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Aquaponics research at Lethbridge College, Alberta

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Aquaponics Association

On-line Conference

Pilot-scale system in Brooks, Alberta, built with help of Dr. James Rakocy in 2001. It was modified to become the first system to utilize all solid waste within the system in aerobic bioreactors also known as “mineralization tanks”.

Brooks aquaponics facility became the first zero-waste farm.

- Aerobic Bioreactor at CDC South pilot aquaponics, Brooks

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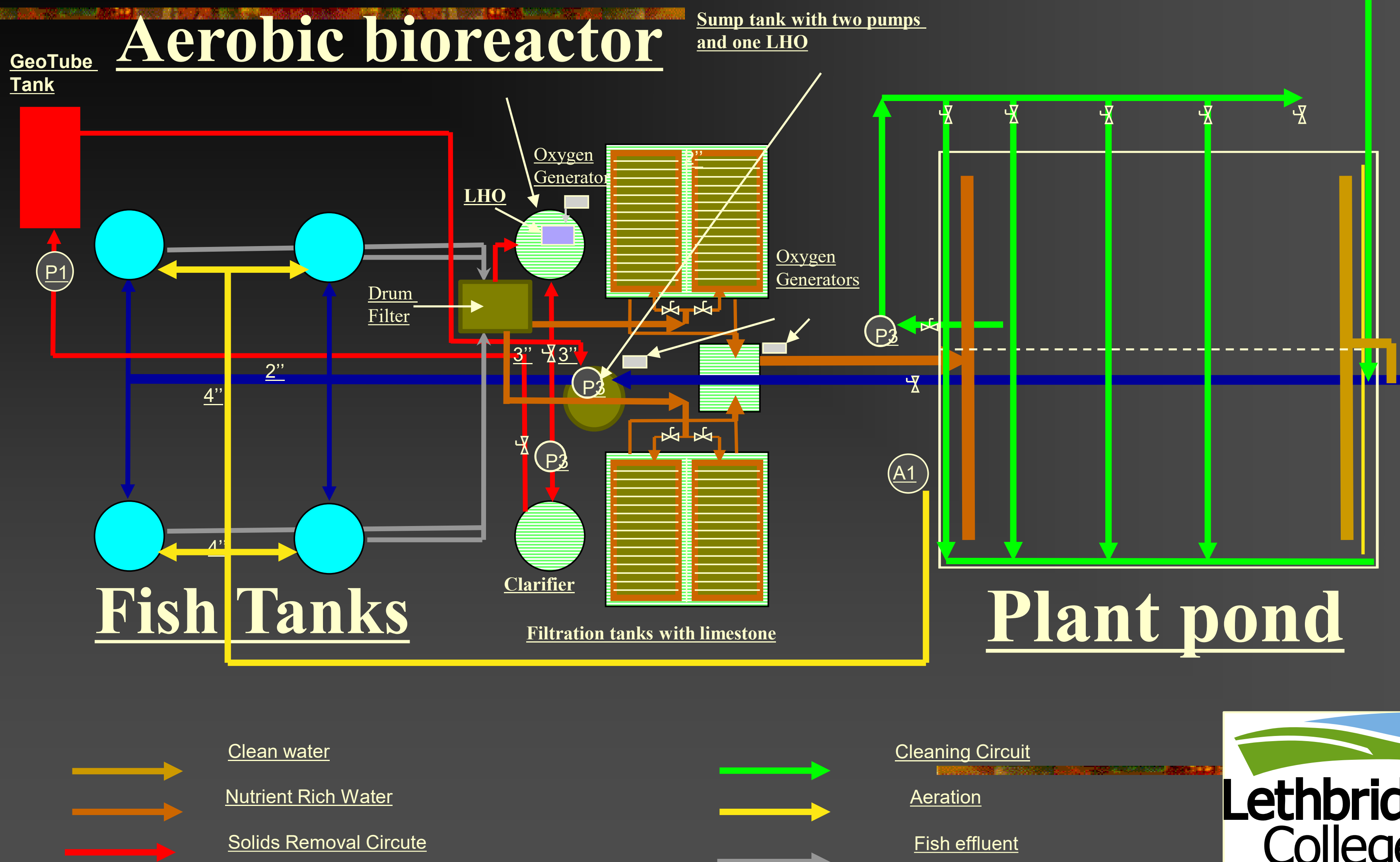
Generation 4 aquaponics system, Brooks, AB, Canada, 2007



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Lethbridge College was awarded by CCI NSERC program for 5 years to further develop and commercialize aquaponics in Canada in 2014. Charlie Shultz was the lead aquaponics scientist at that time.

To date, it is the largest aquaponics project in Canada and one of the largest in the world with total budget $3.2M including $2.2M from the federal government of Canada

Based on 4 Pillars

1. Agri-H_2O
2. Agri-Food
3. Agri-Business
4. Community Engagement

Pillars/Major objectives of NSERC CCI Aquaponics Project at Lethbridge College

Pillar 1: Agri-H_2O
Development of commercial aquaponics production platform

Pillar 2: Agri-Food
Consumer-oriented study on acceptance of aquaponics produce and evaluating its quality industry through engagement and partnerships

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Pillars/Major objectives of NSERC CCI Aquaponics Project at Lethbridge College

Pillar 3: Agri-Business
Economics of aquaponics production – designing economic simulator model

Pillar 4: Community Engagement
Providing support in commercialization of aquaponics technology to communities and industry through engagement and partnerships

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Pillar 1 - Agri-H2O - platformDevelopment of commercial aquaponics production

Main Objectives:

- Creating a Stable Nutrient Rich Plant Solution from Various Fishes Effluents and Solid Wastes
- Continuous Evaluation of the Nutrient Solution Using Specially Designed Aquaponics Modules
- Food Safety
- Organic Certification

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Pillar 1. Agri-H2O

Overarching goal: Development of commercially viable and safe aquaponics production platform for the industry

- The main focus was to further improve the technology to process solid fish waste in aquaculture and use the mineralized solution for plant production

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Objective 1. Creating a Stable Nutrient Rich Plant Solution from the Effluents of Different Fish Species and Solid Wastes

The bioreactors were used to carry out aerobic bio-fermentation process to achieve complete mineralization of all organic fish waste

The resulting mineralized solution was used both as the only nutrient source for plants (decoupled system) and as a nutrient supplement for recirculating aquaponics system

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Objective 1. Creating a Stable Nutrient Rich Plant Solution from the Effluents of Different Fish Species and Solid Wastes

Two production protocols included use of bioreactor mineralized solution (decoupled system) and aquaponics systems

The systems were run at 65°F (18°C) and 80°F (26.6° C)

Warm-water aquaponics included tilapia and barramundi

Cold-water aquaponics included rainbow trout

- Aerobic bioreactor will be an essential component of sustainable agriculture in future

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Why do we need Aerobic Bioreactor?

- Aerobic bio-digestion is a breakdown of organic material into minerals available for plants and CO_2 in the presence of oxygen
- Another term for this process is "mineralization" or "ammonification"
- This process occurs in specially designed aerobic bioreactors

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Only mineral component of poultry manure is left after the process including sand and oyster shells

Specially designed computer control system was able to automatically maintain chosen parameters and collect data every second

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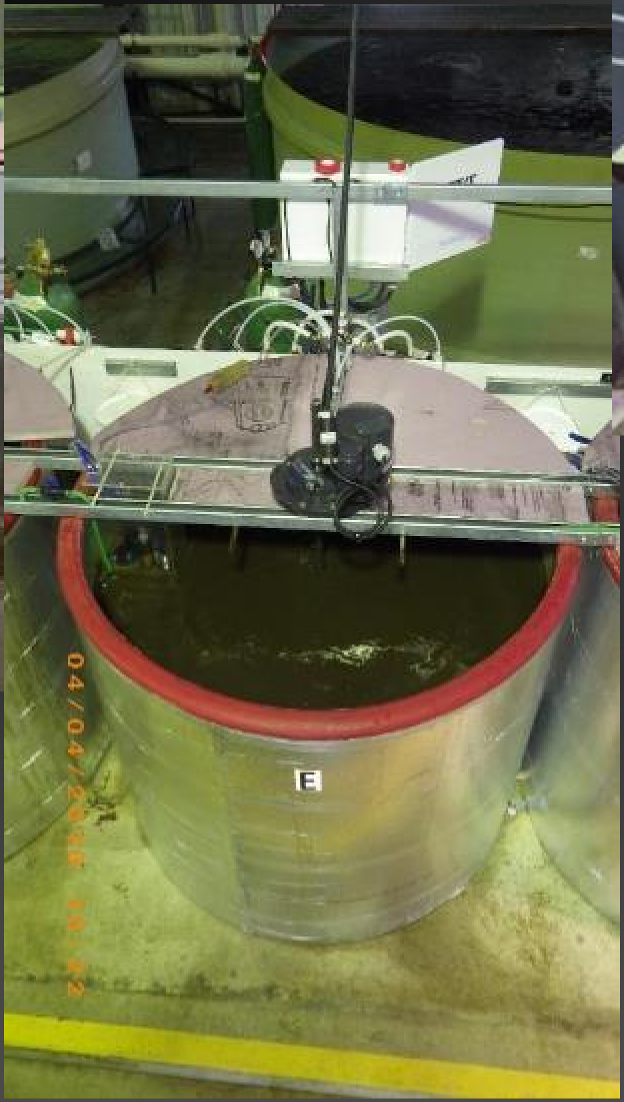

