two groups depending on the relative amounts of them that are used by plants. Those that are used in large quantities are called macronutrients and those that are used in smaller quantities are called micronutrients. There are nine macronutrients. Six of which are the primary components of organic matter and they are carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur. The other macronutrients are magnesium, calcium, and potassium. There are eight micronutrients and they are boron, chlorine, copper, iron, manganese, molybdenum, nickel, and zinc. Following is a list of these elements and some of their essential functions within a plant.

Macronutrients:

Carbon
Carbon is a major component of all organic molecules. It is the element associated with all of the compounds of "life" such as carbohydrates (sugar and starch), proteins, lipids (fats and oils), and nucleic acids (DNA and RNA) .

Hydrogen
Hydrogen is a major component of organic compounds and it is associated with all of the compounds of "life". It also plays an important role, in the form of water, by supplying a source of electrons for photosynthesis.

Oxygen
Oxygen is a major component of organic molecules and it is associated with all of the compounds of "life". It also plays an important role in oxidizing, or excepting, electrons from other molecules in order to allow essential biochemical reactions to occur.

Nitrogen
Nitrogen is an integral component of nucleic acids (DNA and RNA) and amino acids which are the building blocks of proteins. All of these organic molecules are intimately involved in cell division and thus plant growth. Nitrogen also comprises some hormones, coenzymes, and pigments such as chlorophyll, which is necessary for photosynthesis.

Sulfur
Sulfur is found in some proteins and coenzymes. Infact, some plant proteins can have from 0.5% to 1.5% of this element. When it is in the form of a sulfydryl functional group on an amino acid, it can have an important role in stabilizing the shape and structure of proteins by forming disulfide bridges. When it is a part of a coenzymes it helps enzymes carry out their biochemical reactions.

Phosphorus

Plant Nutrient Disorders

Nutrient	Deficiency	Excess
Nitrogen	Older leaves turn chlorotic and may eventually die. Plant is stunted. Foliage is light green	Plant becomes over vigorous, leaves become very dark green. Fruit clusters have excessive growth and fruit ripening is delayed.
Potassium	Older leaves appear chlorotic between veins, but veins remain green. Leaf edges may burn or roll.	Uncommon to show toxicity. Secondary manganese deficiency may occur.
Phosphorous	Stem, leaf veins and petioles turn yellow, followed by reddish-purplish as phosphorous is drawn from them into the new growth. Seedlings may develop slowly. Fruiting is poor.	No direct toxicity. Copper and zinc availability may be reduced.
Calcium	Plant is stunted. Young leaves turn yellow. Blossoms die and fall off. Tomatoes may develop brown spots on the fruit.	No direct toxicity
Sulphur	Younger leaves become yellow with purpling at base. Older leaves turn light green.	Small leaves
Iron	New growth pales, veins stay green. Blossoms drop off. Yellowing between veins.	Very uncommon
Magnesium	Older leaves curl and yellow areas appear between veins. Young leaves curl and become brittle.	No direct toxicity
Zinc	Leaves become chlorotic between veins and often develop necrotic spots.	Reduces availability of iron
Molybdenum	Older leaves turn yellow and leaf margins curl.	Rare. tomato leaves may turn bright yellow.
Copper	Pale yellow. Leaves become spotted. Plant is stunted.	May reduce availability of iron.

Notes:

Phosphorus is a primary component of nucleic acids (DNA and RNA), phospholipids, ATP molecules and several coenzymes. Nucleic acids are necessary for cell division and protein synthesis, which are in turn necessary for plant growth. Adenosine triphosphate (ATP) molecules serve as the energy source that drives almost every biochemical reaction. Phospholipids make up the membrane which surrounds every cell and the membranes that surround many of its internal parts.

Potassium

Potassium is an important cofactor for protein synthesis. It is also very important in helping the plant to maintain water balance and to properly operate the opening and closing of stomata. Stomata are the openings on the underside of leaves that allow gas and water vapor exchange between the plant and its environment. Potassium is also associated with plant tissues that are rapidly growing, such as merestematic regions. Plants will actually transport potassium from leaves, where growth is less rapid, to the maturing fruit, a region of rapid growth.

Calcium

Calcium is important in the formation and stability of plant cell walls. It is one of the constituents of the middle lamella of the cell wall, where it occurs in the form of calcium pectate. It also helps maintain the structure of cellular membranes and plays a role in their permeability. Some enzymes require calcium to be activated. In addition, calcium regulates the way plant cells res

Magnesium

Magnesium is a constituent of chlorophyll, where it occupies a central position in the molecule. Chlorophylls are the only major compounds of plants that contain magnesium as a stable component. Many enzyme reactions, particularly those involving a transfer of phosphate, are activated by magnesium ions.

Micronutrients:

Chlorine

Chlorine is necessary for the plant to carry out the water-splitting step of photosynthesis. It also helps the plant maintain water balance.

Iron

Iron is an essential component of cytochromes. Cytochromes are specialized proteins that make up the electron transport chains within mitochondria and chloroplasts. These chains are necessary for the plant to produce ATP molecules. As electrons are passed down the chain of cytochromes, the iron atoms

Notes:

contained within them are alternately reduced and then oxidized as the electrons are gained and then lost by each of these atoms in the process. Iron is also necessary to activate certain enzymes.

Boron
Boron is a cofactor necessary for the production of chlorophyll. It may also have a role in carbohydrate transport and nucleic acid synthesis, but its exact mechanism is not known. However, symptoms of boron deficiency include stunted roots and shoot elongation, lack of flowering, darkening of tissues and other growth abnormalities.

Zinc
Zinc is active in the formation of chlorophyll and it is necessary for the activation of some enzymes. It is known that it is necessary for the normal development of most plants, but it is also toxic to plants in large quantities.

Manganese
Manganese is important in the formation of certain amino acids and it is needed to activate certain enzymes, especially those associated with aerobic respiration. Under manganese deficiency, leaves suffer from chlorosis, a mottling of leaves.

Copper
Copper is a redox constituent of certain enzyme systems such as ascorbic acid oxidase and cytochrome oxidase. It is also found in plastocyanin, part of the electron-transport chain in photosynthesis.

Molybdenum
Molybdenum is important in enzyme systems involved in nitrogen fixation and nitrate reduction. Plants suffering molybdenum deficiency can absorb nitrate ions, but are unable to use this form of nitrogen.

Nickel
Nickel is a cofactor necessary for an enzyme that functions in nitrogen metabolism.

