Aquaponic System Design Parameters:

Fish to Plant Ratios (Feeding Rate Ratios)

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Aquaponic fish to plant ratios, or more correctly, aquaponic feeding rate ratios, are an area of aquaponics that have been much debated. There seems to be many approaches to sizing the two main components of aquaponic systems (the fish component and the plant component), whether in a hobby-scale context or a commercial-scale context. I often say that ratios are the "Golden egg" of aquaponics as a reliable method often seems difficult for authors, operators and designers to identify!

Unfortunately, many of the approaches used are factually incorrect and have no real association with correct ratio determination methods and approaches. In this fact sheet we will look at the two scientifically determined feeding rate ratios for aquaponics systems (the UVI/Rakocy approach and the Aquaponic Solutions/Lennard approach), and a third method which has recently appeared and discuss them in more detail.

Defining Aquaponic Design Ratios

One of the most important factors in the design of aquaponic systems is knowing how to size the two major components of the aquaponic system; the fish component and the plant component. There are many approaches to this aspect of aquaponic system design; some people recommend a ratio between the volume of water in the fish component and the volume of water in the plant component (mostly for deep flow systems); some people recommend a ratio between the volume of water in the fish component and the volume of media in a media bed (for media bed systems); some people recommend a ratio between the number of fish in the fish component and the volume of media in a media bed or the volume of water in a deep flow tank(s); and there are other approaches.

However, if we take a critical and objective look at what occurs in an aquaponic system, it gives us a better understanding of what may be the most appropriate ratio to consider.

We all pretty much know that aquaponics is an approach where the waste produced by the fish in the system is utilised by the plants in the system as a nutrient (or food) source. This means that the fish are fed, the fish produce waste and that waste is used by the plants as a feed (or nutrient) source. Therefore, it is quite evident that if any balance is to be met, it is a balance between the amount of fish waste produced and the amount of that waste that the plants will use or uptake as their nutrient source.

The amount of fish waste produced is directly related to the amount of fish feed the fish eat. This is similar for us; the more food we eat the more waste we produce. Similarly, the more food the fish eat daily, the more waste they produce daily.

In any aquaponic system, the amount (or number) of plants we can grow is directly related to the amount of nutrient available, and the amount of nutrient available is directly related to the amount of waste the fish produce.

Therefore, if the amount of nutrient available to the plants is directly related to the amount of waste the fish produce, and the amount of waste the fish produce is directly proportional to the amount of feed they are fed, then it makes sense that the amount (or number) of plants that can be grown is directly related to the amount of fish feed that enters the system.

The only really predictable ratio associated with aquaponic system design is based on the amount of fish feed that enters the system as related to the number of plants we grow.

Any other aquaponic design ratios cannot express the direct association between the two major components of the system; the fish component and the plant component.

Using Aquaponic Design Ratios

The number of plants we grow can also tell us how much space, or area, we need to grow those plants. For example, many lettuces grow nicely at approximately 30 lettuce plants per square meter. Therefore, if we know the number of plants we can grow, and we know the species of plant and its preferred or maximal planting density (expressed as the number of plants per square meter), then we can also express the number of plants we can grow as an area (often in the units of square meters or square feet of plant growing area).

The weight of fish in a system (or biomass) and the amount of food those fish will eat is also predictable. Therefore, if we need to set the amount of fish feed that will enter the system; we can relate this to the weight of fish we require to eat that food. For example, many older fish will eat about 1% of their weight in feed per day. If we need 100 g of fish feed to enter the system to match the number of plants we have, then to eat 100 g of fish feed, we need 10 kg of fish (1% of 10 kg is 100g).

Following on from this, there are standard recommendations from the aquaculture industry with respect to how much water a known weight of fish need to live in. Therefore, if we initially know the amount of fish feed we need to enter the system daily, and this will tell us what weight of fish we need to eat that feed, and we know that fish weight needs a certain volume of water to live in, then we can determine the volume of the fish tank(s) we need.

The critical factor in all of this is knowing how much fish feed we need to feed to the system to produce the fish waste concentrations we need to feed a known number of plants. This is called the feeding rate ratio.

How to Design Aquaponic Systems

There are, as I have stated, many ways to design aquaponic systems so we may determine the correct sizes of the two main components; the fish component and the plant component. However, as I have also said and argued, many of these approaches do not use the parameters that actually determine the balance between fish waste nutrient generation and plant nutrient use.

