AQUAPONICS Food for Thought

Mastering Microbes

LESSON

Background:

Scientists have only identified a small percentage of microbes (microorganisms) on our planet, yet microbial diversity is one of the key components in healthy ecosystems. Microbes live within specific niches and serve an essential role in the natural cycling of living materials. Healthy systems have a rich, diverse microbial community that provides a bridge between animals and plants. Microbial communities serve specialized roles.

One of the advantages of an aquaponics system is that it is a closed system recycling and reusing water and nutrients. The recycling of nutrients is achieved with the action of microbes. Nitrifying bacteria are essential in converting ammonia produced by fish to plant fertilizer. This process also removes waste products from the water that are toxic for fish. Microbes protect the health of other living organisms in an aquaponic system and are found on all surfaces including the tank, the clay pellets, and on both the surface and in the gut of fish, and coating the roots of plants. In addition, heterotrophic bacteria metabolize organic matter (plant and animal waste) to release essential micronutrients through a process called mineralization. Like other living components of a system microbes need moisture, the right temperature, air, and correct chemical balance in their environment in addition to nutrients.

Monitoring the health of the microbial community could be challenging, as they are microscopic. Aquaponic water chemistry (nitrate, nitrite, and ammonia) is tested to assess whether microbes are serving their role by keeping the system in balance. Some microbes in a system can be unhealthy for the system. They can cause disease in plants, fish, or consumers. These are often found where there is not a balance; where there are anaerobic (oxygen deplete) conditions and/or poor circulation. Using healthy practices, such as washing your hands and plants before eating, keeping plant leaves from contacting water, making certain there isn't contamination, and keeping a check on water quality and circulation can help maintain a healthy system.

Learning Objective:

Students will build upon prior knowledge about microbes and their role in ecosystems while learning how to maintain health of microbes in their aquaponics system.

Essential Questions:

1. What is a microbe?
2. Where can microbes be found and why do they matter?
3. What roles do microbes play in an aquaponic system?
4. How can you ensure microbes in your system are healthy?
5. How does the role of microbes in conventional farming compare to the role in the aquaponics sytems?

Core Idea:

Microbes have essential roles in living systems including aquaponics.

Standards Correlation:

LS2-2 Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems

LS2-3 Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem

Science/Engineering practice:

- Asking questions (for science) and defining problems (for engineering)
- Constructing explanations (for science) and designing solutions (for engineering)
- Engaging in argument from evidence

Crosscutting Concepts:

- Cause and Effect: mechanisms and explanation
- Energy and matter: flows, cycles and conservation

Vocabulary:

- **bacteria** – single celled organisms that helps with food digestion, decomposition of organic matter, serves an important role in cycling including providing oxygen, nitrogen cycle, and carbon cycle; found in many shapes but most common are round (coccus), rod (bacillus) and spiral (spirillum); approximately 1 million 106 bacteria in a ml of water. Bacteria are the driving engine behind the aquaponics system.

- **biological filtration** – media that provides surface area beneficial bacteria to colonize so they can perform nitrification and mineralization of the water.

- **biological surface area** – the total area on which microbes can live within the aquaponics system.

- **fungi** – decompose plant material to obtain food; grow in finely branched networks of strands; exist in size from microscopic single cells to mile long chains of cells yet can only absorb small molecules; most commonly found on land.

- **macroscopic** - visible without an aid, visible to the naked eye.

- **microbe** – short for microorganism; used to describe something that can't be seen with the with the naked eye; essential in recycling of nutrients; very tiny, typically single celled organisms including bacteria, virus and fungi. Microbes free nutrients from organic compounds. They are responsible for nutrition cycling in an aquaponics system and function in communities.

- **microbiology** – the branch of science or the study of micro-organisms.

- **microscopic** – organisms that can only be seen through a microscope.

- **mineralization** – the process whereby an organic compound is broken into a simpler compound; often from proteins to amino acids to ammonia to nitrates; the solid waste is broken down and returned to the water so that the plants can use it and the water quality can support microbes, fish and plants.

- **oxidation** – the loss or gain of electrons during a reaction; in aquaponics the redox reaction or conversion of ammonia to nitrite to nitrate by oxidizing bacteria.

- **virus** – simplest and tiniest of microbes that must exist within another living cell or "host" they take over; composed of genetic material (DNA or RNA) surrounded by a protective viral coat.

