



Report Title:

Media Bed Sizing Test for Backyard Aquaponic Systems



Client: Backyard Aquaponics

Client Contact: Joel Malcolm
Backyard Aquaponics

Date: 5/11/2010

Author: Wilson Lennard (PhD.)



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Introduction:

Aquaponic Solutions has developed a sizing model so that aquaponic systems using a media bed approach for the hydroponic plant growth and filtration component may be sized. The model may be used to match the size of the media bed (eg: gravel bed) with the size of the fish tank and the biomass of fish which will be kept in the fish tank component. The model gives output media bed sizings for three situations:

1. The media bed volume for the biofiltration requirement of the system
2. The media bed surface area for the fish feed input to plant growth surface area requirement of the system (ie: fish to plant ratio)
3. The media bed surface area for the solids mineralisation requirement of the system

Aquaponic Solutions has asked backyard Aquaponics if a number of their backyard aquaponic system kits may be analysed with the model to substantiate the sizing of the system(s) and to confirm that the systems will operate to the design specifications, with respect to:

1. Meeting the media bed surface area requirement for correct fish to plant ratio
2. Meeting the media bed volume requirement for correct biofiltration of the released fish waste in terms of nitrification efficiency
3. Meeting the media bed surface area requirement for correct solids mineralisation of all released solid fish waste from the fish rearing component

Backyard Aquaponics was more than happy to have their systems analysed with the Aquaponic Solutions model and so provided the system size parameters used in this analysis.

How the Model Works – Standard Application:

The model has been developed so that the correct media bed may be sized based on several inputs associated with the fish rearing component of the system. The inputs include the fish tank volume, the fish culture density, the fish feeding rate and the protein content of the fish feed used. The outputs generated are a media volume required to meet biofiltration requirements, a flow rate required to meet the biofiltration requirement, a media bed surface area required to meet the total solids mineralisation requirement of the solid fish waste produced, a media bed surface area required

to balance fish waste nutrient production with plant nutrient uptake for leafy greens and a media bed surface area required to balance fish waste nutrient production with plant nutrient uptake for fruiting plants. Both outputs with respect to the media bed requirement based on fish feed input to plant surface area requirement ratio's are based on the models for commercial aquaponic systems as developed by Dr James Rakocy and his team at the University of the Virgin islands (UVI).

The model has been developed to be used as a guide to sizing media bed aquaponic systems when in the design phase. Generally, the largest modelled media bed size is what is appropriate for that particular system and so the largest modelled media bed is what is generally utilised in the design. The model is a guide only and practical application has shown that media bed aquaponic systems operate in a wide range of situations and with a wide range of fish numbers, fish biomass and fish feed inputs. The model gives the average indicated size of the media bed that matches the fish tank and fish culture density utilised.

How the Model Works – Application for System Analysis:

Because Backyard Aquaponics already has systems available, the model may be used in a manner which allows the system(s) to be analysed based on the existing conditions (ie; fish tank volume and media bed size are already set). In this style of application, the model allows the system to be analysed and because the media bed size is already set, the output generated is based on the maximum suggested fish culture density that is appropriate for that system. This is possible because the best operating approach for any system may be determined by simply determining the most suitable fish culture density for that particular system, based on the size of the existing components.

This means that virtually any aquaponic system will or may operate in a successful manner (as has been shown and proven by the years of successful system operation by many and varied individuals). Optimisation of that system is simply determined by what the best fish culture density is for the available media bed size.



Method:

Six of Backyard Aquaponics available kits were entered into the model. Entered parameters were:

1. Fish tank volume
2. Daily feed rate – set at 1% of fish biomass (this is an average feed rate for fish above 100g in weight)
3. Feed protein level – set at 45% for this study, as most native fish eat a 45% protein diet
4. Specific Surface Area (SSA) of the media – 300m²/m³ has been used for this study as this is an average SSA for gravel media

The final input parameter was fish culture density. Several examples of fish culture density were entered into the model until the output for media bed size (leafy greens – generally the highest output from the model – see the “How to use...” document that is provided with the model for further details) matched the media bed size of the system as it is available.