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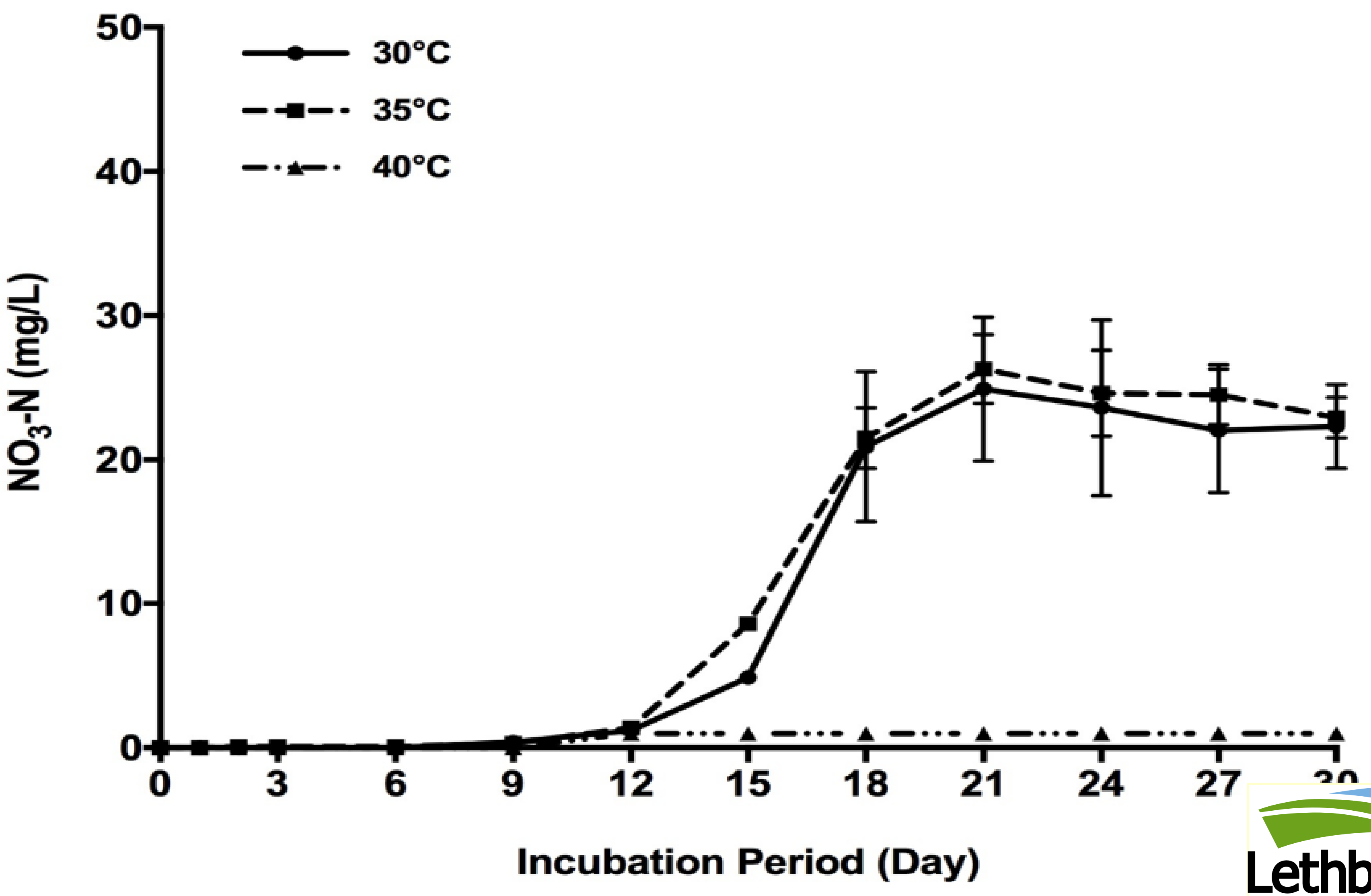
Extensive bioreactor studies were conducted to investigate the effect of temperature, pH, DO, dry solids content and microbial inoculum on the mineralization of organic solids from different fish species including tilapia, trout and barramundi

- Kinetics of nitrification during aerobic digestion of aquaculture solid waste



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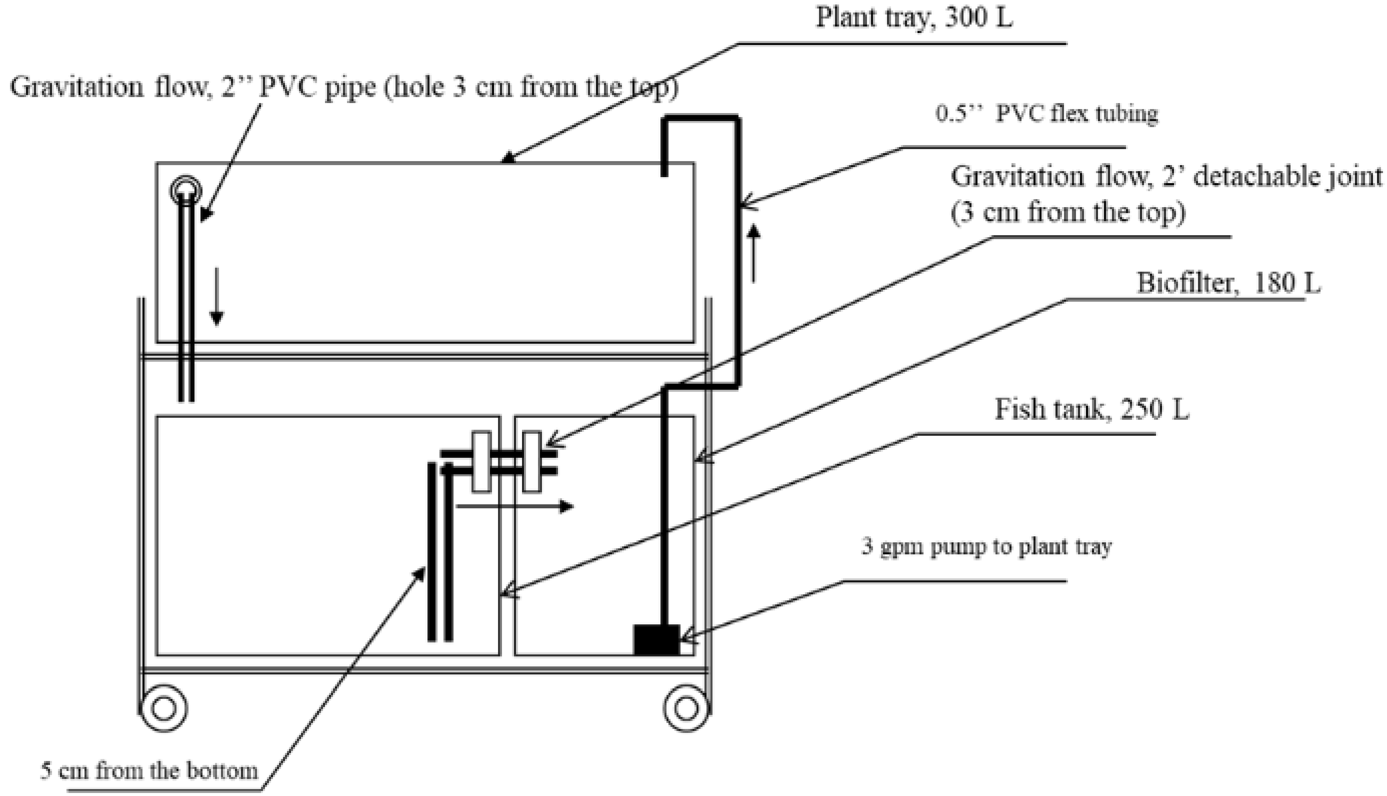
Recommended parameters for fermenting mixture

Available Dissolved Oxygen -	≥ 2 ppm
Temperature –	30-35°C
pH	6.0-6.5
Dry solids content –	1-5%
C:N ratio –	5-35

How valuable is the fish sludge as a source of plant nutrients?

To answer this question a mass balance study has been conducted using 700 L aquaponics modules

3. Side view


Plant tray, 300 L
Gravitation flow, 2'' PVC pipe (hole 3 cm from the top)
0.5'' PVC flex tubing
Gravitation flow, 2' detachable joint (3 cm from the top)
Biofilter, 180 L
Fish tank, 250 L
3 gpm pump to plant tray
5 cm from the bottom

Materials and Methods

Sampling

- 4 plant samples (3 plants each) wet and dry biomass of shoots and roots measured
- 3 fish samples (4 plants each) wet and dry biomass measured
- Weekly water samples collected for analysis