Materials:

- images of microbes from aquaponics system (photo copied and laminated or way to project images for the entire group) (Appendix 1)
- large paper and markers to draw essential elements of aquaponics system
- copies of reading section for students (Appendix 2)
- student science journals or paper and pencil
- dry wipe board and markers to record shared input
- graphic showing microbes role in aquaponics (Appendix 3)
- copies of Fascinating Facts handout or project on screen (Appendix 4)
- copies of bacteria physliology worksheet for homework (Appendix 5)
- copies of biological surface area handout (optional) (Appendix 6)

Engage

(10 minutes)

Have students work with a partner to identify the essential elements of an aquaponics system. Explain that when we say “essential” we refer to those components that are critical for the system to function. Leave out anything that helps or is nice but not critical. Think about earliest systems like rice fields where fish were added in southeast Asia or the Aztec Chinampas with “floating islands”, as well as today’s systems or even systems of the future. What are the bare minimum components to function well and explain why those elements are critical components for the system.

Have students join two other teams of two and share their lists and rationale for the essential elements listed. Put list aside and we will come back to it later.

Explore

(15 minutes)

Microbiology on line Fascinating Facts handout (Appendix 4):

Take a minute and let’s talk about microbes.

What is a microbe?
Draw what you think a microbe looks like.
Where are microbes found?
What do microbes do?
What questions do you have about microbes?

Have students share what they know. Create a class list: What is a Microbe?
Some examples may include:

- Microscopic organisms (can be seen with the aid of a microscope, most often single celled. (video showing scale https://www.youtube.com/watch?v=l7kZjdeo0Cs)
- Oldest form of life on earth. Without microbes life couldn’t exist.
- Microbes include bacteria (back-tear-ee-uh), archaea (are-key-uh), fungi (fun-jeye) and protists (pro-tists).
- May not mention Archaea so share: Archaea are bacteria-like creatures that have some traits not found in any true bacteria.
- Many microbes such as bacteria and fungi don’t produce their own food
- Protists include primitive algae (al-gee), amoebas (ah-me-buhs), slime molds and protozoa (pro-toe-zoh-uh).
- Viruses (vey-rus-is) exist only within a host; take over the host
- Microbes are found in every environment on Earth.
- Some are extreamophiles living where nothing else can live.
- They serve important roles converting materials to usable nutrients, oxygen, etc.

Explain

Post for everyone to read or hand out brief reading on microbes (Appendix 2):

Every productive living environment teems with a diversity of microbes. All of these are essential in decomposing organic matter and releasing nutrient elements. The more fertile and productive an environment is the healthier the microbial community is within that ecosystem. Microbes need moisture, air, temperature in a preferred range, and nutrients. Most microbes cannot create organic matter through photosynthesis and depend on the waste of plants and animals for their source of energy. Dead plant matter provides carbohydrates (sugars and starches, etc).

- Ask students to identify any unfamiliar words in the reading. Clarify the words as a class and then ask students to explain the passage to their partner.

- Have students identify what conditions in their aquaponics system will effect the presence and health of microbes (you can give clues to what do they test the system for with the freshwater test kit temperature, pH, oxygen, water and food (nutrient) availability, light).

- Ask students if they think all bacteria live at the same temperature, pH, oxygen, and amount of water. If students don't mention it, share with the students that each species has its own needs and particular range of values in which it grows and reproduces most rapidly.

Without microbial communities aquaponics systems can't exist. Microbes are involved in all processes - from living in the fish gut, to helping the fish uptake nutrients, to converting toxic ammonia to nitrate that can be used by plants.

Role of microbes:

1. Responsible for nitrification process – oxidizing ammonia to nitrite then to nitrate *(Nitrospira sp., Nitrosomonos sp. and Nitrobactor sp.)*
2. 100s to 1000s of other types of microbes are in the system also performing this task as well as others.
3. Mineralization processes – taking organic compounds and breaking them down – solid wastes to nutrients; depends upon different environmental factors.
4. When it comes to microbes; we are just beginning to understanding all they do and the diversity of microbes; most species are unknown, hard to get sample species to grow in the lab.
5. Algae – produce oxygen and organic matter.

Microbes find an environment that suits them best (some prefer no light), finds food sources, start growing and colonizing a system, move into unoccupied niches where there aren't microbes. If they become more crowded, competition starts and you'll see changes in population.