Deficiencies and Excesses

Since there is no soil to act as a buffer, your aquaponic crops will quickly respond to a nutrient deficiency or toxicity. Nutrient deficiencies are more common than toxicities, with the most common deficiencies in an aquaponic system being potassium, calcium and iron. Without proper amounts of any of these elements, plant growth will suffer and, with fruiting plants that

Notes:

have greater nutritional demands, fruit set might not occur. If you have an extreme deficiency or toxicity, the plants will respond quickly and symptoms such as discoloration of foliage will occur. A minor deficiency or toxicity may not initially show symptoms, but eventually will affect plant growth, vigor or fruiting.

In research, hobby and commercial systems, the deficient elements are sometimes added in minute quantities with no ill effects to the fish. Specifically, potassium and calcium are added in the form of potassium hydroxide and calcium hydroxide and iron is added in the form of chelated iron. These components will alter your pH and if added in too large of quantities can be toxic to the fish.

Another option to increase total nutrients available to the plants is to mix a hydroponic solution to approximately 1/4 of the recommended strength and gradually add it to the fish tank water. This will increase the levels of all nutrients and should be done with care.

Measuring Conductivity

Conductivity is a measure of the rate at which a small electric current flows through a solution.
When the concentration of nutrients is greater, the current will flow faster. When the concentration of the nutrients is lower, the current will flow slower.

You can measure the water in your fish tank to determine the total dissolved solids with an electrical conductivity (EC) or TDS (total dissolved solids) meter. An EC meter usually shows the reading in either micromhs per centimeter (uMho/cm) or microsiemens per centimeter (uS/cm). 1.0 uMho/cm is equivalent to 1.0 uS/cm. A TDS meter usually shows the reading in milligrams per liter(mg/l) or parts per million (ppm). A reading of 800 or more uMho/cm is adequate for growth of most leafy crops and a reading of 1500 uMho/cm is adequate for more fruiting crops.

EC Meter

EC is generally measured at 77^{o} F/25^{o} C. If the temperature of the solution is raised, the EC will read higher, even though

Notes:

no nutrients have been added. If the temperature drops below 77^o F/25^o C, the EC will decrease. Therefor, it is important to always measure your EC at a consistent temperature of 77^o F/25^o C. Some EC and TDs meters compensate for varying temperatures.

Advanced Nutrient Testing

Neither an EC or TDS meter can indicate precisely what nutrients make up the solution. More complete test kits are available for this purpose. Many commercial growers test their nutrient solutions on a regular basis to ensure they are feeding an adequate diet for plant growth. Regular leaf analysis is an excellent tool for determining the health of your plants. Leaf tissue samples are dried, crushed and analyzed to determine the exact nutrient content.

Most of the more complex kits will test nitrogen, potassium, phosphorous and sulfur. Commercial labs offer more precise results. In the event of a combination of nutrient deficiencies, the symptoms of one problem may mask the symptoms of another. A leaf tissue analysis may be the only way to determine what is wrong with your plants.

Chapter Five - Plant Nutrient Requirements - Quiz

1. Electrical Conductivity is a the measure of:
    (1) the rate at which a small electrical current flows through a solution
    (2) the way positive ions affect a solution
    (3) the specific nutrients within a solution
    (4) plant growth

2. Nutrient excesses are more common than nutrient deficiencies. True / False

3. The three most common nutrient deficiencies in an aquaponic system are:

    1. ________________________________

    2. ________________________________

    3. ________________________________

4. Leaf discoloration is the most common sign of a nutrient disorder. True / False

5. Describe a potassium deficiency:

____

____

6. Describe a calcium deficiency:

____

____

7. Describe an iron deficiency:

____

____

8. You can measure the concentration of nutrients (total dissolved solids) in your fish tank water with an____.

Chapter Six

Photosynthesis, Transpiration and Light

Notes:

Transpiration and Photosynthesis

Plants require a constant supply of energy to grow and this energy comes from light. In nature, plants receive light from the sun. In the classroom, you may need to add artificial light so the plants have an adequate amount of light.

There are various types of artificial lights that provide differing light spectrums. Before learning about these artificial lights, it is important to understand how plants use light in the growth process.

Transpiration and photosynthesis are the two major processes that are carried out by green plants that use energy from the sun. Both of these processes use large amounts of light energy but only in photosynthesis is a significant amount of energy from light actually stored for future use. Light influences other processes such as flowering, seed germination, certain growth stages and pigment production but in these cases only very small amounts of energy from light are used.

During the transpiration process, plants draw in carbon dioxide from the air through their pores and water from their roots and give off oxygen and water vapor. Energy from the sun evaporates water from the plant cell walls. Although this results in a movement of water in the plant tissue (xylem), this energy is neither stored nor used to bring about vital reactions involved in the synthesis of foods, in assimilation, growth and reproduction.

In photosynthesis, which literally means "putting together (synthesis) by means of light (photo)", water is drawn up through the stem from the roots and into the leaf tissue where the chloroplasts, containing chlorophyll (a green pigment), can be found. There the water encounters carbon dioxide which entered the leaf from the air through minute breathing pores (stomata) located abundantly on the underside of the leaves. The stomata also permits the outflow of water vapor and oxygen. The light, carbon dioxide and water produce carbohydrates, which are stored in the plant and later released as energy for other vital plant functions.

Energy stored as chemical energy in foods (carbohydrates, fats, proteins) is continually released in living cells during the process of respiration. Basically, photosynthesis stores energy and respiration releases it, enabling cells to perform the work of living. By releasing energy, respiration provides the energy needed for all other plant functions.

All animals ultimately depend on photosynthesis because it is the method by which all basic food (sugar) is created.

Notes:

Light Spectrums

White light, as it comes from the sun, is composed of waves of red light, through successively shorter waves to violet light. The band of colors that compose the visible spectrum of light (that which we can see) include, starting with the longest rays, red, orange, yellow, green, blue, indigo, and violet. The visible spectrum represents only a part of the radiant energy that comes from the sun. Only a part of the visible spectrum is effective in photosynthesis.

Wavelengths exist that we our unable to perceive with our eyes. Beyond the red rays are still longer rays called infrared and beyond the violet rays are even shorter rays called the ultraviolet.

The fact that chlorophyll is green to the eye is evidence that some of the blue and red wavelengths of white light are absorbed, leaving proportionally more green to be transmitted or reflected and seen.

Much of the red, blue, indigo and violet wavelengths are absorbed and used in photosynthesis while part of the red and most of the yellow, orange and green are barely used in photosynthesis.