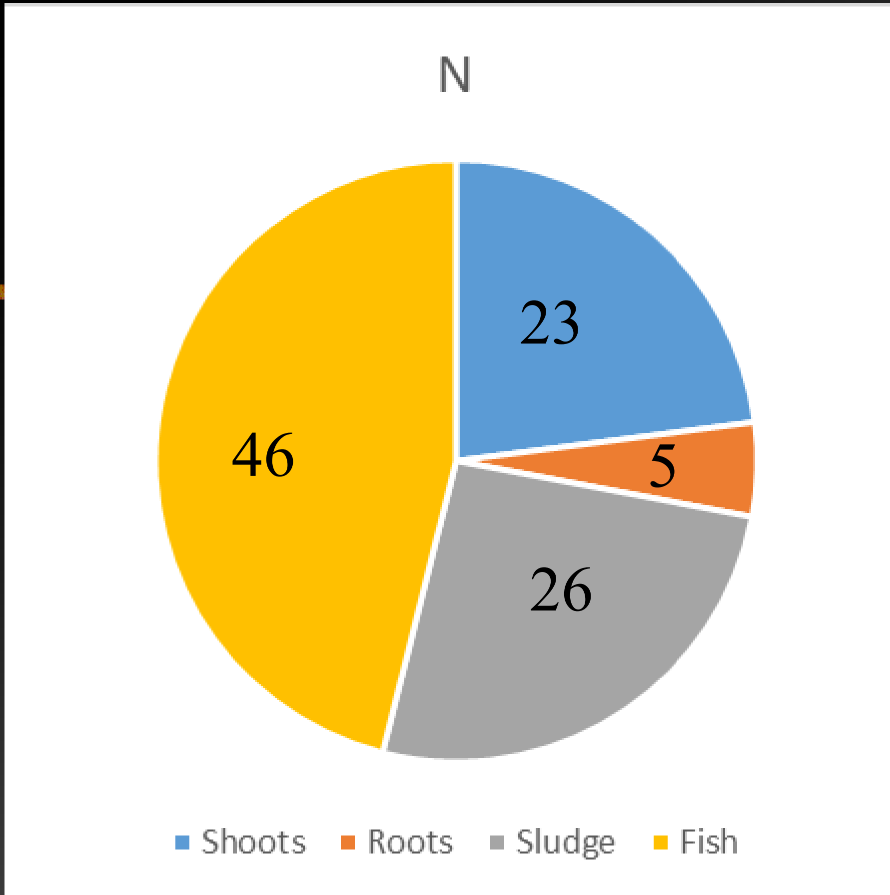
Operations

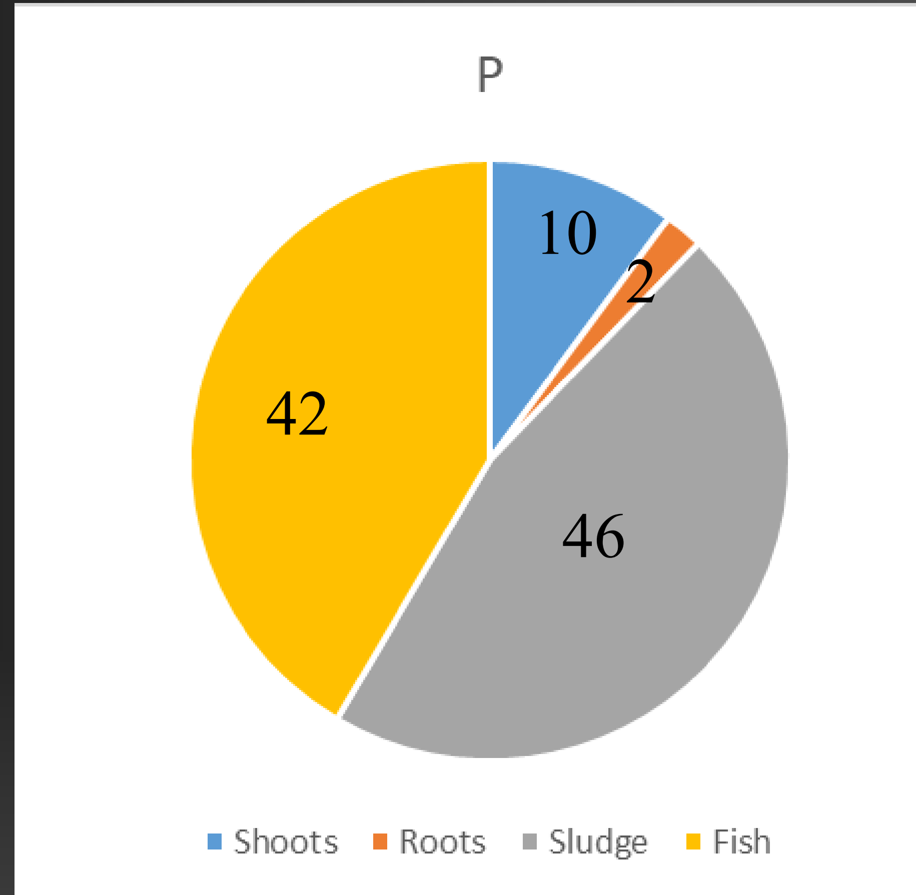
- 9 mini-aquaponic modules with 4 fish and 8 plants each
- Plants and fish grown for 4 weeks prior to harvest
- Fish fed with 3 g of feed per day per system
- pH and temperature monitored twice per week, and EC once per week

Harvest

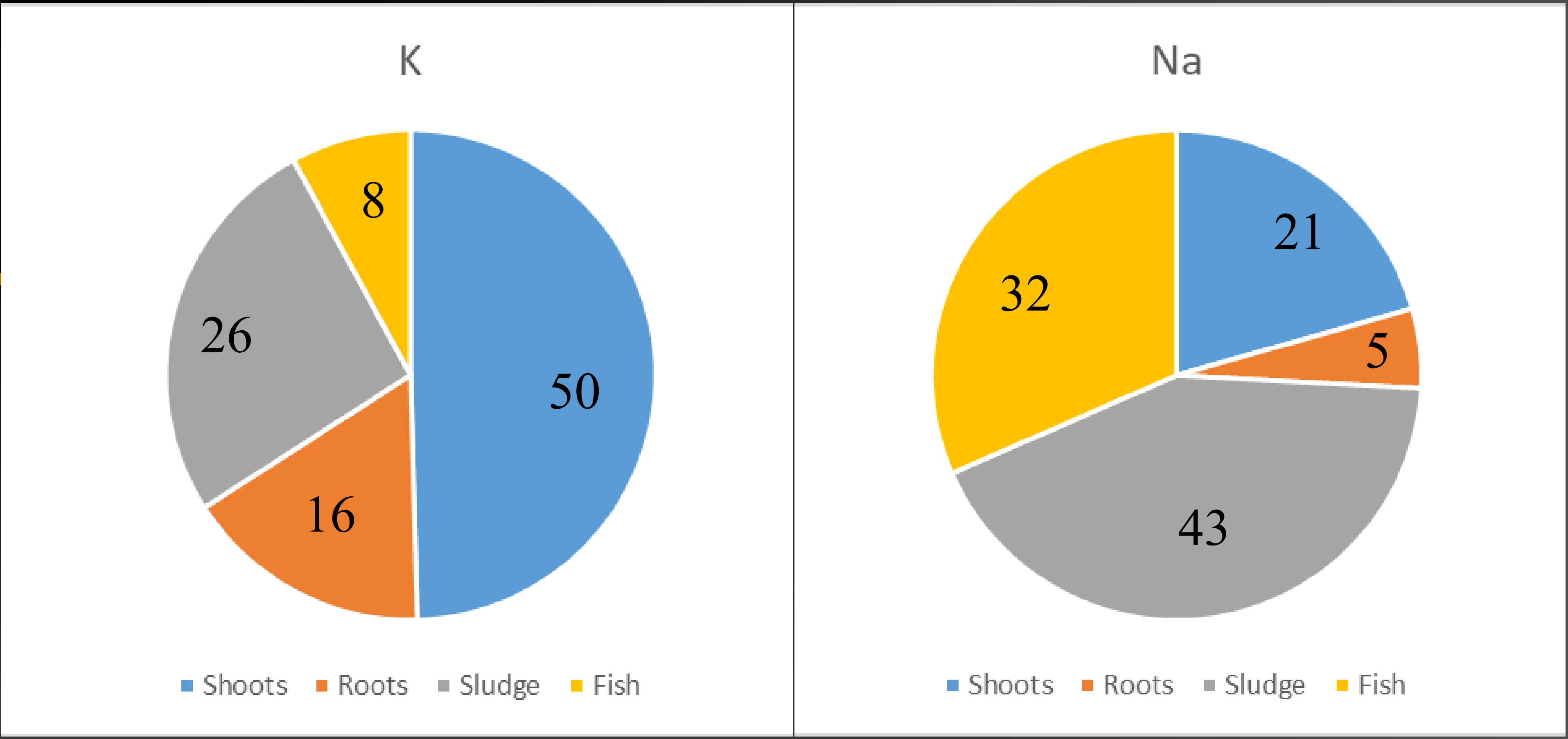
- Plants and fish harvested separately
- Fresh weight recorded for plants and fish for each module
- Plants dried with weights recorded