Let's state the correct way to size an aquaponic system (hobby-scale or commercial-scale) in easy to follow steps first:

1. Determine **how many plants**, and of what species, we wish to grow (eg: 30 lettuce plants).
2. Determine **the area those plants need** to grow (eg: 1 square meter – because the maximal density for lettuce is 30 plants per square meter).
3. Determine **how much fish feed** the fish need to eat to meet the nutrient requirements of the plants (this relates to the feeding rate ratio).
4. Determine what **weight of fish** we require to eat that amount of fish feed.
5. Determine what **volume of water** that weight of fish needs to live happily in.

From this simple approach we can therefore determine the key factors that lead to good and predictable component design sizings; **how much fish feed** we need related to the **number of plants** we wish to grow or the **area** those plants require to grow in; known as the feeding rate ratio.

When using this simple approach, the key ingredient is knowing how much fish feed we need to grow the number of plants we have and this is where feeding rate ratio's apply.

Aquaponic Feeding Rate Ratios

The amount of fish feed added to an aquaponic system daily is directly related to the number of plants that may be supported. The fact to consider is that as for us, if fish eat a certain amount of food they produce an associated and predictable amount of waste. This waste is then used by the plants. If the amount of fish feed that enters the system on a daily basis changes for appreciable periods of time (ie: weeks), then the number of plants that may be supported by the nutrients derived from that fish waste must also change because the amount of nutrients available to the plants changes as the fish feed amount changes.

So, the actual ratio associated with aquaponic systems that allows us to correctly size the two main components of the system, the fish component and the plant component, is based on the daily fish feed amount as associated with the number of plants, or the area those plants require to grow in, required to take up that fish waste as nutrient.

This association of fish feed amount to plant number or growing area is the fabled feeding rate ratio. There are two developed and scientifically tested feeding rate ratios currently in existence; the Rakocy feeding rate ratio and the Lennard feeding rate ratio. In addition, there is a third approach that has recently begun to be adopted; so lets take a closer look at these three feeding rate ratio approaches.

The UVI/Rakocy Approach

Dr James Rakocy and his UVI (The University of the Virgin Islands) team began scientific analysis and development of aquaponic systems over 30 years ago and have produced a plethora of scientific information and publications on the subject.

Rakocy and his team at UVI were the first to develop a scientifically proven and predictable approach to aquaponic feeding rate ratios. The Rakocy/UVI feeding rate ratio is expressed as the grams of fish feed required to be fed to the system per day as related to the plant growing area (expressed as grams of fish feed/square meters of plant growing area per day; or $g/m^2/day$).

The Rakocy approach was determined by taking a look at how aquaponic systems work. Rakocy quickly determined that fish feed contains the essential mixture of nutrients required for the healthy and maximised growth of the fish, but that fish have different nutrient requirements to plants.

The key factors in this difference are:

1. Fish do not require any where near the level of two main nutrients that plants do (Potassium – K, and Calcium – Ca).

2. Fish metabolism relies on large proportions or quantities of protein that fish utilise via metabolic pathways that convert this protein into energy. The major waste products after this metabolism are Nitrogen (N) and Phosphorous (P).

3. Fish do not need the same level of other key macro-nutrients that plants do (Sulphur – S, Magnesium – Mg and Iron – Fe, to name a few).

The outcome, and what Rakocy determined, is that plants require a different mixture of nutrients than what fish feed contains and therefore, a method was required to account for this.

Early experimentation showed that fish would never be able to supply the essential Potassium (K), Calcium (Ca) and Iron (Fe) in the amounts that the plants needed, as the fish feed simply did not contain enough of these nutrients at any feeding rate. This lead to the adoption of an approach to supplement these missing major nutrients via the addition of Potassium and Calcium carrying buffers (for a discussion on aquaponic system buffering, see my Aquaponic System Water Chemistry fact sheet) and Chelated Iron.

Further work determined that the fish feed also does not contain enough of other key nutrients required for plant growth.

The way Rakocy accounted for this was to push the feeding rate ratio up to a point where, besides the Potassium, Calcium and Iron, all other nutrients were present in the fish waste at, or above, the amounts required for proper plant growth. Therefore, the approach is to feed elevated amounts of fish feed so that all the nutrients required for plant growth are present to at least the minimal plant requirement. However, the outcome was that when the minimal requirement for all nutrients was met, there was an excess of Nitrogen (N).