Look at images that show different microbes from an aquaponics system (Appendix 1)

Now lets focus primarily on the bacteria in your system. How do we maintain the microbe community when we can't even see them?

1. To maintain healthy bacteria you want to be consistent:

- Feed fish regularly on schedule without overfeeding.
- Check water quality for consistent levels (the range of pH should stay within 6.8 – 7.0) Nitrifying bacteria prefer a pH range between 7.5 – >8 pH – (fish prefer pH 7, plants prefer 6.0 – 6.8). pH is an indicator of nitrification working and if it is the pH will drop; if not it will rise but that can also be caused by anaerobic pockets in the system.
- Temperature (colder = slows down process; warmer water = faster reactions); bacteria prefer temperature between 25 – 30° C (77 – 86°F).
- Check nitrogen cycling, is it working?
- Be careful not to disturb microbial communities, especially those who like to be in the dark, most don't like UV light.

2. Provide a good biological surface area – places bacteria can live; there are some in the water but many also attach to walls, pipes, and clay pellets. Surface area refers to the square feet within system that can house bacteria – increased surface area can increase abundance and diversity or types of bacteria. Maintain a high surface area – add, but don't subtract. (Appendix 6 provides an activity to calculate surface area for different materials.)

3. Diversity of environments = good diverse microbial community = new levels of productivity.

4. Notice your system. Does all the water move the same everywhere or are there spots where there isn't much movement. These might create anaerobic (low oxygen) areas. It is okay to allow for anerobic regions, in limited amounts, less than 3 % of system. But not in the grow beds.

5. Notice the water movement in your system, water rapidly turning over allows for good filtration and oxidation.

6. Never use or put anything you are unsure of in your system – keep hands clean, tools clean for the system – clean bucket for adding water.

Evaluate

Look back at the diagram we started with today. Make any adjustments to what is essential in an aquaponics system both in what your list or your reasons for listing it?

Share lists and critique what needs to be added or subtracted with justification for the change.

Additional Resources:

1) Microbes image gallery (images to share some of the diversity) – they are everywhere, they are small and they rule the world! http://ngm.nationalgeographic.com/2013/01/125-microbes/oeggerli-photography

2) Microbe image gallery from electron microscope http://www.denniskunkel.com/index.php

3) cyanobacteria diversity http://www-cyanosite.bio.purdue.edu/images/images.html

4) The secret world inside you High School Science and Literacy Activity AMNH

Appendix 2:

Microbes

Every productive living environment teems with a diversity of microbes. All of these are essential in decomposing organic matter and releasing nutrient elements. The more fertile and productive an environment is the healthier the microbe community is within that ecosystem. Microbes need moisture, air, temperature in a preferred range, and nutrients. Most microbes cannot create organic matter through photosynthesis and depend on the waste of plants and animals for their source of energy. Dead plant matter provides carbohydrates (sugars and starches, etc).

Appendix 4:

Facinating Facts: Did you know...

1. If you pick up a handful of garden soil you will be holding hundreds if not thousands of different kinds of microbes.
- One single teaspoon of soil contains 1 billion bacteria & 120,000 fungi & 25,000 algae.

2. Microbes have been around longer than anything else on Earth, longer than even dinosaurs.
If you imagine Earth began as a single day:
- Microbes appeared at 5am
- Dinosaurs appeared at 10pm
- … And humans appeared seconds before midnight

3. There are 10 times more bacteria in the average human's digestive system than there are cells in the entire body. This is approximately 1kg of bacteria.

4. There are more microbes on one person's hand than there are people on the planet.

5. Microbes generate at least half the oxygen we breathe.

6. Most microbes do not cause disease – less than 5% do.

7. The toilet handle in most bathrooms at work has 400 times more germs than the toilet seat.

8. Dr. Winkle Weinberg, an infectious disease expert, reckons that when we have a cold and cough the virus particles can travel at 320 kilometers an hour and up to 900 meters. That is faster than a passenger jet at takeoff!