This then indicates the maximum potential fish culture density for that particular system. Domestic media bed aquaponic systems generally operate within a range of 1 – 20 kg of fish per 1,000L of fish tank water.

Results:

Six media bed Backyard Aquaponic system kits were put through the model and the maximum potential fish culture for those systems determined.

Table 1: Results for Backyard Aquaponics systems modelling analysis

System	Fish Tank (L)	Grow Bed (m ²)	Model max fish density (kg/m ³)	Max advised fish density (kg/m ³)
Entertainer	1,000	5.28	17	20
Courtyard	1,000	2.64	10	12
Backyard	2,000	7.92	15	17
Family	3,000	10.56	14	15
Budget	1,000	2.64	10	10
Salad	700	0.7	5	5

The above table outlines the results of the analysis of the 6 media bed systems available from Backyard Aquaponics. Column 4 (Model max fish density) outlines the maximum fish culture

density for the system. Column 5 (Max advised fish density) represents the maximum suggested fish culture density for that particular system.

Interpretation of the Results:

As can be seen in the results table above, the maximum potential fish culture density for each system except the “Salad” system is between 10 and 20 kg/1,000L. For the “Salad” system, it is 5 kg/1,000L. This means that for each individual system, as long as the suggested maximum fish culture density isn’t exceeded, the system will work to biofilter **all** dissolved fish wastes (eg: the nitrification of all ammonia), to grow **all** plants with the required amount of nutrients for those plants and mineralise **all** solid fish wastes that the fish produce.

Discussion:

The Aquaponic Solutions model was developed so that any domestic scale, media bed, aquaponic system could be designed by anyone. However, the model can also be used to check and determine the correct operating fish culture density of existing media bed aquaponic systems. It is in this way that the model has been used to determine the optimal operating parameter of fish culture density for 6 Backyard Aquaponic system kits.

Fish culture density directly affects many other parameters in media bed aquaponic systems. However, it should always be taken into account with other important parameters, such as fish feed input.

The model uses three (3) important parameters as the drivers for media bed size suitability:

1. Media volume for biofiltration needs
2. Media bed surface area for fish feed input uptake by plants (fish to plant ratio)
3. Media bed surface area for solid fish waste mineralisation

The volume of media (eg: gravel) required to meet the biofiltration requirement of the dissolved ammonia released by the fish is always far lower than the volume of the media bed generally used in aquaponic systems, so we can be assured that the biofiltration requirement is always met.

The surface area for plant growth required to balance the fish waste output with plant nutrient uptake is a complex ratio (often called the “fish to plant ratio”) or association that is much debated in aquaponic circles and there are many approaches to setting this ratio. In fact, the ratio is never associated with actual fish numbers, fish weight or fish tank or grow bed volumes, but with the amount of fish feed that enters the system on a daily basis and the efficiency at which the fish convert that feed. This is because the amount of fish feed that enters the system has a direct relationship with the amount of fish waste (either dissolved or solid) produced by the fish; the more feed that enters the system, the more nutrients the plants need to uptake and therefore, the more plants which can be grown and supported. Fish will eat varying amounts of feed on a daily basis, so it can be seen that if you have a small biomass of fish in the system, but they eat a high amount of feed, you can support more plants than if the fish only ate a small amount of feed. Alternatively, you could have a high biomass of fish, but feed a small amount of feed and so support fewer plants. The fish are converters that work at fairly stable conversion rates, so it is more about the amount of fish feed you give those fish to convert into waste nutrients rather than the actual amount of fish present. By modelling the daily amount of feed that enters the system, based on knowing the biomass (density) of the fish and the daily percentage of that biomass that enters the system as fish feed, we can determine the most appropriate media bed size for the system because we can easily predict the amounts of the wastes produced.

The surface area of the media bed required to meet the solid fish waste mineralisation requirement of the system is also a hotly debated topic in aquaponic circles. In fact, there are known and well established associations for media bed surface area and solid waste breakdown or mineralisation rates in reciprocating (ebb & flow or flood & drain) aquatic systems. This means that flood & drain aquaponic media beds do have the ability to break down and mineralise solid fish waste and if the balance between the daily amount of solid fish waste and the surface area of the media bed is determined then it can be expected that the media bed will go on mineralising solid fish waste in perpetuity.