The way Rakocy lowered the excess Nitrogen in the system was to use an ingenious approach where a level of controllable de-nitrification (de-nitrification is the removal of nitrogen from the system via the conversion of Nitrate to Nitrogen gas which simply bleeds out of the system and into the air) was employed via his tanks containing orchard netting. In these tanks, solids build up to a point on the netting whereby a small, controllable amount of anaerobic de-nitrification occurs which removes Nitrogen from the system. In addition, part of the management approach to control the nitrogen release or uptake rate is to also remove most of the fish waste solids quickly from the system via sedimentation and to periodically exchange small amounts of system water.

The net outcome was that all plant nutrient requirements were met via the fish waste produced and because a lot of fish waste is required to meet the minimal requirement of the plants in terms of nutrients, a high amount of fish were also produced.

This was an ideal approach as Rakocy stresses that one of the most important advantages of aquaponics is the combined production of appreciable quantities of both fish and plants. In fact, the Rakocy approach via his UVI feeding rate ratios probably produces the highest amount of fish, in relation to the amount of plants, of any aquaponic approach.

More importantly, this Rakocy approach produced an aquaponic system which had minimal hands-on management requirement in terms of water quality analysis; the major water test performed is just pH determination. This makes for an extremely robust and easy to manage aquaponic approach that translates well to many growing situations.

The Rakocy/UVI feeding rate ratios are actually expressed as a range; from 60 – 100 grams of fish feed per square meter of plant growing area per day (**60 – 100g/m^2/day)** for *Tilapia spp.*. This feeding rate ratio is expressed across a wide range because plants that feed lightly (eg: lettuce, basil etc…) can be grown at the lower end of the range (ie: 60 g/m^2/day) and plants that are heavy feeders (eg: tomato's, peppers etc…) may be grown at the upper end of the range (ie: 100g/m^2/day).

The Aquaponic Solutions/Lennard Approach

I came to aquaponics a little later than James Rakocy and have been studying it for the last 12 years. My initial foray into aquaponics was an extensive literature review as a lead up to my PhD studies. This, of course, made me acutely aware of the pioneering scientific work of James Rakocy.

One of the main requirements of any PhD is to produce "…new and novel…" information. This means I could not simply copy the work of Rakocy and had a strong requirement to produce new and different methods and approaches.

On reading and understanding Rakocy's work I decided to develop a different approach to aquaponic feeding rate ratios, and this is what the main thrust of my PhD work was about.

I reasoned that if using the Rakocy approach produced an excess of Nitrogen, then what happens if Nitrogen is actually balanced in aquaponic systems (ie: fish waste nitrogen production equals plant nitrogen use)? The hypothesis was that, as long as an approach was developed to make sure the entire plant nutrient requirements were still met, then less fish feed (and fish) would be required to operate the system.

This approach was also developed from a commercial perspective; meaning that if fish numbers could be lowered then so would capital outlay costs to construct the fish component and this may lead to acceptable economic returns.

I spent 3 ½ years performing a series of experiments that eventually allowed me to develop a new and unique method of determining aquaponic feeding rate ratios. The outcome was a complex mathematical model that allowed me to predict the amount of fish feed required to be fed to the fish species I used (Murray Cod – an Australian native, commercial fish) to grow a known number of lettuce plants (Green Oak variety). This mathematical model was based on replicated experiments that were statistically analysed and so a good amount of predictability was assured via the statistics (to the 95% certainty level).

The predictive model was then used to set the fish feeding rate based on the plant number required to be grown in a rotational lettuce production experiment over many weeks. The outcome was that my model predicted the Nitrogen removal rate to a very high level of accuracy (97% of the Nitrogen produced by the fish was removed by the plants).

However, the experimentation also showed that several other key nutrients were limited when Nitrogen is balanced! These included Phosphorous, Potassium and Calcium and several other nutrients. The chapter in my thesis that discusses this actually argues that at the least, Phosphorous supplementation is required and supplementation of other nutrients would also be required. What this work demonstrated was that Rakocy was spot on; if you want to make sure that ALL nutrients are available to the plants then you need to accept that Nitrogen will be in excess and if you balance Nitrogen then all the other nutrients will be limited.

I wrote up my thesis, submitted it and was conferred to the degree of Doctor of Philosophy in Applied Biology in 2006. My thesis is therefore an accepted scientific publication; published in 2006.