Signs of Light Deficiencies

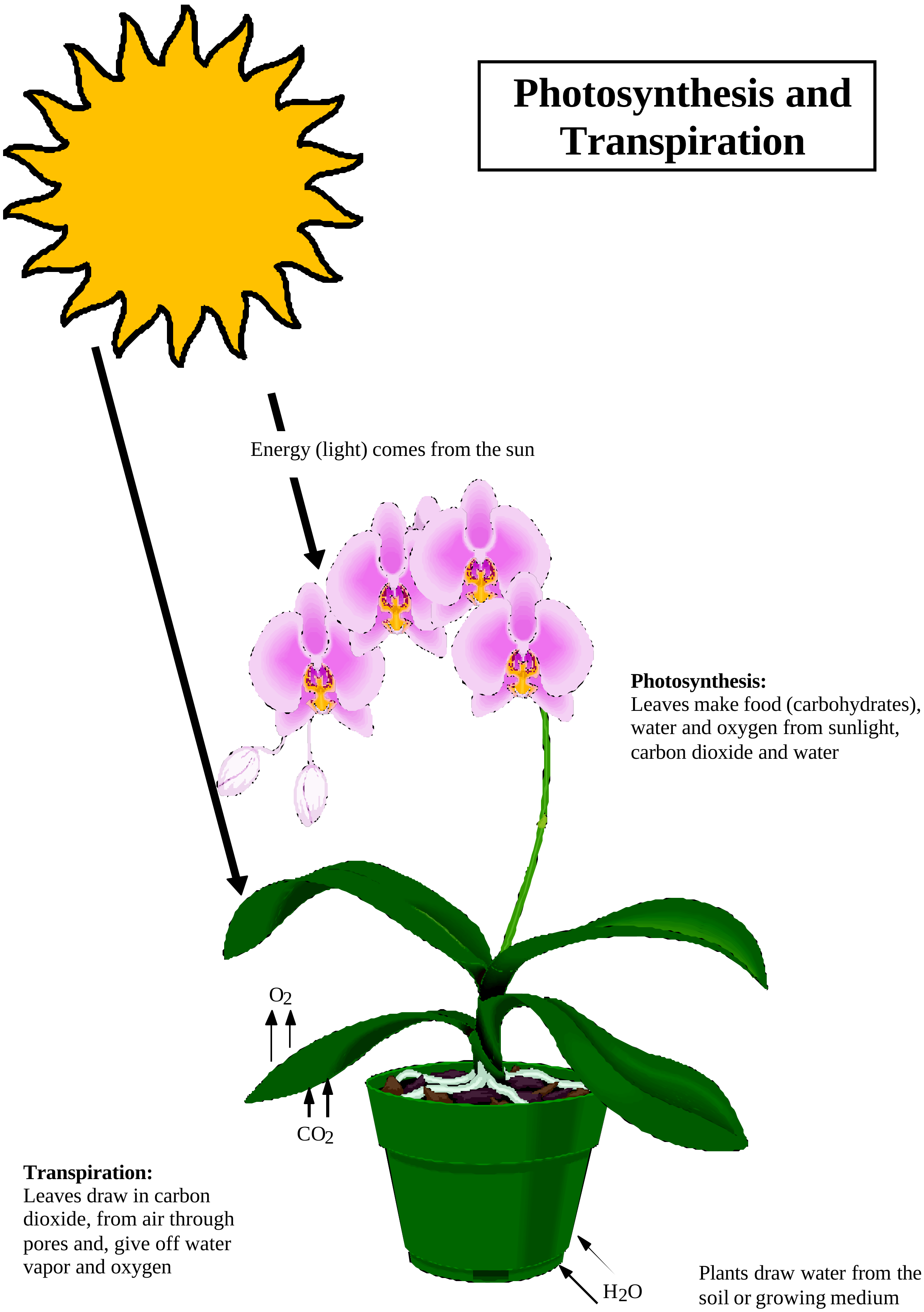
-plants will stretch and reach toward the light source
-stem elongation
-plant deformities
-no fruit set

Artificial Lighting

If an aquaponic grow bed is in direct sunlight, the plants should receive adequate amounts of light and absorb the spectrums they need. If the fish tank is in direct sunlight, green algae, which need nutrients, light and water, will quickly bloom, competing with your plants for available oxygen. The fish tank should be screened or somehow shielded from direct light to help to prevent algae blooms.

In a greenhouse setting, supplemental light is sometimes used to extend the hours of light a plant receives during low light conditions (cloudy weather or short days) and to extend the growing season of a plant. If you are growing in an area with some, but limited sunlight such as a windowsill, supplemental artificial lighting will be needed.

Photosynthesis and Transpiration



Notes:

Any supplemental light is beneficial to increased plant growth and production. The higher the intensity and the broader the spectrum, the greater the benefit.

You can grow in a completely enclosed space with no natural light if you provide all artificial light but there are several draw-backs:
-the cost of the lights and the energy to run them is high
-there may be a compromise of the plants needs if the artificial lighting does not provide the complete light spectrum the plant needs
-artificial lighting will not exactly duplicate the spectrum of light the sun provides

Lamp Placement

When lighting your plants, the proximity of the lamp to your plants is directly related to the intensity of the light provided. The closer the lamp, the more intense the light, and the smaller the space the light covers. When you raise your lamp, the intensity is lessened. It is important not to have your lamp so close that it burns the plant leaves.

Increased intensity and coverage can be achieved by installing a light mover that will rotate your light. You can also use reflective paint or reflective surfaces (aluminum foil, for instance) surrounding the growing area to increase light.

Types of Lights for Plant Growth

HID (High Intensity Discharge) lights are the common choice for supplemental lighting in a large space such as a greenhouse. They are the most efficient and very intense. Metal halide, mercury vapor, and high pressure sodium lights are examples of high intensity discharge lights.

If you are growing in an area that has some natural light, such as in a windowsill, you can probably light it with a less intense light. Fluorescent tubes will likely provide the additional light that you need.

Fluorescent lights will also be adequate for propagation of seedlings, plant cuttings, and some low-light house plants.

In a grow room without noticeable natural light, HID's are necessary to provide ample light for plant production. High Intensity Discharge lights can create an excessive amount of heat. When using HID's, ventilation and cooling may be necessary. Vented reflector hoods are available for this purpose. Also keep in mind that HID's require high amounts of electricity and are more costly to run than most other types of lights.

Notes:

Incandescent Light
Although some supplemental light is better than none, incandescent light offers the lowest level of intensity and is generally better used as a room light than a plant light.

Specialty incandescent grow bulbs are available and will provide a better light spectrum than a standard incandescent bulb. The intensity is still limited though.

Standard incandescent bulbs are high in the red spectrum but low in the blue spectrum which most plants need for vegetative growth.

Incandescent bulbs are inexpensive to initially buy but they are generally not efficient or effective for plant growth.