PERCENTAGE OF TOTAL AMOUNTS OF MINERALS ALLOCATED IN DIFFERENT COMPONENTS OF AQUAPONICS SYSTEM

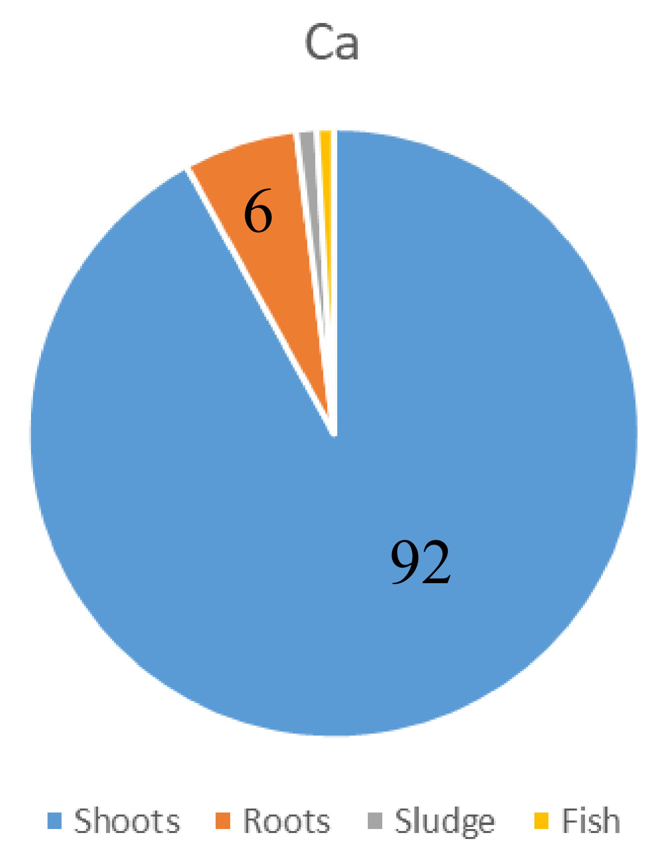


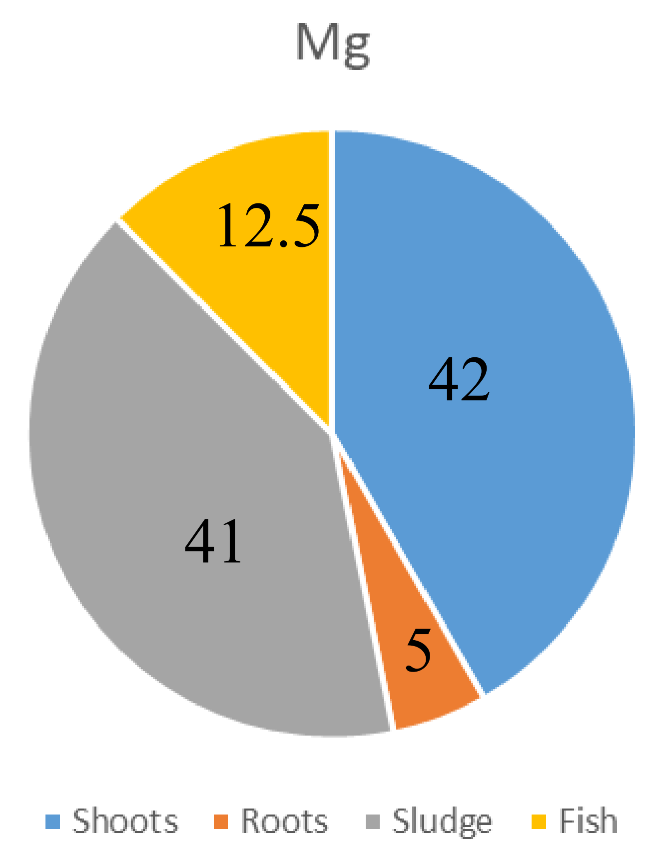


Shoots Roots Sludge Fish

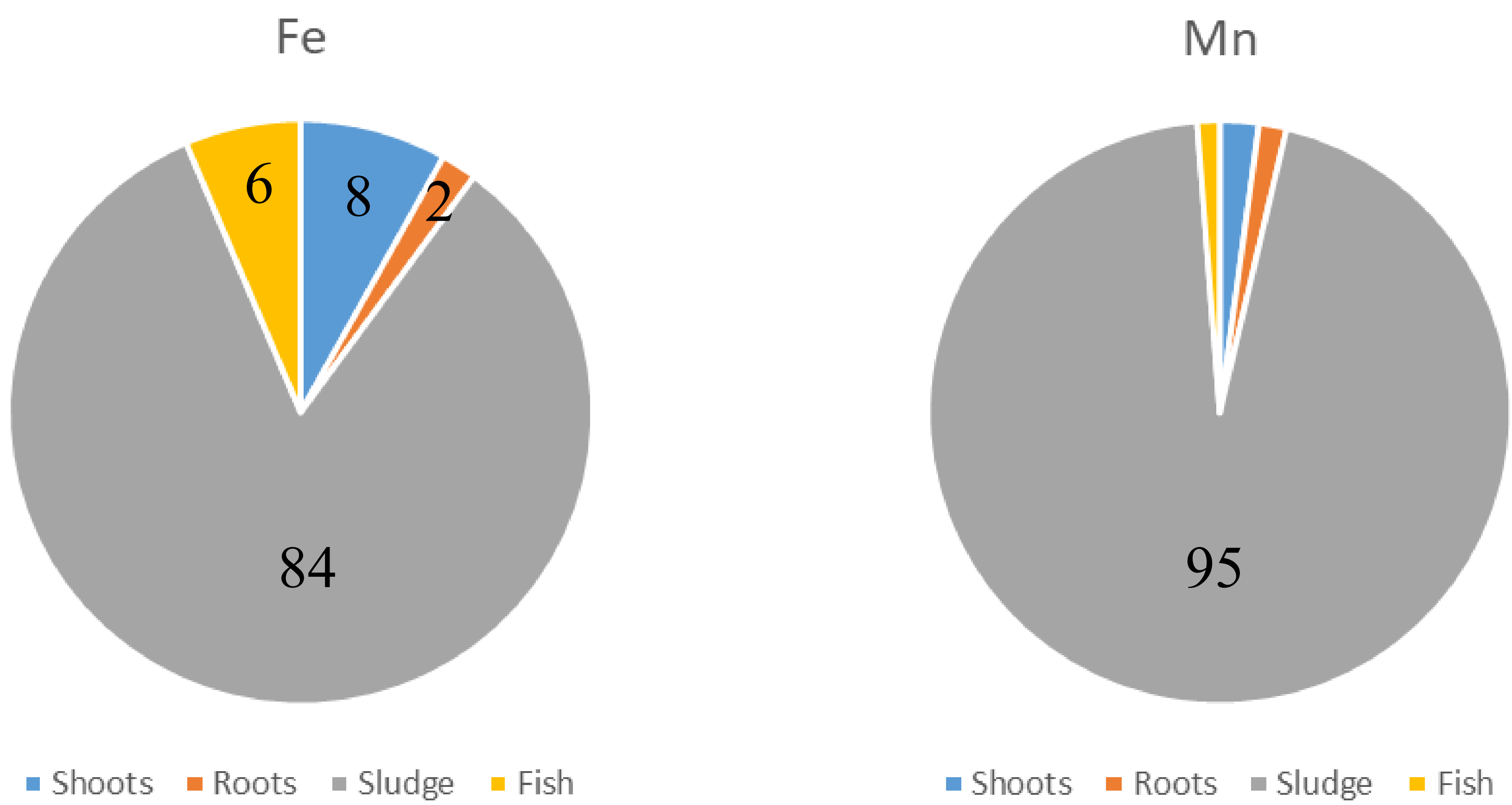

K
8
26
50
16
Shoots Roots Sludge Fish
Na
21
32
5
43
Shoots Roots Sludge Fish

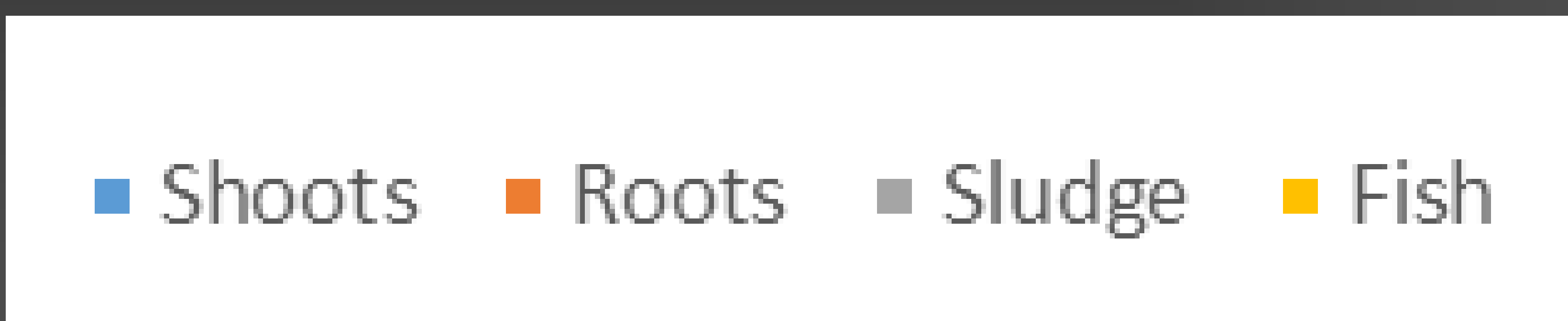

Shoots Roots Sludge Fish

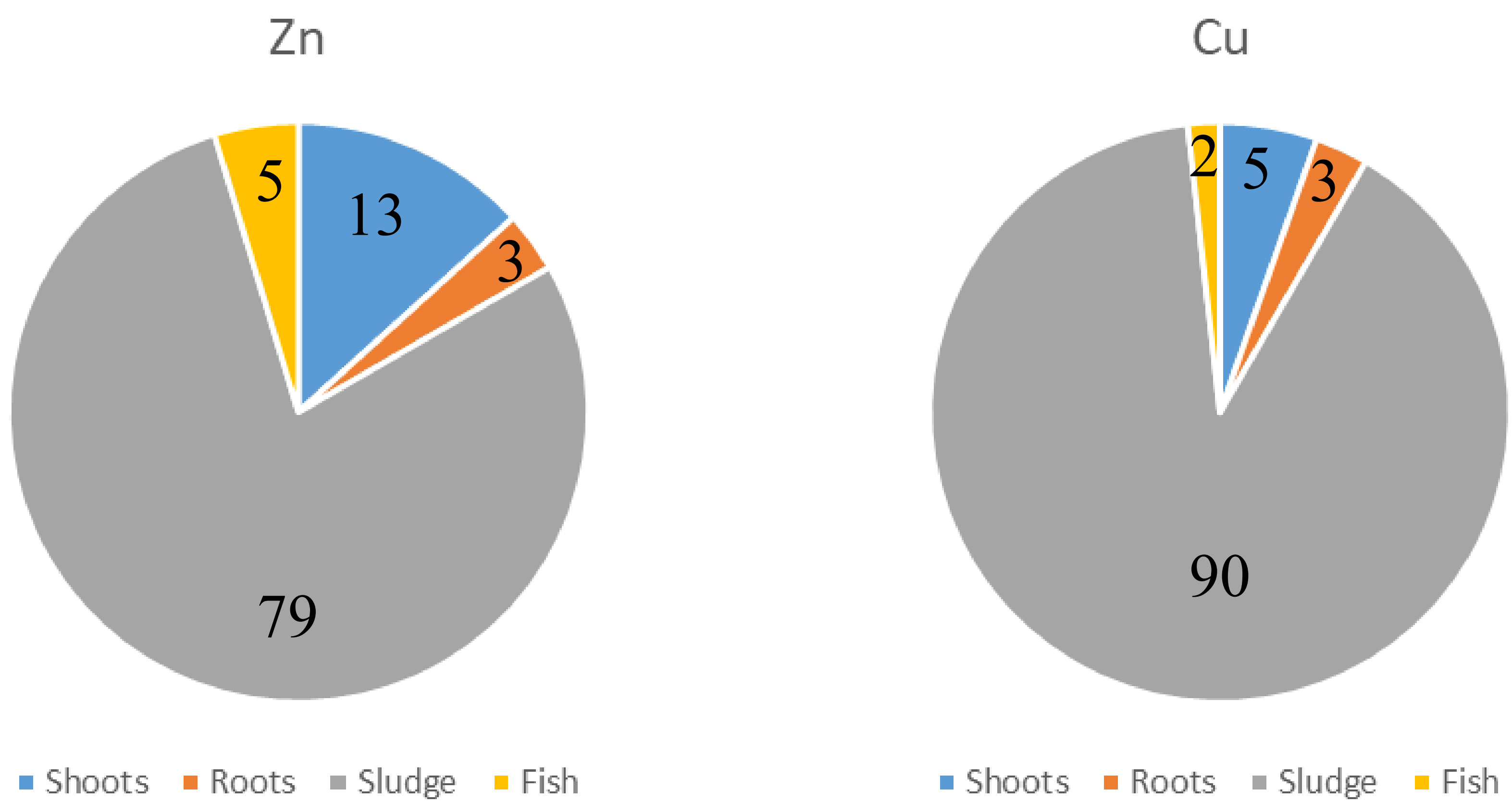


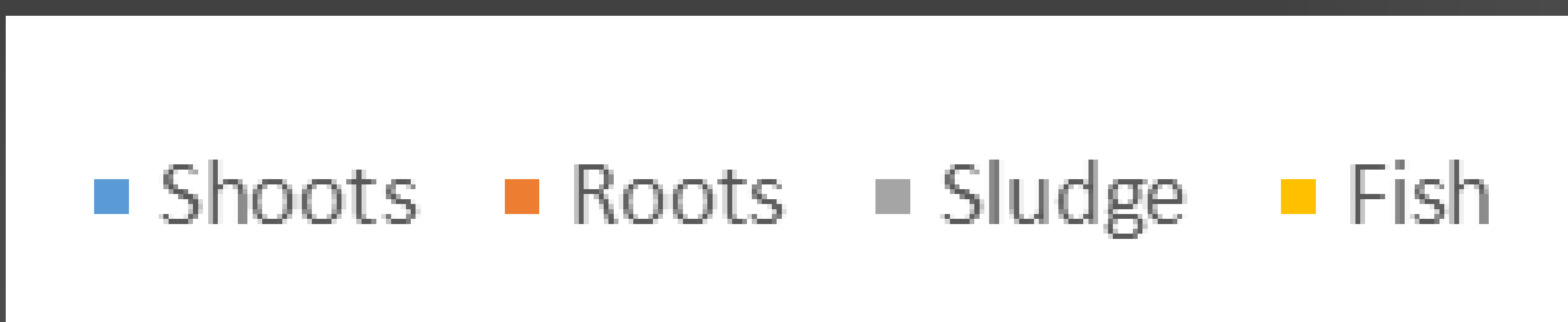


Shoots Roots Sludge Fish


Fe
6
8
2
84
Shoots Roots Sludge Fish
Mn
95
Shoots Roots Sludge Fish


Shoots Roots Sludge Fish


Zn
13
3
79
5
Shoots
Roots
Sludge
Fish
Cu
5
3
90
2
Shoots
Roots
Sludge
Fish


Shoots
Roots
Sludge
Fish

The aquaponic crop studies in the NSERC project demonstrated that the sustainable plant production required significantly less fish feed input per sq. m, when nutrients were supplemented with mineralized sludge