In 2005 (whilst still a student) I started to construct a commercial scale aquaponics facility and started a business. We successfully grew Murray Cod, Basil and other herbs for over 2 ½ years. It was during this phase (2005 – 2006) that I substantially evolved and fully developed my approach.

Four key areas were developed:

1. I evolved and further developed my model to account for the nutrient deficiencies of the other nutrients required for proper plant growth when Nitrogen is balanced (ie: my model is now not based on Nitrogen balancing).

2. I then expanded my mathematical modelling to include a number of different fish species and a large number of plant species and groups, making the model highly specific to the fish and plants chosen for culture.

3. I developed my system of "off-line" fish waste solids mineralisation for re-addition to the system for the utilisation of all the nutrients available in all of the fish wastes (for more information, see my Media Beds and Sizing fact sheet).

4. I developed my own set of unique aquaponic buffer formulations that matched the number of specific fish and plant varieties I could model for.

The advanced modelling has lead to my approach being an all-encompassing model that allows one to predict the amount of fish feed required (and the associated biomass of fish) to grow a known number of plants of many different varieties; each variety of plant, or mixture of varieties of plants, have their own unique ratio. This means aquaponic systems can be designed to meet the requirements of any fish and plant combination in the context of complete nutrient balancing. It also means that aquaponic systems may be designed so that any form of hydroponic plant culturing component may be adopted (without any changes to the modelling approach).

I believe this leads to what are the most important advantages of aquaponics:

1. Duel crop production - both fish and plants are produced in appreciable quantities.

2. Zero net nutrient accumulation - nutrient concentrations are controlled and available in the correct mixture always and neither positively (ie: go to high) or negatively (ie: go too low) accumulate.

3. Minimal water use - zero water exchange (no water is removed from the system - my first system ran for 2 ½ years with zero water released).

4. Zero nutrient release to the environment - therefore, no direct environmental impact from nutrient-rich waste waters.

5. 100% nutrient utilisation - the only way nutrient leaves the system is via fish or plants and no nutrient is wasted.

The off-line mineralisation approach has allowed all the nutrients from the fish waste to be utilised.

A unique set of buffer formulations allows the provision of the specific nutrient mixture for any crop; with minimal buffer additions and the method means essentially, the correct nutrient mixture for any plant species cultured may be provided.

Because my approach is so specific to the plant species and fish species cultured, or the mixture of plant species cultured, it is difficult for me to state a general feeding rate ratio; this is not a general approach, it is one of high specificity developed for the predictability required for large scale, high output farming. And this is probably the main reason I have been reticent to release any feeding rate ratio information as it does not represent the generalisations that hobby-scale and small commercial-scale operator's want, and in fact, would probably confuse the situation.

It is also difficult to provide a feeding rate ratio that may be compared directly with the Rakocy feeding rate ratio as my approach states ratios in different units (Rakocy ratio – g/m^2/day; my ratio – kg of fish feed per plant number) and the Rakocy ratio is a generalised approach to meet all plant species requirements, whilst my approach is highly specific to each individual fish and plant species or variety.

However, an example can be provided here:

My ratio (via the model) states that for a fish species like *Tilapia spp.*, 1 kg of fish feed, fed daily, will support approximately 1,500 lettuce plants in a rotational planting/harvesting scheme.

If you assume that the lettuces are planted at a density of 30 plants per square meter, then this may be translated to an equivalent that may be compared directly to the Rakocy ratio.

In these terms, as a means of comparison, my feeding rate ratio is approximately **16 g of fish feed/m^2/day**. That is approximately 3.75 times less than the Rakocy ratio. If you assume the lettuces are planted at a density of 25 plants per square meter, then this translates to **13 g of fish feed/m^2/day**, or approximately 4.5 times less than the Rakocy ratio.

As I have said, my approach is very specific and so this ratio will not hold true for any other fish or plant species than the *Tilapia spp.* or lettuce stated. If feeding rate ratios for one species of fish or plant are applied to others, then the system can easily go out of balance. As I have also said, the approach relies on occasional broader water testing and the use of highly specific buffer formualtions.

In addition, my ratio assumes that aquaponic systems are designed using standard, modern, recirculating aquaculture filtration technologies so that no anaerobic activity is present in the system, so that all the system Nitrogen is totally represented as plant available Nitrogen.