The current study has set media bed and fish tank sizes, so we need to determine what other parameter we can manipulate so we can get the system in balance for biofiltration, fish to plant ratio and solids mineralisation. The only parameter we can manipulate is the amount of daily fish feed we feed to the system. This amount of fish feed should be directly linked to the amount (or biomass) of

fish in the system as well, so we know the individual fish in the system are getting their required daily intake of feed so they are healthy and grow well.

As stated, the biofiltration capacity is almost always met, so we don't need to worry about this. The UVI fish feed input to plant growth area ratio (the fish to plant ratio we use) for leafy greens is $60\text{g}/\text{m}^2$ of bed surface area. This means that, for a 2m^2 bed, we need to add about 120g of fish feed per day. This weight of fish feed also represents about 1% of the fish's biomass in the system (because adult fish eat about 1% of their body weight in feed per day). Therefore, if 120g represents 1% of the total fish weight, we will need about 12kg of fish in the system. Therefore, if we have 12kg of fish eating 1% (120g/day) of their body weight, we can support 2m^2 of media bed for plant growth. In this way, we can manipulate the fish biomass (and subsequent fish culture density) to meet our media bed size.

In terms of solids mineralisation we can also determine what the correct media bed size is based on the daily fish feed input. Again, fish will release predictable amounts of solid fish waste based on the amount of feed that is fed to the system. There are known mineralisation and solids breakdown rates for solid waste particles in media beds, so these can also be used to determine the correct media bed surface area so all the solid wastes the fish produce on a daily basis are mineralised by the bed. As for the fish to plant ratio, we can manipulate the fish feed input to the system so the amount of solid waste produced may be fully mineralised by the media bed and so the media bed is sized correctly based on the daily fish feed input.

Because we can link these amounts of fish feed added, amounts of dissolved ammonia produced, amount of plants required to uptake the wastes and the amounts of solid fish wastes produced we can use one measure as our tool to test for appropriate bed size. In the current study we have linked all these parameters and associations via the parameter "fish culture density" (this is only possible because we set conserved associations between fish density and fish feed input).

Therefore, the outcome is that we get a potential fish culture density that matches the media bed size for all the systems tested. If this fish culture density is not exceeded, then the system should operate at an optimised production rate for many years. Keeping the fish culture densities below the suggested level will also assure that the fish are happy as oxygen levels should always be sufficient.

As stated in the results section of this report, we have directly matched the appropriate fish culture density for the systems with the size of the available media bed surface area. These fish culture density figures change if we change the assumptions we have made for fish feed input as a % of the fish weight in the system. In this study we have assumed a 1% daily input of feed, 1% being 1% of the total fish biomass of the system. This is what sets our final fish culture density result. So, whilst the result is actually a fish feed input rate, we have stated this as a fish culture density because that is more appropriate for people to use and understand.

The outcomes are as stated in the results table for each individual system. If operators use the fish densities as the model suggests for these particular systems (while using an average 1% daily feed rate) then the number of fish in the system, and ultimately, the amount of fish feed those fish eat and the amount of waste they produce from that feed should be processed, used or converted by the media bed of the system. This also indicates that most domestic scale, media bed based aquaponic systems have the ability to operate well and perform all tasks, as long as some basic principles of design are followed. What the current study proves is that many of the aquaponic systems available on the market (including those of Backyard Aquaponics), or made at home, have a basic “built in” ability to perform correctly, all that needs to be taken into consideration is what is the best fish culture density and daily feed input rate for that particular system.

Finally, there is much precedent for the fact that media bed aquaponic systems operate well across a wide range of inputs and operating conditions. Therefore, the outcomes of this study are suggested fish densities and in all likelihood, fish densities and feed rates outside of these modelled results may still work very well.

The study suggests that, at the maximum fish culture densities stated, the domestic media bed aquaponic systems that Backyard Aquaponics sells should work very well to biofilter, solids mineralise and grow plants using the established media bed based aquaponic approach.