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This findings were confirmed by Fresh Flavor Inc., a commercial aquaponics company in Alberta

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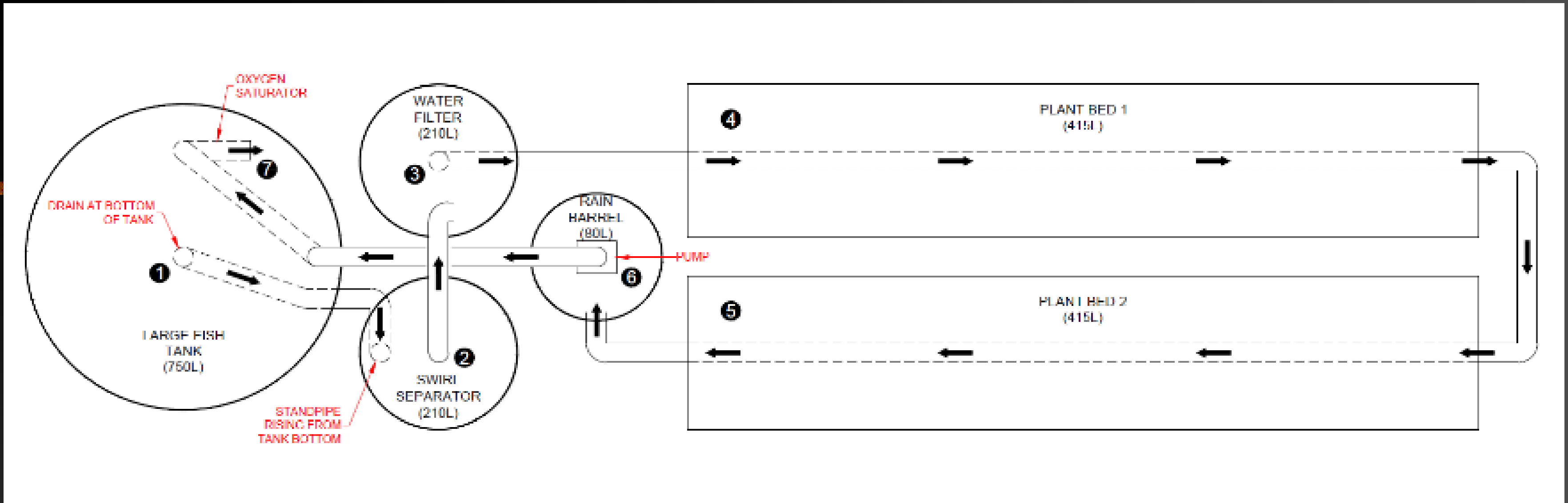
Not every mineralized solution works!

Study of bioreactor mineralized solution as the only source of nutrients compared to aquaponics

The purpose of this trial was to compare warm and cold water systems with different nutrient supplies. Specifically, some systems had their nutrients supplied by fish whereas other systems had only bioreactor fluid. There were a total of 6 warm water and 6 cold water systems each equipped with 4 rafts that contained 2 plant species each.

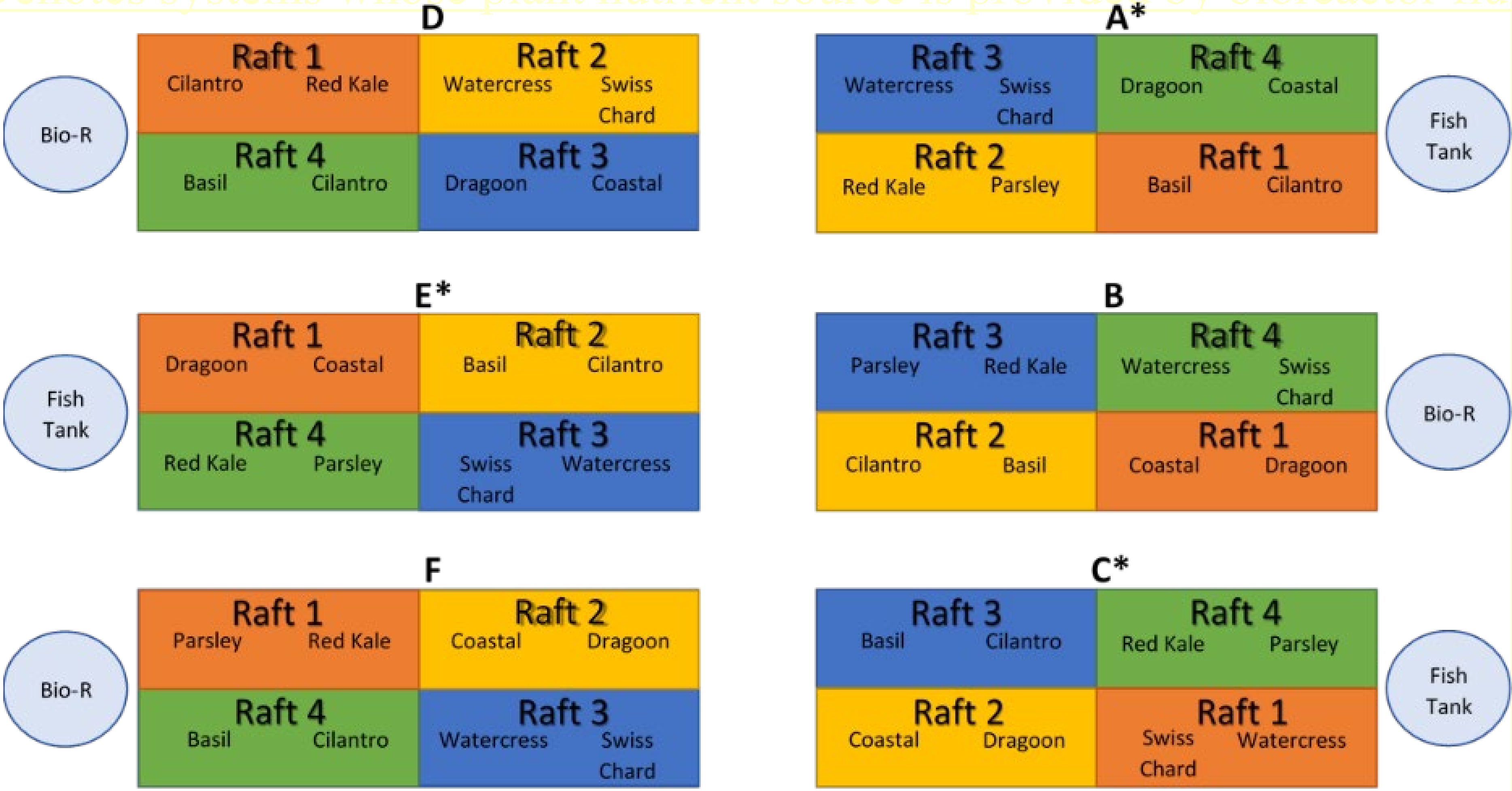
- Approximately 220L of bioreactor liquid was added to warm water systems and cold-water systems.
- Plants were harvested each week.
- Plant biomass of each system was recorded as a function of plant height (cm), root length (cm), wet shoot (g) and dry shoot (g) that was measured at the time of harvest.