A Third Approach

I have recently discovered, via two associated examples, that a third approach is being used to set a feeding rate ratio by using what I call an "active system management approach". The approach is based on, from what I understand (I admit that I have not had in-depth discussions with either incumbent), the management of the amount of fish feed being fed to the system based on active and regular Nitrate concentration determinations.

Basically, Nitrate concentrations are regularly tested and by actively changing the daily fish feeding rate to the system, the Nitrate concentration is kept as close to constant as possible (if Nitrate concentrations were graphed therefore, they would appear as a "flat line" across the page).

Nitrate tests determine the concentration of Inorganic Nitrate (NO_3^-) in the water. However, Nitrogen is a complex element in aquatic systems and may be found in many forms; some that the plants can take up and some that the plants cannot take up. Nitrate, therefore, is not the only Nitrogen species found in the system and Nitrogen may also be found in dissolved organic forms. In addition, Nitrogen is in continuous flux and organic forms may quickly change, or be converted, to inorganic forms (via bacterial conversion). Therefore, Nitrate analysis will not give an accurate representation of the Total Nitrogen in the system or the conversion rates of the many forms of Nitrogen to plant available forms.

There is also an inherent risk associated with this approach, as the context I have seen it applied in is one of using what are known as "hybrid aquaponic systems". Hybrid aquaponic systems are designs that utilise both media beds (for the screening out of solid fish waste particles from the water column, biofiltration requirements and solids mineralisation requirements) and deep flow channels (for the culture of the majority of the plant varieties in the system) as the plant growing component. (For a discussion of the assumptions and a scientifically associated sizing method associated with this design approach, see my Media Beds & Sizing fact sheet).

The risk associated with using a Nitrate determination approach in a hybrid aquaponic system context is that in aquaponic systems that utilise media beds, in any proportion, there is a chance that a proportion of the media bed may be operating in an anaerobic phase.

Aquaponic media beds accumulate solid fish wastes and are designed to do this by acting as a mechanical filter that screens these solids and removes them from the water column; this, in itself, is not the issue. The risk is present because if the media beds are not designed or sized correctly to handle and adequately treat the amount of fish waste solids that accumulate in them so that these solids are processed (ie: mineralised) using an aerobic (oxygen-rich) approach, then a proportion of the media bed may convert to an anaerobic phase.

Anaerobic conditions develop when oxygen concentrations fall to near zero. When fish waste solids, or equally, worm cast solids, accumulate in regions or zones within the media bed, they may accumulate to levels whereby the oxygen concentrations at the centre of the accumulated solid fish waste mass (or worm cast mass) may fall to zero; thus developing an anaerobic zone within that mass of solids. In these conditions of low or zero oxygen concentration, anaerobic bacteria begin to operate to process these fish waste solids from inside the mass to the outside.

A quick search of the internet will reveal that many people know that fish waste solids (or worm casts) accumulate in the bottom of media beds. The supposition is that because the media bed is regularly flooded and drained, that this ensures that adequate oxygen concentrations are always available in this zone of the bed, or as it has been stated, this zone stays "fresh".

We have already seen that James Rakocy uses a controlled anaerobic de-nitrification approach in his "orchard netting" tanks whereby if he leaves the netting in for a number of days and doesn't clean it, the solids particles build-up enough on the netting to cause some internal de-nitrification to occur. This anaerobic de-nitrification still occurs, even though there is oxygen-rich water constantly moving through the orchard netting tank. Rakocy can control this process and stop it immediately by simply removing the netting and cleaning the solids off of it.

The argument for media beds by some aquaponic authors is that in a media bed, the regular flooding of the bed supplies enough oxygen-rich water so that anaerobic activity does not occur in the solids accumulation zone. However, if the constant flow of oxygen-rich water through Rakocy's orchard netting tank (which is far more open and mixes oxygen-rich water to a far higher degree with the solids) still enables anaerobic conditions, then why are anaerobic conditions not occurring in media beds where solids accumulate to a far higher concentration and water flows are more restricted? The answer, obviously, is that anaerobic conditions do prevail in the bottom zones of media beds where solids (fish waste or worm castings) accumulate.

In addition, with media beds, there is no available mechanism to quickly remove the solids (unlike Rakocy's method) so that anaerobic conditions may be stopped, limited or controlled when required.

Media beds do accumulate solids and anaerobic conditions, regions or zones, can and do exist if the media bed has not been correctly sized (for a discussion of media bed sizing, see my Media Bed and Sizing fact sheet).