Fluorescent Light
Fluorescent tubes offer a broader color spectrum and are available in a variety of kinds, including bright white, cool white, warm white, plant bulbs, daylight and full spectrum. The combination of warm and cool white offer the broadest light spectrum.

Fluorescent bulbs are relatively inexpensive, long-lasting and provide even, cool lighting.

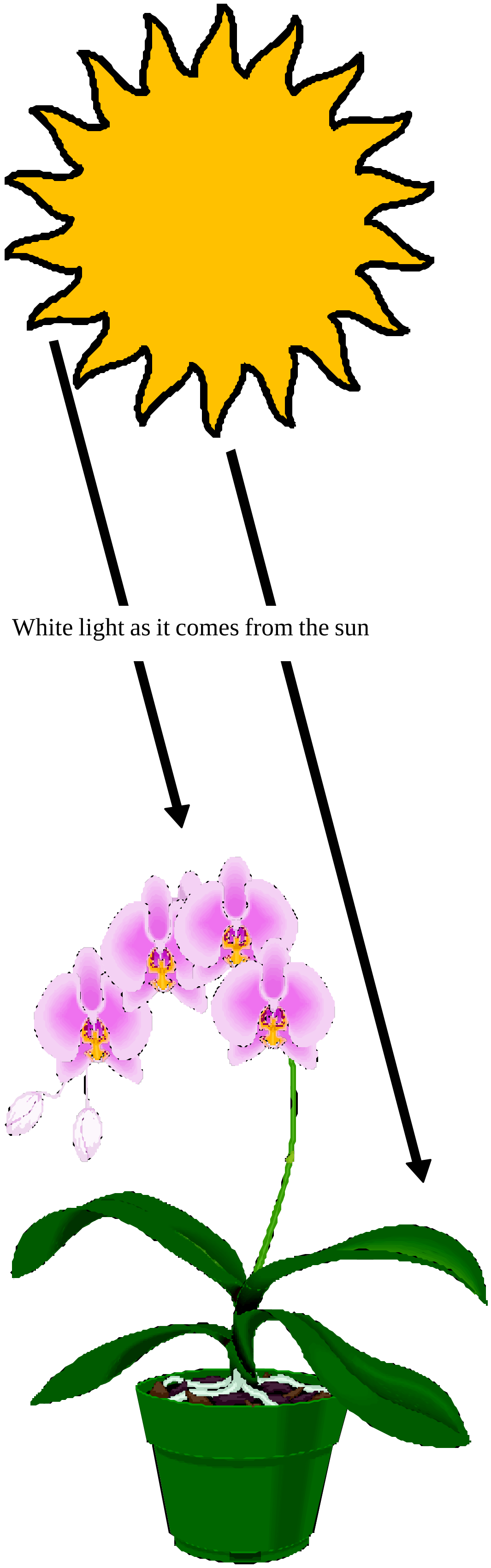
The disadvantage of fluorescent lights is they are low in intensity and need to be very close to the plants to be effective. Seedlings, cuttings, and most house plants will benefit from fluorescent lighting.

Metal Halide Light
Metal halide lights offer a broad spectrum, with ample blue light for vegetative growth. The metal halides are more efficient than Mercury Vapor lights which, at one time, were the primary source of HID light.

Metal halides are one of the best light sources for plant growth and, if one were using only one type of light, metal halide would be the best choice.

High Pressure Sodium Light
High pressure sodium lights are very efficient. They are long lasting and strong in the yellow-red spectrums. Their only disadvantage is that they aren't quite strong enough in the blue spectrum for vegetative development.

The high pressure sodium lights are a good choice for flowering plants. The combination of metal halide and high pressure sodium offers the broadest light spectrum and must be used in situations where no natural light is found.



Light Spectrums

Wavelength	Visible to the human eye	Used in photosynthesis	Used in flowering
Infrared (longest rays)			
Red	☑	☑	☑
Orange	☑		☑
Yellow	☑		☑
Green	☑		☑
Blue	☑	☑	
Indigo	☑	☑	
Violet	☑	☑	
Ultraviolet (shortest rays)			

Chapter Six - Photosynthesis, Transpiration and Light
Activity Worksheet

Date	Type of Plant	Type of Light	Observations

Chapter Six - Photosynthesis, Transpiration and Light - Quiz

Student:_______________________________ Date:_____________ Period:________________

1. The energy that plants require comes from light. True or False
2. What two major plant processes require light:
   1. ______________________________
   2. ______________________________
3. During transpiration, plants use ____________________________________ and give off ________________ and ___________________________.
4. The transpiration process stores energy for other plant processes. True / False
5. In the photosynthesis process, plants use____________________________________ to create ____________________________________.
6. Photosynthesis takes place in the chloroplasts within the leaf tissue. True / False
7. The orange rays are the longest rays of sunlight. True / False
8. List the four primary types of supplemental light:
   1. ______________________________
   2. ______________________________
   3. ______________________________
   4. ______________________________
9. Incandescent light is very effective for plant growth. True / False
10. High pressure sodium lights are strong in the ______________________________ but week in the _________________________ spectrum.

Chapter Seven

Fish Anatomy and Physiology

Notes:

External Anatomy of Finfish

Most fish used in aquaculture are considered to be bony fish with hard, calcium based endoskeletons. The skeleton gives the fish form and protects the internal organs such as the digestive system, nervous system and reproductive system. Being familiar with the external anatomy of the fish you keep makes you better able to distinguish between the sexes and to spot abnormalities caused by disease. In addition, the names of various fins and parts of the body occur in the description of fish species.

Fins

The fins are made of stiff rays covered by skin. Some may be jointed and some separate near the edge of the fin. In certain fish some of the rays are bony, stiff and unjointed. They are referred to as spines. Almost half the fin rays in the Dorsal fin of Cichlids are bony spines. So the front (Anterior) portion of such a fin is called the Spiney Dorsal and the rear (Posterior) portion is called the Soft Dorsal. In some other species the Spiny Dorsal and the Soft Dorsal are completely separated and form two distinct Dorsal Fins. The number of rays in the fin is used in classification.