Flow chart of aquaponics modules used for nutrient trials.



Schematic diagram of warm water aquaponic systems

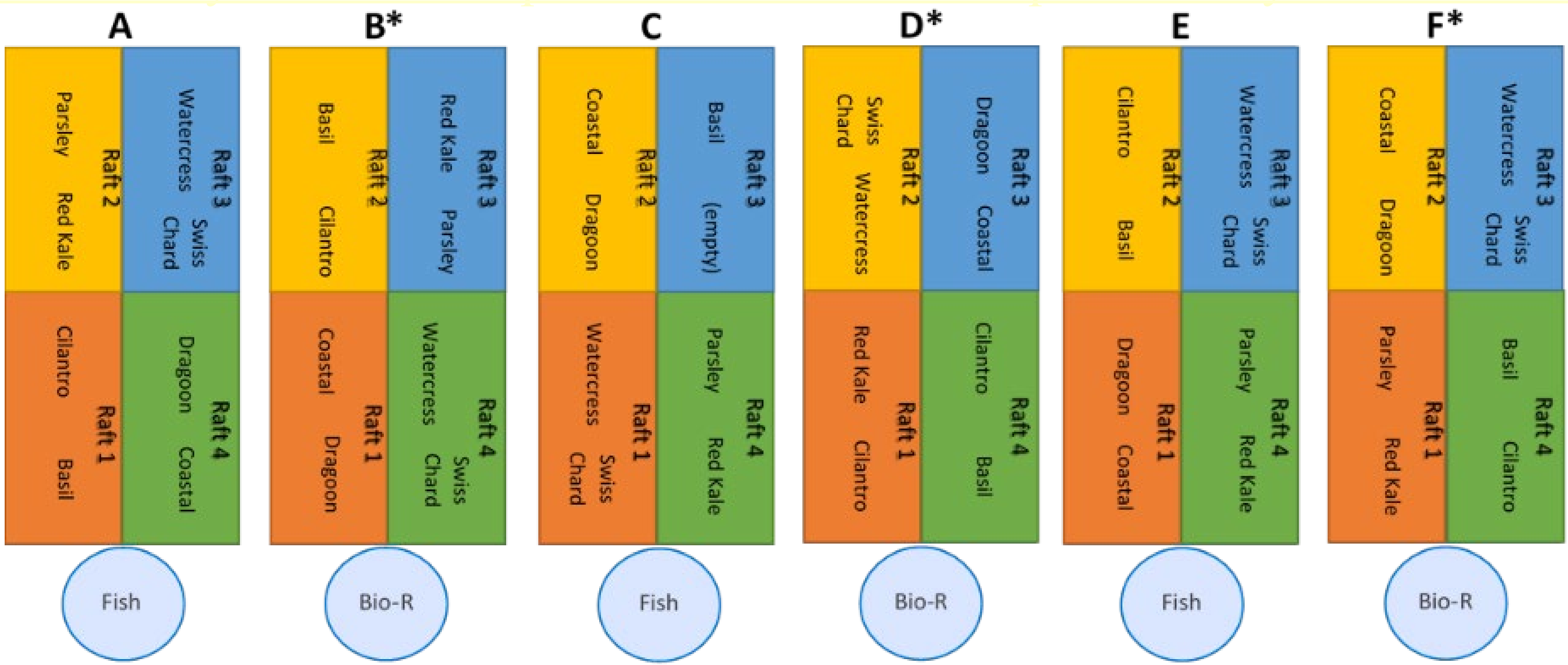
Denotes systems whose plant nutrient source is provided by bioreactor flu



*Denotes systems whose plant nutrient source is provided by bioreactor fluid.

Schematic diagram of cold water aquaponic systems

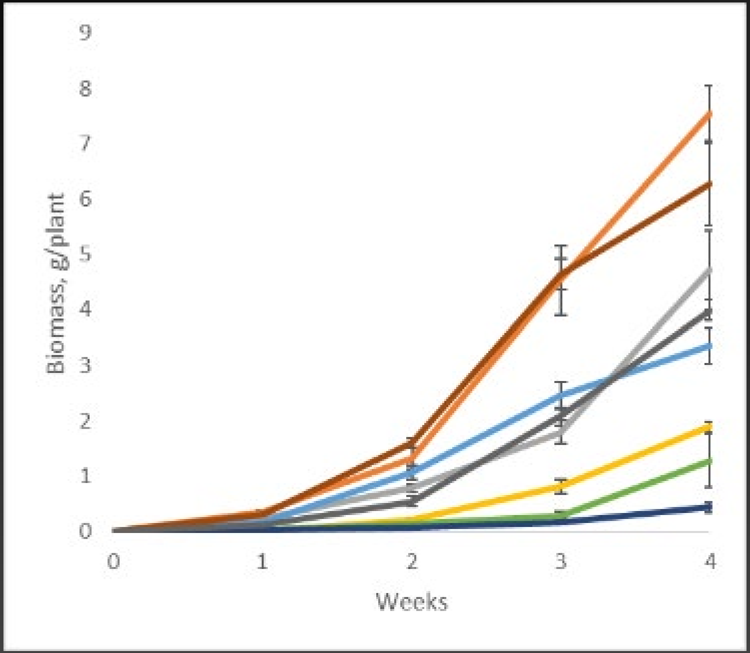
Denotes systems whose plant nutrient source is provided by bioreactor flu



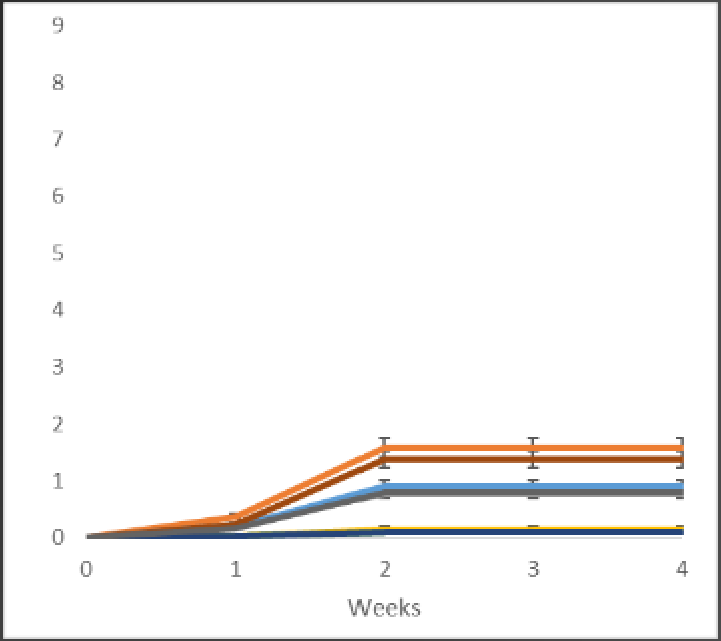
*Denotes systems whose plant nutrient source is provided by bioreactor fluid.

Dry Shoot Biomass (g) of plants grown on different nutrient source in Warm Systems by Week

Aquaponics



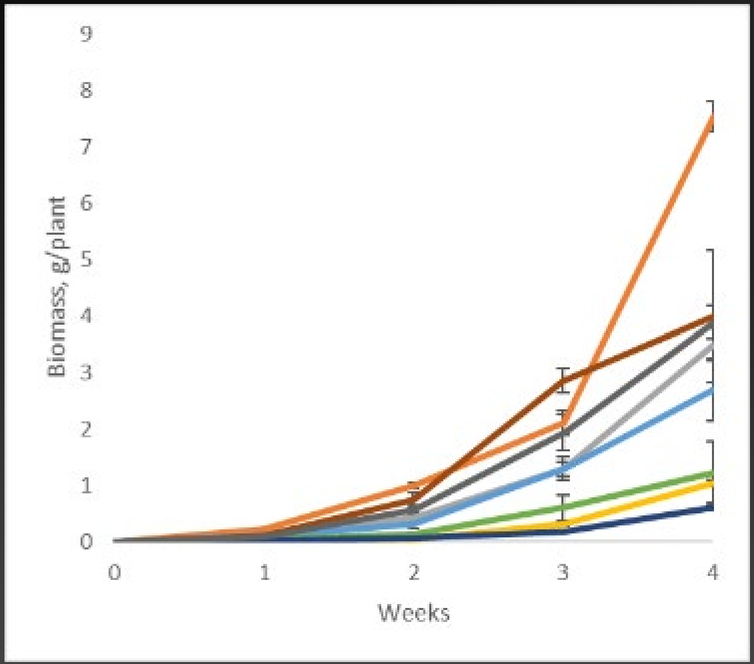
Bioreactor



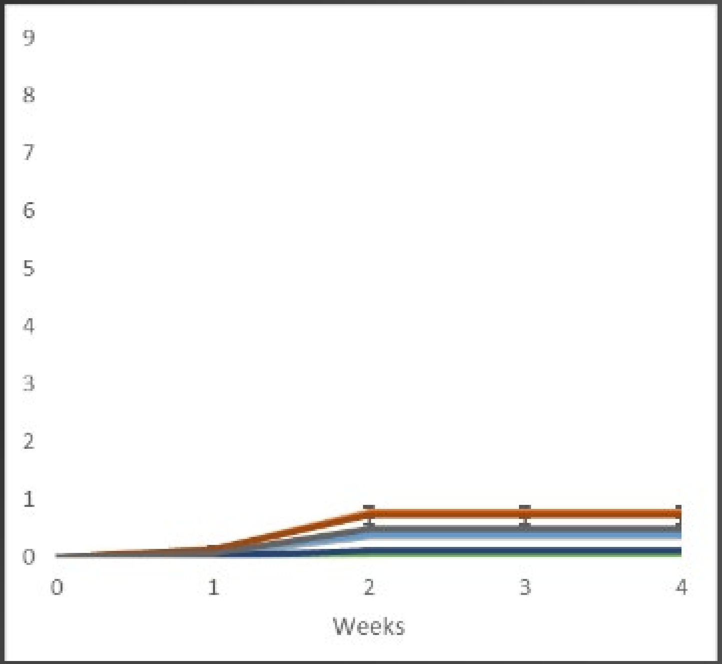
S Chard, Red Kale, Nufar, Dragoon, Cilantro, Parsley, Romaine, W. Cress