In the context of using a Nitrate concentration approach to managing the fish feeding rate to the aquaponic system, how can this anaerobic zone phenomenon affect things?

As we have seen, in this method, fish feeding rate is directly managed by performing regular Nitrate concentration tests. If Nitrate accounted for all the Nitrogen in the system, then this would be fair enough. However, as we have also seen, Nitrogen exists in many forms in aquatic systems with anaerobic conditions, which do occur in the bottoms of media beds. These anaerobic conditions lead to de-nitrification occurring and the de-nitrification rate is completely uncontrollable.

If de-nitrification is occurring then several species of Nitrogen, other than Nitrate, may be present. In reality, anaerobic conditions cause complex Nitrogen processing to occur and like nitrification, several steps are involved.

The overall chemical chain of Nitrogen species (starting with Nitrate at the left) associated with de-nitrification may be represented like this:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

It can therefore be easily seen that the Total Nitrogen concentration in aquaponic systems is spread amongst many different forms of Nitrogen when anaerobic conditions are allowed and in systems that contain some proportion of media beds, the presence of some areas of anaerobic activity is of a high likelihood.

It is evident that three broad outcomes in terms of Total Nitrogen concentrations in aquaponic systems can occur:

1. In properly designed aquaponic systems (with filtration that quickly and efficiently removes all of the solid fish wastes as quickly as possible) with 100% aerobic conditions, almost all the Nitrogen in the system represents plant available Nitrogen.

2. In aquaponic systems that develop anaerobic zones (like those that contain some proportion of media beds), denitrification occurs via many steps that produce many more forms of Nitrogen which are not all available to the plants (and at least one of those forms, Nitrite – NO_2^-, is, as we all know, toxic to fish).

3. In aquaponic systems that contain some proportion of media beds, all fish waste solids remain in the system and so much of the Nitrogen is in a dissolved organic form and therefore, not available to the plants.

The outcome in terms of the Nitrate determination method in terms of managing fish feeding rates in aquaponic systems that contain media beds is that Nitrate is highly likely to never represent the true concentration of Total Nitrogen in the aquaponic system and cannot provide a predictable concentration of plant available Nitrogen.

The other, probably most important, affect that occurs when aquaponic systems experience zones of anaerobic activity is that the de-nitrification process produces alkalinity (a process that causes pH to rise).

In aquaponic systems that operate under aerobic conditions, nitrification (the conversion of Ammonia to Nitrate) causes a pH fall or drop. Therefore, we usually need to add buffers to make the pH rise back up to where we want it to be (approximately pH 7). It is the addition of these buffers that allow us to also supplement Potassium (K) and Calcium (Ca); nutrients that are not available in aquaponic systems at the concentrations required for normal plant growth (we normally use Potassium and Calcium based buffers to do this).

De-nitrification actually causes the opposite affect to nitrification; it makes the pH rise. If enough anaerobic activity is present, then the pH rise caused by de-nitrification can over-power the pH fall caused by nitrification and the pH stays high (above pH 7). This means we cannot supplement the Potassium and Calcium required (via the addition of Potassium and Calcium based buffers) and the plants do not get access to these important nutrients at adequate concentrations.

This is why people with media bed aquaponic systems (either hobby-scale or hybrid commercial-scale) sometimes need to add an acid (or pH down agent) periodically to their systems; because their media beds are operating to some extent in the anaerobic mode and this is making the pH rise. The reason the media beds are de-nitrifying is because they have enough accumulated solids in them (either fish waste solids or worm casting solids) to produce zones of low or zero oxygen which leads to anaerobic zones and de-nitrification activity.

If an aquaponic system requires the addition of an acid or a pH down agent, then this is a sign that anaerobic conditions are prevailing and the media bed(s) need to be cleaned. Aquaponic systems (even media bed systems) should always operate under aerobic conditions and if they are not, then it is because they have not been designed correctly and so the solids that enter them are not quickly and efficiently broken down and mineralised. This is usually because the media bed has not been sized correctly and the bed solids mineralisation (breakdown) rate cannot keep up with the solids entry rate, and so solids accumulate (for a discussion of correct media bed sizing, see my Media Bed and Sizing fact Sheet).

Finally, as James Rakocy has argued and scientifically shown, and as I have scientifically shown, if you balance fish feed input with plant nutrient requirement only in terms of Nitrogen, then all other nutrients required for plant growth are limited and the plants will experience deficiencies.