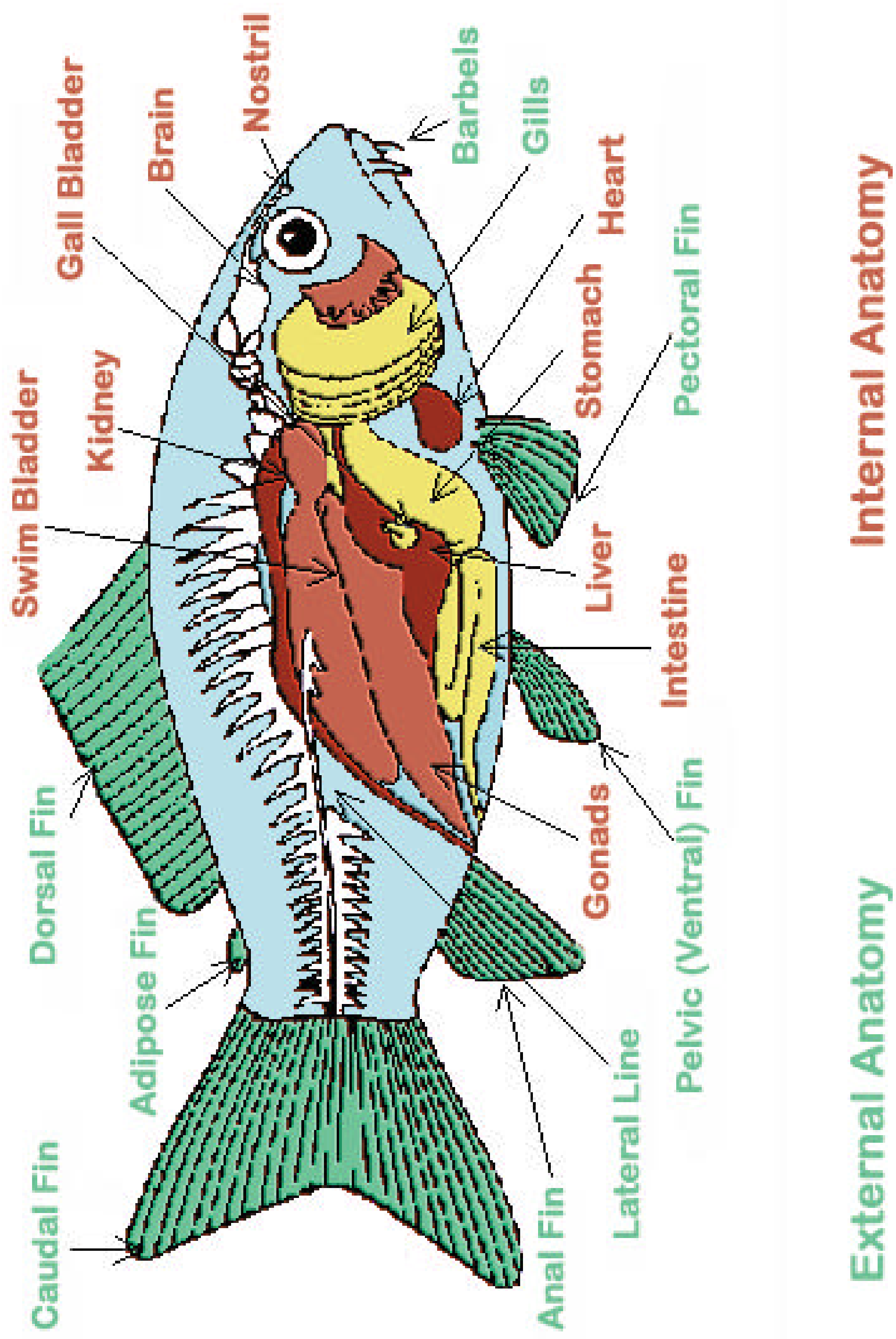
Each fin on a fish is designed to perform a specific function.

Fin	Function
Dorsal fin	Lends stability in swimming
Ventral fin	Serves to provide stability in swimming
Caudal fin	In most fish the Caudal (or tail fin) is the main fin propelling the fish
Anal fin	Lends stability in swimming

Skin

The skin of fish is divided into two layers, the Epidermis (outer) layer and the Dermis (inner). The Epidermis is made up of Epithelial cells, arranged one above the other. These cells are constantly shed and replaced with new ones. Interspaced between the Epithelial cells are slime cells which produce Mucoid secretions that form the very important protective covering we know as the slime coat. The Dermis lies under the Epidermis and many important functions happen there.

Finfish Anatomy



Notes:

Scales

The deeper Dermis of the skin is made up of connective Fibroblasts, Collagen and Blood Vessels. The scales of a fish lie in pockets in the Dermis and come out of the connective tissue. Scales do not stick out of a fish but are covered by the Epithelial layer. The scales overlap and so form a protective flexible armor capable of withstanding blows and bumping. There are two main types of scales. Both are round but, in one the edges are serrated and the other they are completely smooth. In the Mailed Catfish the scales are replaced by bony plates and in some other species there are no scales at all.

Pigment (color) cells

The many pretty colors and patterns seen in fish are produced by cells in the Dermis. The cells are named for the pigment they contain.

Melanophores	*Brownish-Black pigment called Melanin*
Erythrophores	*Red pigment*
Xanthophores	*Yellow pigment*
Iridophores	*Contain crystals which refract and reflect light, given many fish their metallic look.*

Fish can change color from one moment to the next and will often do so in the process of mating, survival and feeding. This is caused by the movement of Melanin grains within each cell. When dispersed, they Absorb more light and the area of the fish darkens. When tightened the fish goes pale.

Gills

Respiration is carried out by means of gills located under the gill covers. The walls of the Pharynx is perforated by five slit-like openings. The tissue between the slits is called the Gill arch and on each side of the fish there are five Gill Slits and Four Gill Arches. On the Gill Arches are the actual Gills, a delicate system of blood vessels covered by a very thin Epithelium through which the gaseous exchange takes place.

Lateral Line

The lateral line consists of a series of scales, each modified by a pore, which connects with a system of canals containing sensory cells and nerve fibers. It runs in a semi line from the gills to the tail fin and can easily seen in fish as a band of darker looking scales running along the side. The Lateral line has shown to be a very important sensory organ in fish. It can detect minute electrical currents in the water. It can also function as a kind of echo location process that helps the fish identify its surroundings.

Notes:

Physiology of Fish

Physiology is the function of the body systems. In aquatic animals these systems are adapted to the water environment. Each of these systems is part of the process of fish consuming food and oxygen and excreting ammonia rich waste and carbon dioxide, which are both used by the plants in an aquaponic system. There are nine body systems found in aquatic animals. They are:

1. Circulatory
2. Digestive
3. Excretory
4. Muscular
5. Nervous
6. Reproductive
7. Respiratory
8. Sensory
9. Skeletal

Circulatory System

The circulatory system distributes blood throughout the body. Generally this system consists of a heart, veins and arteries. Pumping action of the heart causes blood flow through the arteries to the gills, where it picks up oxygen and carries it to the rest of the body. Fish only have a two-chambered heart. The atrium receives oxygen-poor blood from the body. That blood is transferred to the ventricle, which then pumps it to the gills where the blood is oxygenated and then sent back to the rest of the body. Oxygen is necessary for all cells of the body to function. As the blood delivers oxygen to the cells, it picks up carbon dioxide, a waste product, which is carried in the blood back through the veins to the heart and gills. The gills release the carbon dioxide to the environment and pick up more oxygen.