Dry Shoot Biomass (g) of plants grown on different nutrient source in Cold Systems by Week

Aquaponics

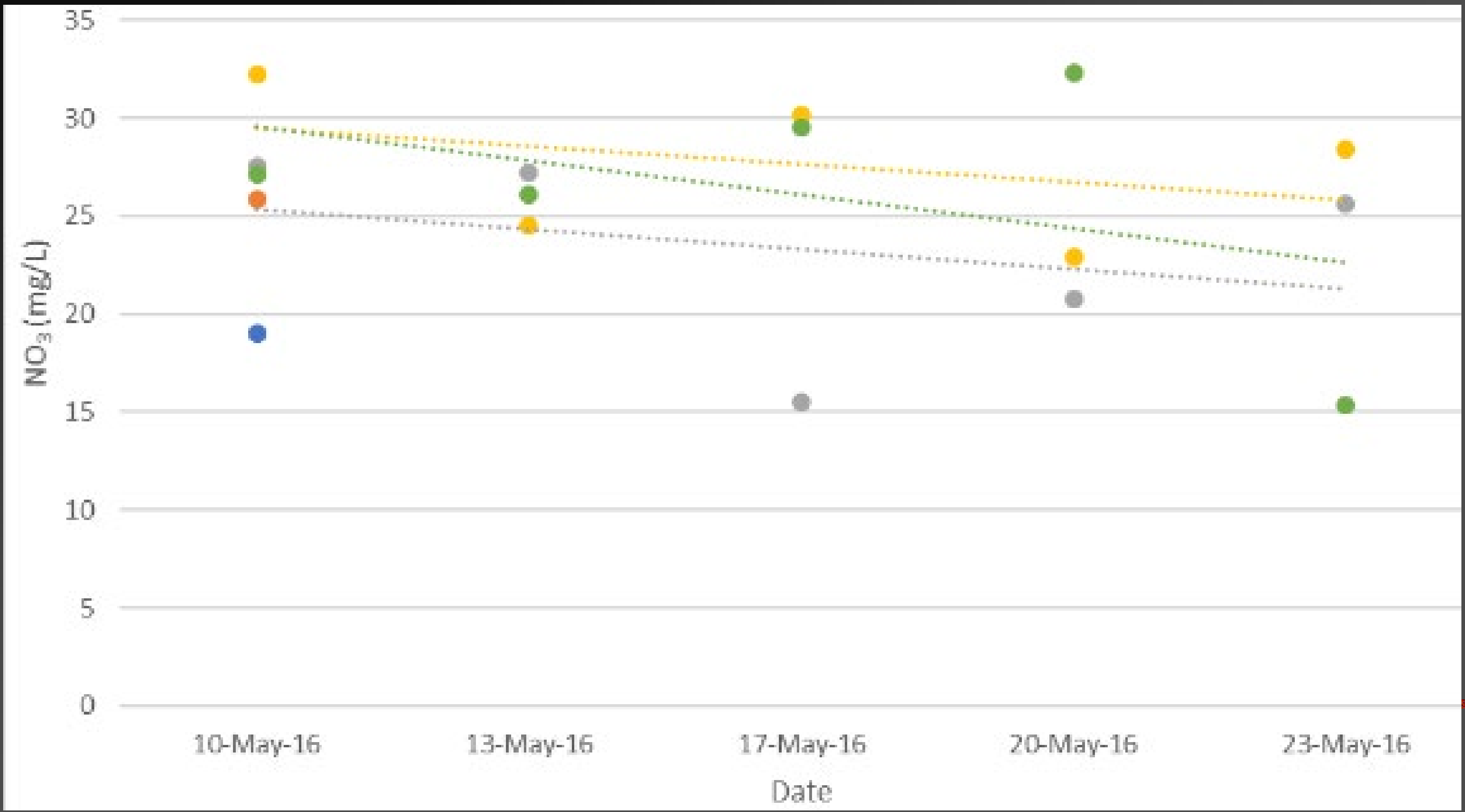


Bioreactor

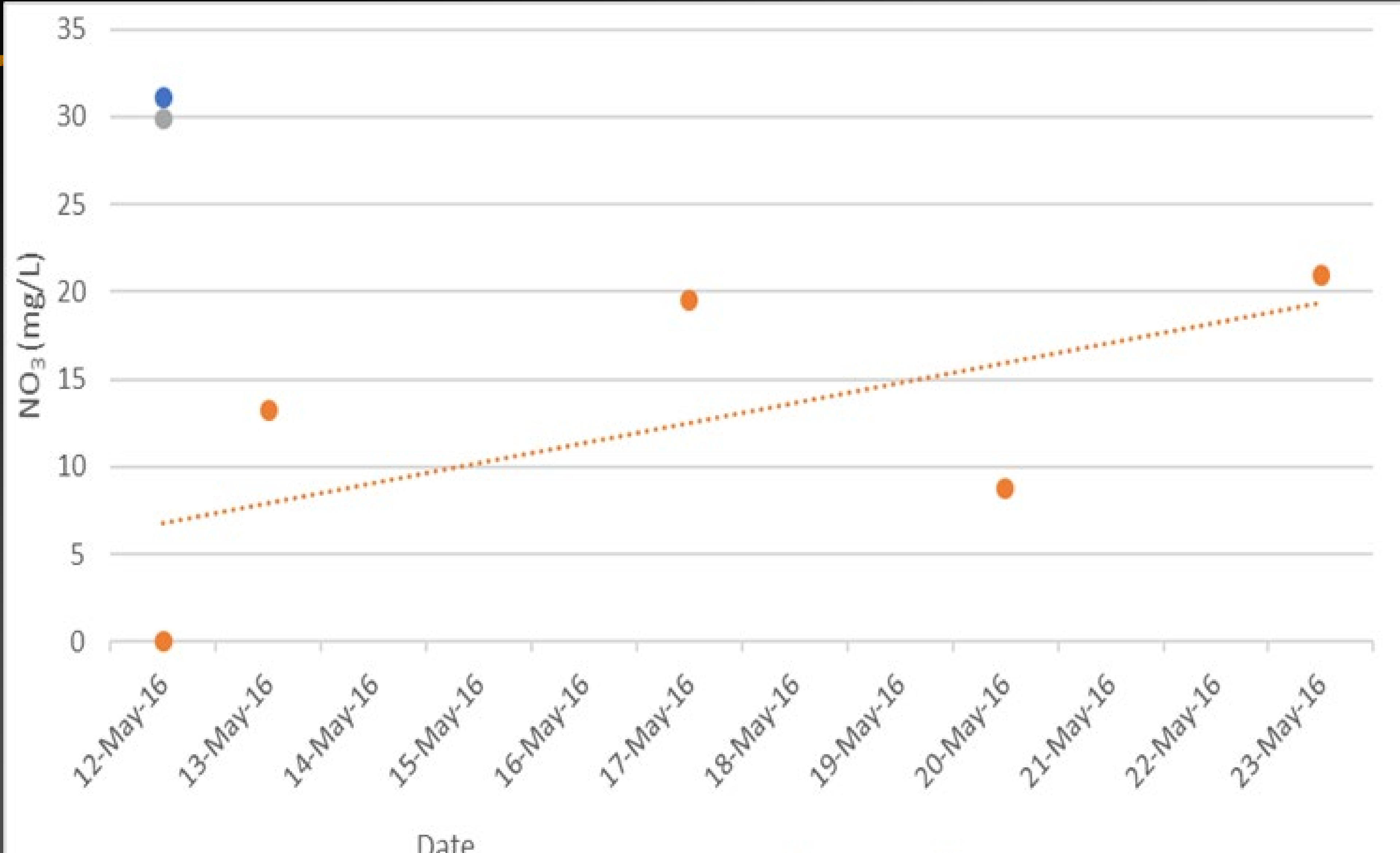


Dynamic of Nitrate (NO3) content in aquaponics system

Warm-water system

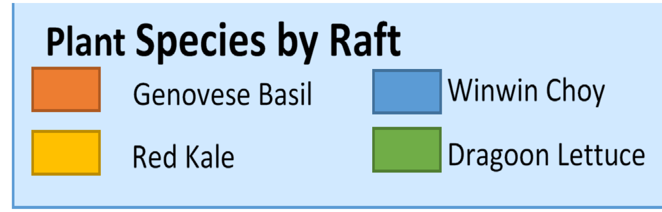


Cold-water system



Schematic diagram of aquaponic systems replicated for each cold and warm water treatment