Therefore, the question is:

Does the Nitrate concentration determination method represent a predictable method for the overall sizing and design of aquaponic systems?

The answer is; probably not, because the Nitrate concentration in any aquaponic system containing media beds will never represent the true Total Nitrogen content of the system and therefore, does not represent the true total of all the Nitrogen available to the plants in the system.

In addition, if de-nitrification is occurring (which may be "masked" or not apparent, as Nitrate analysis does not represent the Total Nitrogen in the system and does not detect de-nitrification), then this can lead to negative outcomes for the system in terms of pH control, the supplementation of vital Potassium and Calcium and the presence of accumulated solids (whether fish waste solids or worm castings).

The next logical question is:

Can the Nitrate determination method be used for aquaponic systems that use traditional solids filtration approaches where media beds are not employed?

The answer is; maybe, to an extent! This is because modern aquaculture solids filtration approaches deliberately utilise configurations that encourage aerobic conditions, and so the Nitrate concentration will likely represent something much closer to the Total Nitrogen concentration than a media bed containing system which will most likely have some proportion of anaerobic activity occurring in it.

The "extent" is that, as I have explained in the section on my method, when Nitrogen is used as the balancing nutrient species in aquaponic systems, it is definite that other essential nutrients for plant growth will be limited. If an approach is not employed to account for this, then nutrient deficiencies in the plants will be realised. This has been proven by scientific analysis which has shown that if Nitrogen plant requirements are used to balance total nutrient input to the system then all other nutrients will be limited and the plants will show experience deficiencies (as Rakocy always argued).

In addition, aquaponic systems contain a lot of dissolved organic nutrients, especially Nitrogen, and the Nitrate determination method will not "read" or detect the levels of the Dissolved Organic Nitrogen in the system and therefore, can never account for the Total Nitrogen available in the system.

And, if conditions prevail that enhance the possibility of anaerobic zones where de-nitrification occurs, then this can affect pH control and affect the available concentrations of other essential nutrients because this can lower, or negate, buffer additions.

Therefore, the aquaponic operator must be aware of all of these possible outcomes and their possible overall affect on the management of the system for correct plant nutrient supply.

Conclusions

We have seen that the only predictable and scientifically verified way to size the components (fish and plants) of aquaponic systems is to base the calculation on the ratio of fish feed input to plant number or growing area. We have also seen that the currently accepted way to state this in terms of some ratio is via a feeding rate ratio.

There are currently only two scientifically verified feeding rate ratio's available; the Rakocy feeding rate ratio (UVI feeding rate ratio) and my own feeding rate ratio. The Rakocy ratio has been developed as an all-encompassing approach that is easy to use and one that produces far higher numbers of fish than any other approach. My ratio is far more specific and has been developed for the large-scale, commercial production of fish and plant crops in very exacting conditions. Both approaches were developed under different scientific circumstances and via different practical drivers, and for different outcomes, and should have equal validity if used in the correct design context.

The third approach, the Nitrate determination method, does have some validity as a hypothesis, but scientific testing by the UVI team and myself has shown that when Nitrogen is balanced, all other nutrients are limited. Because this approach seems to be currently predominantly used in a media bed or hybrid aquaponic system design approach context where anaerobic conditions are usually present, questions of its validity as a design methodology arise.

However, once the aquaponic system has been constructed, it is a fair assumption to accept that the Nitrate determination approach may be used as an ongoing management method for aquaponic systems that encourage aerobic conditions (unlike media bed systems, which may encourage anaerobic conditions if not designed correctly), as long as the operator is aware that nutrient deficiencies are likely to be encountered at some point with respect to the other essential, nutrients required for healthy plant growth.

It is up to the operator to decide what is the most appropriate design approach/method to use for their particular aquaponic system, business or commercial application.

A Final Word

Whilst I have argued that the Nitrate determination approach is not an appropriate method in terms of an aquaponic system management approach for aquaponic systems, it may be applied as a management tool for systems that encourage aerobic conditions, as long as the limitations in terms of the availability or non-availability of other plant essential nutrients are known and accounted for.

Happy Aquaponicing.

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Lennard, W.A.. (2006). "Aquaponic integration of Murray Cod (*Maccullochella peelii peelii*) aquaculture and Lettuce (*Lactuca sativa*) hydroponics." Thesis submitted for fulfilment of the Degree of Doctor of Philosophy. RMIT University, Victoria, Australia.

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