Digestive System

The digestive system converts food into a form that can be used by the body for maintenance, growth and reproduction. The digestive system consists of all the parts of an organism involved in taking food into the body and preparing it for assimilation into the body. In most species this includes the mouth, esophagus, stomach, intestines, liver, anus and other associated organs. Digestive systems vary according to whether the animals are herbivores (consume only plants), carnivores (consume only animals) or omnivores (consume plants and animals).

Excretory System

Life processes produce waste products. The excretory system eliminates wastes from the body. Typically it consists

Notes:

of the kidneys, urinary ducts, urinary bladder and urinary opening. Kidneys filter the wastes from the blood. The urinary bladder holds the wastes until they are excreted through the urinary opening.

Some waste products from metabolic processes are toxic. Especially troublesome are the nitrogen wastes produced as a result of the breakdown of proteins and nucleic acids. Ammonia (NH3) is the direct waste product of this metabolism, but it is very toxic. Due to this toxicity, most animals have to expend energy, in the form of ATP, in order to convert it to a less toxic form such as urea or uric acid before it can be excreted. However, since ammonia is very soluble in water and fish live in an aquatic environment, they do not need to expend additional energy in removing this waste product from their bodies. It simply diffuses across the membranes of their gills. In fact, this method is so efficient that the kidneys play only a minor role in the removal of nitrogenous wastes from aquatic species.

Muscular System

The muscular system provides movement internally and externally. Muscles vary in strength and function and contract and relax to cause movement. Organisms require movement for such functions as obtaining food and oxygen and eliminating wastes.

Nervous System

The nervous system, a complex system, supplies the body with information about its internal and external environment. The system conveys sensation impulses (electrical-chemical changes) between the brain or spinal cord and other parts of the body. It consists of the brain, spinal cord, many nerve fibers and sensory receptors. The sense organs and receptors receive stimuli and convey these through the nerve fibers to the brain or spinal cord where they are interpreted. The brain or spinal cord may send responses to the stimuli back through the nerve fibers.

Reproductive System

Sexual reproduction is the process of creating new organisms of the same species through the union of the male and female sex cells - the sperm and eggs. Males and females exist in most species of fish. Testes in the male produce sperm and ovaries in the female produce eggs or ova. Fertilization occurs when the sperm unites with the egg, forming a zygote. After a period of incubation the zygote develops into a new organism. An understanding of the reproductive process is important to the success of the culture of a species.

Notes:

Respiratory System

The respiratory system takes in oxygen from the environment, delivers it to the tissues and the cells of the body and it picks up carbon dioxide from the tissues and cells delivering it to the environment. Gills are the respiratory organs of fish, shellfish and crustaceans. Water taken in is forced over the gills where oxygen is removed by diffusion into the blood.

Sensory System

The sensory system includes the five senses-sight, touch, taste, smell and hearing and relays information through the nervous system. In addition to the five primary senses, fish have the lateral line which has shown to be a very important sensory organ that can detect minute electrical currents in the water.

Sight

Vision underwater poses many special problems. The most significant is the small amount of light available in all but the uppermost layers of water. Vision under water is limited to a few yards at best and fish do not use this as one of their primary senses.

Smell

In most fish the sense of smell is highly developed and is probably used more in the location of food than sight.

Hearing

It has been shown that fish can hear, but its full function is still not understood.

Taste

Taste buds in fish are located in the mouth and also in the skin covering the head, fins, barbels and lips. Its entirely probable that fish can taste food well before it enters their mouth.

Touch

Fish also have elevated tactile sense. In certain catfish who use their Barbels as extensions of their body.

Skeletal System

The skeletal system is the rigid framework which gives the body shape and protects the organs. It is composed of bony or hard material and cartilage. Tissue and organs attach to the skeleton. In aquatic animals the skeleton can be internal or external. Fish possess an internal skeleton (endoskeleton) and oysters, shrimp and crawfish possess an external skeleton (exoskeleton).

Fish belong to the subphylum of animals called vertebrae. These animals are distinguished by the fact that their skeletal system includes a vertebral column that encloses a spinal chord. Of all of the classes of vertebrates, the bony fishes are the most numerous both in the number of individuals and in the number of species that exist.

Chapter Seven - Fish Anatomy and Physiology - Quiz

Student:______________________________ Date:_____________ Period:___________

1. A _________________________ lends stability in swimming.

2. The skin of a fish has two layers, the ____________________ and the _____________.

3. The Pelvic fin is located just below the gills. True or False

4. Respiration is carried out in the __________________.

5. The scales of a fish lie in pockets in the Dermis and come out of connective tissue.
   True or False

6. List five of the nine body systems in aquatic animals:

1. ________________________

2. ________________________

3. ________________________

4. ________________________

5. ________________________

7. The circulatory system distributes _______________________ the body.

a. carbon dioxide
b. blood
c. ammonia
d. oxygen

8. The Lateral line is a part of the ________________________.

9. The sense of ___________________ is highly developed in fish and probably used more than the sense of ____________________________.

10. Fish possess an internal skeleton and oysters possess an external skeleton.
    True or False

Chapter Eight

Fish Nutrition and Health

Notes:

Feed Development

In nature fish, whether carnivores, herbivores or omnivores, seek out food to maintain their body functions and survive. Each species has developed nutritional needs that must be met for the fish to survive. In recirculating aquaculture and aquaponic systems, the culturist is the sole provider for food and it is essential that they consistently provide a balanced diet to the fish.

The science of aquatic animal nutrition is based on principles developed in many disciplines of the sciences including chemistry, biochemistry, physics, microbiology, physiology, medicine, genetics, mathematics, endocrinology, cellular biology and animal behavior. The availability of dry, species-specific fish feed is quite new and is a result of greater demands in aquaculture and the need for a well-rounded, balanced diet for cultured fish. Since about 1960 prepared diets for rainbow trout and channel catfish have been used. More recently, feed developed specifically for food fish such tilapia, perch and salmon and ornamental fish such as cichlids, koi and marine fish, have become available.