9. Bacteria are on average 1-um (micrometers in size) can be 1/100th of a hair in thickness. A human hair is about .17 μm

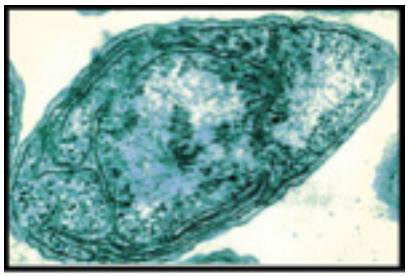
Appendix 5:

Bacteria Physiology

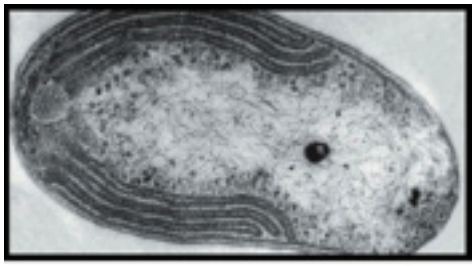
Bacteria are prokaryotes (simplest of all single celled organisms) and they fall into two major categories: The Domain Bacteria and the Domain Archaea. Bacteria are commonly occur all around us. Archaea are some of the oldest life forms on Earth and many are only found in extreme environments, like hot sulfur springs. Most bacteria don't make their own food. That means they have to rely on other organisms to provide them with food. Bacteria serve a crucial role as they break down, or decompose, other living things to obtain energy.

When most people hear the word bacteria, they think of something that is bad for you. In fact, very few bacteria cause illness. Most bacteria actually help you! Bacteria are used to make food, such as cheese and yogurt, and they can also help us break down harmful substances in the environment. Scientists created a type of bacteria that could gobble up oil from oil spills. Some bacteria live inside the guts of animals (including our gut!) and help them to digest food.

Bacteria have a very simple cell design. Most of them have a thick outer covering called the cell wall. On the picture, label the cell wall (it's the outermost layer). Just within the cell wall is the cell membrane. Label the cell membrane. The watery interior of the cell is called cytoplasm, and it has the texture of jello. Label the cytoplasm. Sprinkled throughout the cell are small roundish structures called ribosomes. Ribosomes make proteins for the cell. Label all of the ribosomes red. Every prokaryote cell has DNA floating within the cytoplasm, which usually looks like a twisted strand of spaghetti. DNA contains the instructions for the cell, basically it is the control center. Find the DNA and label it.



Nitrosomonas europaea



Nitrobacter winogradskyi

1. What are the oldest life forms on earth? _____
2. What does "decompose" mean?_____
3. What is the control center of the bacteria cell?_____
4. Where do Archaea live?_____
5. To what domain do common bacteria belong?_____

(Images from http://www.freshwaternaturalist.com/ncycle/ lesson adapted from)

Appendix 6:

Biological Surface Area

What is the Biological Surface Area (BSA) for your system? Calculate the system BSA based on the information below.

Microbes benefit from as large of a biological surface area possible. The BSA is the area in your system where microbes can live, grow, colonize and reproduce in order to oxidize and mineralize systems. The surface for bacteria can be obtained from a wide choice of materials, each with a specific surface area (SSA). The SSA indicates the total surface that one cubic meter of a particular material would have if all its particles had the volume of their surfaces measured. SSA is also known as the surface area to volume ratio, expressed as sq feet/cubic foot $2ft^2/ft^3$ or square meters per cubic meter (m^2/m^3).

Surface area is composed of the biofilter media (the material that fills the growing bed where plants attach and where bacteria live) as well as all of the other space where bacteria can grow. Common biofilter media include gravel, sand, fiber mesh pads, clay pellets and plastic filter medium.

SSA multiplied by the Volume of growing bed = Biological Surface Area

Biofilter media	Size	SSA	Void Ratio
Sand	.12	270	40%
Pea Gravel	.57	85	28%
¾ crushed granite	.75	45 – 60	35%
River rock		21	40%
Matrix growing media - fiber	n/a	260 – 290	91%
Clay pellets/ hydrotron	.59	250 – 279	30%

Void ratio – space between different particles, capture solids and can get anaerobic

It is possible to use any biofilter medium and determine the volume needed by knowing the SSA. However, it is worth mentioning that the larger the SSA in the media is, the higher the risk of clogging if the water has some suspended solids, which can easily occur in overstocked aquaponic systems that are not adequately supplied with biological and mechanical filters to remove fish wastes.

A system needs a minimum of 2.5 sq feet biological surface area per gallon of water for enough bacteria to grow to for oxidation and mineralization to keep the system healthy. It is better to have 10 sq ft minimum per gallon of water for 100 sq ft/lb of fish in system.