Todays fish feeds are fine-tuned descendants of familiar commercial feeds used in raising poultry and other livestock. Each fish species needs exact amounts of protein, carbohydrates, fats, vitamins and minerals and the newer, specialized feeds provide this. This allows a fish culturist to produce the highest quality of fish with the best feed conversion ratio, while providing a diet composition that mimics what the fish would find in nature.

Feed Conversion Rations

Animal	Average pounds of feed per pound of product
1 lb. fish	1.6
1 lb. Chicken	2.4
1 lb. rabbit	3.0
1 lb. eggs	4.6
1 lb. turkey	5.2
1 lb. pork	4.9
1 lb. lamb	8.0
1 lb. beef	9.0

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Feed Conversion

In commercial aquaculture and aquaponics, the conversion of feed to gross fish weight is referred to as the feed conversion ratio and is very important. When you compare fish to other animals grown for meat (see chart on previous page), you see that the feed conversion ratio in farmed fish is very low compared to other meat sources. In commercial fish culture, fish feed is the greatest expense of production.

The food a fish consumes contains the energy and nutrients essential for the growth, reproduction and health of aquatic animals. Deficiencies or excess can reduce growth or lead to disease.

Feed Components

The important components of all commercial dry fish feeds include protein, carbohydrates, fats, vitamins, minerals, preservatives, coloring and, in some cases, medicines.

Protein

Protein is the most critical ingredient and serves three purposes in the nutrition of fish:

1. provides energy
2. supplies amino acids
3. meets requirements for functional proteins

Proteins are long chains of amino acids linked by bonds called peptide bonds. All amino acids contain nitrogen so all proteins contain nitrogen. Measuring the nitrogen content is a method of calculating protein content.

Protein requirements for fish are considerably higher than those for warm-blooded land animals. Animal protein sources are generally considered to be of higher quality than plant sources but animal proteins cost more. It has been proven that a combination of protein sources in a fish's diet provides a better feed conversion ratio than any one single protein source. The most common source of animal protein in commercial fish feeds is fish meal. Other common sources of animal protein include meat scraps, slaughterhouse offal, blood meal, liver meal and dairy products. Plant proteins used in commercial fish feeds can include soy meal, corn meal, cottonseed meal, alfalfa meal, wheat meal and rice meal.

The percentage of protein required for maintenance of fish is much lower than that for rapid weight gain. Commercial growers want to maximize production and will usually feed

Notes:

a higher-protein food than a hobbyist or anyone keeping fish for fun. Young fish require more protein and, specifically, more animal protein than older fish. Most commercial feeds formulated for carp, koi and other herbivores contain between 10% - 35 % protein, for catfish and trout between 25% - 30% protein and for carnivores such as steelhead salmon, 40% - 45% protein.

Carbohydrates

The main role of carbohydrates in food is to provide energy. Some form of carbohydrates should be included in every fish diet but the amount varies by species and water temperature. Warmwater fish digest dietary carbohydrates better than coldwater fish. In addition, the ability to use carbohydrates as an energy source varies among species. Although carbohydrates are the least expensive form of dietary energy, it is recommended that no more than 12% of the volume of a fish feed consist of digestible carbohydrates.

Fats

The addition of fats in a fish's diet provides energy and spares protein but not all fish species can adequately digest fat. The ability of a fish to digest fats is primarily governed by the environmental temperature. If the melting point of a fat is above that of the environmental temperature, it will solidify in the fish's gastrointestinal tract and be poorly digested. Conversely, if the melting point of a fat is below that of the environmental temperature, it will be quite digestible and provide energy to the fish. Warmwater fish living in temperatures above 68^oF (28^oC) utilize saturated fats better than unsaturated fats.

In addition to energy, dietary fats provide essential fatty acids (EFA) which are necessary for normal growth and development. Also, dietary fats aid in the absorption of fat-soluble vitamins.

Vitamins

Vitamins are organic compounds required in the diet for normal growth, reproduction and health and they function in a variety of chemical reactions in the body.

Vitamins in fish diets have been well studied, particularly for trout and salmon. Eleven of the water-soluble vitamins and four fat-soluble vitamins have been found essential for salmonid nutrition. Research with carp, catfish and other fish species shows their needs to appear to be essentially

Notes:

the same. The water-soluble vitamins required in a fish's diet are:
-thiamin
-riboflavin
-pyridoxine (Vitamin B_6)
-pantothenic
-niacin
-biotin
-floate
-vitamin B_{12}
-choline
-myoinositil
-vitamin C

The fat-soluble vitamins required in a fish's diet include:
-vitamin A
-vitamin D
-vitamin E
-vitamin K

Minerals
A number of minerals including calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), iron (Fe), zinc (Zn), copper (Cu) and selenium (Se), can be absorbed directly from the water by fish and are often available in the water in sufficient quantities. This fact makes research on fish's dietary needs of these minerals inconclusive. Most researchers do agree, though, that fish require all of the minerals required by other animals. As a prevention to disease and dietary deficiencies, minerals are usually added to commercial feeds.

Preservatives
Anti-oxidants such as ethoxyquin and BHT are included in most commercial feeds to slow the breakdown of vitamins.

Colorings
The purpose of colorings are two fold - the first being to make the food more attractive to fish and the second being to make the natural colors of fish come out. With sight-feeding fish such as trout, bass and sunfish, the color and texture of the feed pellets is important. In farmed or aquarium grown fish, the lack of natural skin and flesh coloring can be a draw back. The addition of paprika or synthetic carotenoids helps bring our the natural color of the fish.

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Medicines
Drugs have been added to fish feeds both to prevent and cure diseases. Medicinal feeds should only be used according to the manufacturers instructions. Prolonged use should be avoided to avoid the fish building an immunity to specific medications.

Feeding Behaviors

Each individual fish species has developed unique behavioral feeding patterns. By knowing and understanding the behavioral patterns of the fish you're raising, you are better able to accommodate their needs. Some environmental factors that influence feeding behaviors include:

Sensory Use
Which sense - sight, smell, taste, touch, hearing - does this fish primarily use in finding food?

Season of the Year
The peak growth period for most fish is in the spring and summer so feed demand is generally higher during this time of the year. Many species virtually cease feeding during spawning and slow feeding during times of extremely cold temperatures.

Time of Day
The demand for feed by most fish species will peak at dawn and dusk.

Physical Contact with Food
Quite often the texture of a potential food source is felt before the fish will eat it.

Digestive System

As we learned in Chapter 7, the digestive system converts food into a form that can be used by the body for maintenance, growth and reproduction and the parts that make up the digestive system include the teeth, pharynx, esophagus, stomach, pyloric ceca, intestine, gall bladder and liver.

In the process of eating and digesting food, the teeth are used for grasping, holding and crushing. The food leaves the fish's mouth and passes through the esophagus, a short passage lined with mucus secreting cells that leads to

Notes:

the stomach. The stomach walls are lined with cells secreting hydrochloic acid and pepsinogen for the initial stages of protein digestion. The pyloric ceca secrets enzymes for digestion and provides surface area for absorption of nutrients. As the partially digested food passes through the intestines, additional enzymes are secreted for digestion and nutrients are absorbed from the food. The gall bladder stores and releases bile for digestion and absorption of fats and the liver produces bile and removes some of the waste products from the blood.

Chapter Eight - Fish Nutrition and Health - Quiz

1. In recirculating aquaculture and aquaponics systems, providing a proper, balanced feed is important because the fish rely 100% on the culturist to satisfy their nutritional needs.
True or False

2. Feed conversion ratio is ____.

3. It takes more feed to raise a pound of fish than it does to raise a pound of beef. True or False

4. The main role of carbohydrates in food is to provide __________________________.

5. _________________________ is the most critical ingredient in fish food.

6. Which one is not a purpose of protein in the nutrition of fish:

a. provides energy
b. supplies amino acids
c. enhances color of fish
d. meets requirements for functional proteins

7. Fish can absorb minerals from the water through their skin. True or False

8. List the four environmental factors that influence feeding:

    1. _________________________________
    2. _________________________________
    3. _________________________________
    4. _________________________________

9. The role of the digestive system is ____
____.

10. In the process of eating, the teeth are used for grinding, holding and grasping. True or False

Additional Information Sources and Pertinent Web Sites

Sources for Manufactured Aquaponic Systems and Growing Supplies

American Hydroponics, Arcata, CA, 800-458-6543 www.amhydro.com

Aquatic Eco-Systems, Apopka, FL, 800-422-3939 www.aquaticeco.com

CropKing, Inc, Seville, OH, 800-321-5656 www.cropking.com

Hydro-Aquatic Technologies, Princess Anne, MD, 410-957-2680

Ringger Foods Aquaculture Division, Gridley, IL, 309-747-2152 www.aquaranch.com

Aquaponics Related Web sites

Aquaponics products and information on aquaponics, hydroponics and aquaculture
http:///www.aquaponics.com

Cabbage Hill Farm – an excellent site which includes a mini-manual on building an aquaponic greenhouse
http://www.cabbagehillfarm.org

University of the Virgin Islands Agricultural Experiment Station - features information on aquaculture and aquaponics research and commercially viable systems
http://rps.uvi.edu/aes/aes_home.html

Fishing For Information – a hypertext guide to Internet resources in aquatic science
http://www.stir.ac.uk/aqua/fishing/default.htm

Aquaculture Information Center
http://www.nal.usda.gov/aic/aicsites.html

AquaNIC - Aquaculture Information Network Center
http://www.ansc.purdue.edu/aquanic/

Aquaculture Research Institute, University of Idaho
http://www.uidaho.edu/ag/aquaculture/uiari/index.html#list

The GrowRoom – links to hydroponic resources
http://www.growroom.com/

Hydroponic Lettuce Production
http://www.cals.cornell.edu/dept/flori/lettuce/cea1.html

Classroom of the Future
http://www.cotf.edu

Project and Experiment Ideas

An aquaponic system is an excellent tool for experimentation and proving or disproving an hypothesis related to aquaculture, aquaponics or hydroponics. Following are four theories and experiments that can be done to prove each.

Hypothesis 1:
Plants need adequate light for growth and development. Insufficient light will produce small plants.

Experiment 1:
Set up aquaponic system with artificial lights on 1/2 the plants and no additional lighting on the other 1/2 of the plants. Monitor and document which one best supports plant growth.

Hypothesis 2:
A healthy aquaponic system has ample nutrients for leafy crop growth, but fruiting plants might be lacking sufficient quantities of certain elements.

Experiment 2:
Plant a leafy crop such as lettuce and a fruiting crop such as tomatoes and monitor to see which one does best in aquaponics.

Hypothesis 3:
A pH of 7.0 is the best for an aquaponic system. At a lower pH, nitrification slows down and the water quality will be reduced, stressing the fish At a higher pH the plants will be stressed.

Experiment 3:
Set up three aquaponic systems. Maintain each at a different pH, one at 6.0, one at 7.0 and one at 8.0. Observe and document the ammonia, nitrite and nitrate levels, plant growth and fish health.

Hypothesis 4:
Denser fish populations will support more plant growth due to increased fish waste and nutrients in the water. Too dense of a population will not survive.

Experiment 4:
Set up two aquaponic systems, stock one with 1” of fish/gallon of water and the other with 1/2” of fish per gallon of water. Observe the difference in plant growth.

Other Related Products from Nelson/Pade Multimedia

Introduction to Aquaponics Video This 50 minute video (VHS-NTSC) covers the history of aquaponics, applications of aquaponics, necessary equipment and system components, various system designs, plant and fish selection, plant and fish care, day-to-day operation, water quality and the nitrogen cycle, environmental considerations and references. “$29.95 VHS or DVD; $49.95 DVD PLUS with four back issues of the Aquaponics Journal in .pdf format

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Desktop Aquaponics Booklet Desktop Aquaponics (booklet) provides information, directions, diagrams, photos and drawings on how to establish an aquarium-based home/hobby aquaponic system. An aquaponic system can be a living, beautiful addition to your home and this booklet shows you how to set one up and keep it flourishing year-round. Great for hobbyists or students. This booklet is available in print or electronically. Printed $14.95, Electronic

All About Aquaculture CD-Rom This interactive CD-Rom is an overview of the aquaculture industry and covers over 100 topics about aquaculture and fish farming. $29.95

Hydroponic Farming Video This video is an introduction to the hydroponic greenhouse industry. Topics covered included greenhouse construction, hydroponic equipment selection and set-up, crop selection and day-to-day operation. $29.95 VHS or DVD; “$99.95 DVD PLUS (includes Start and Succeed Package, business plan and Encyclopedia of Hydroponic Gardening)

How to Start and Succeed in the Hydroponics Business Interested in starting a commercial hydroponics business? This is the first step. This popular book set includes a manual that walks you through the steps involved in establishing a hydroponic greenhouse business, a sample 30-page business plan and a list of contacts in the industry. $49.95

Encyclopedia of Hydroponic Gardening CD-Rom This interactive CD-Rom allows you to explore the world of hydroponic gardening through video, pictures and text. $29.95

Hobby hydroponics Video A 30 minutes video, Hobby Hydroponics is a step-by-step guide to establishing a hydroponic garden. $29.95

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