*Denotes systems that had bioreactor fluid additions



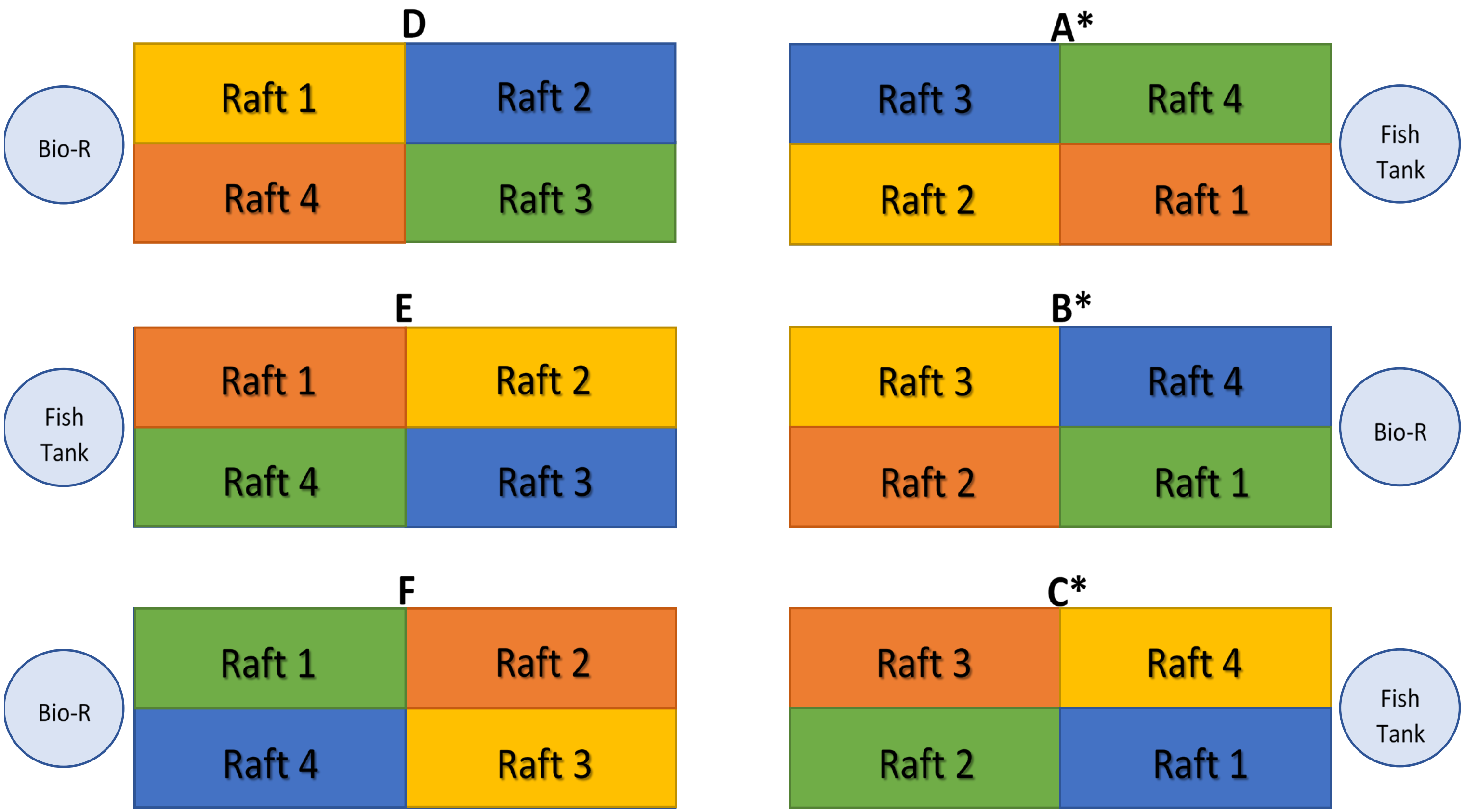
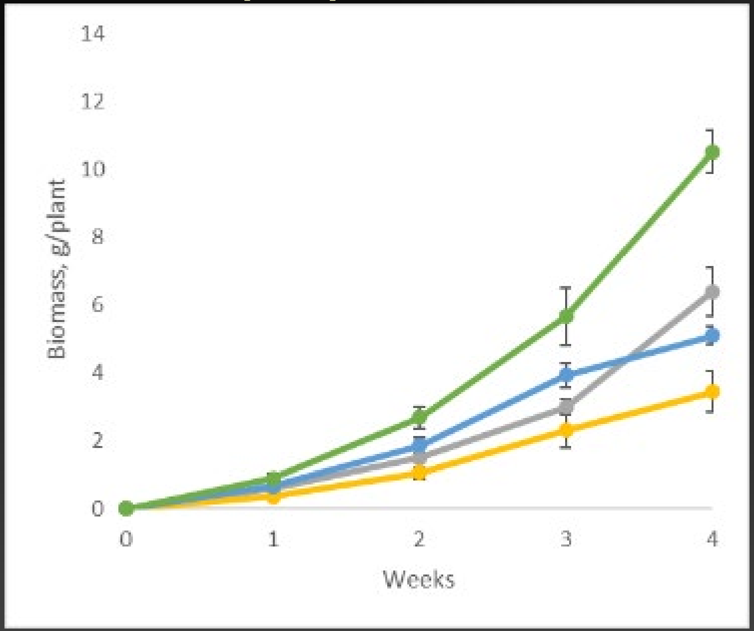


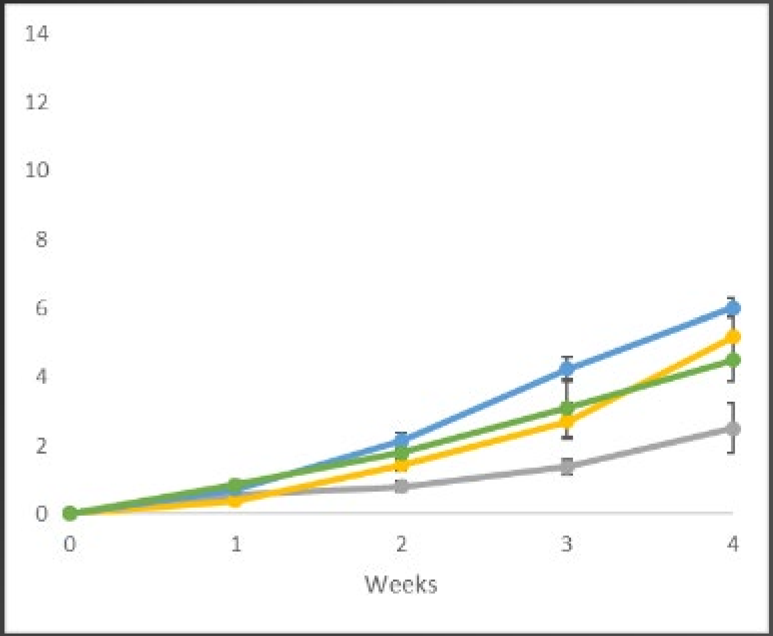
Figure 1. Schematic diagram of trial 8 (June 19-July 17, 2017) testing 5L daily additions of bioreactor fluid to systems A, B* and C*. This layout was the same for both warm and cold-water systems. Each system contained a total of 2000L of fish water effluent prior to the bioreactor fluid added to systems A*, B* and C*.*

Dry Shoot Biomass (g) of plants grown on different nutrient source in Warm Water Systems by Week

Aquaponics

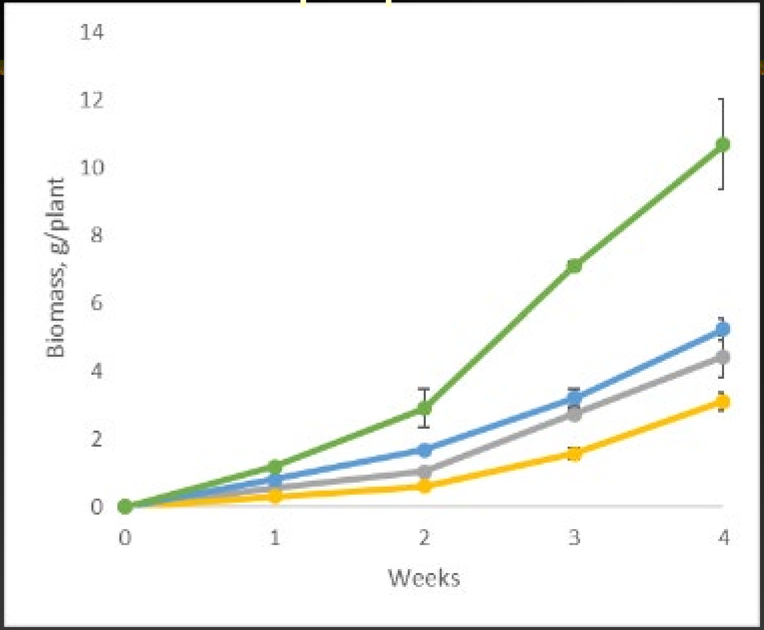


Bioreactor

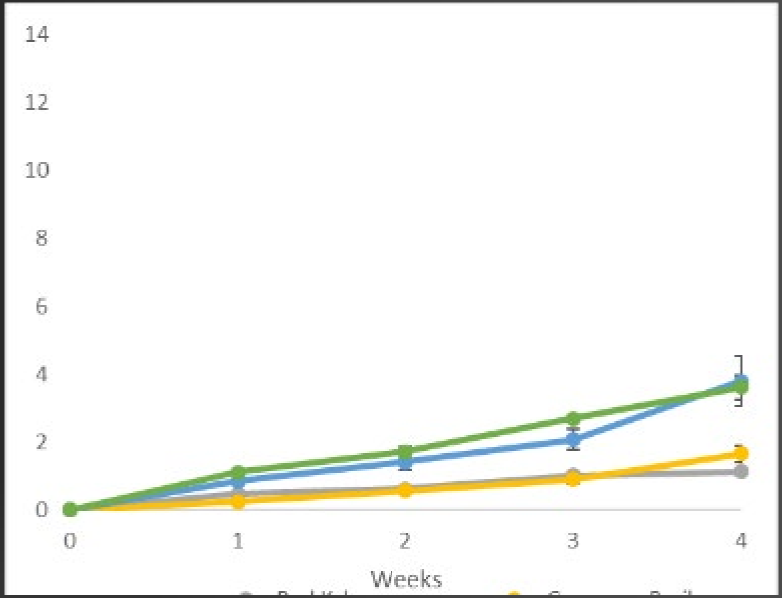


Dry Shoot Biomass (g) of plants grown on different nutrient source in Cold Water Systems by Week

Aquaponics



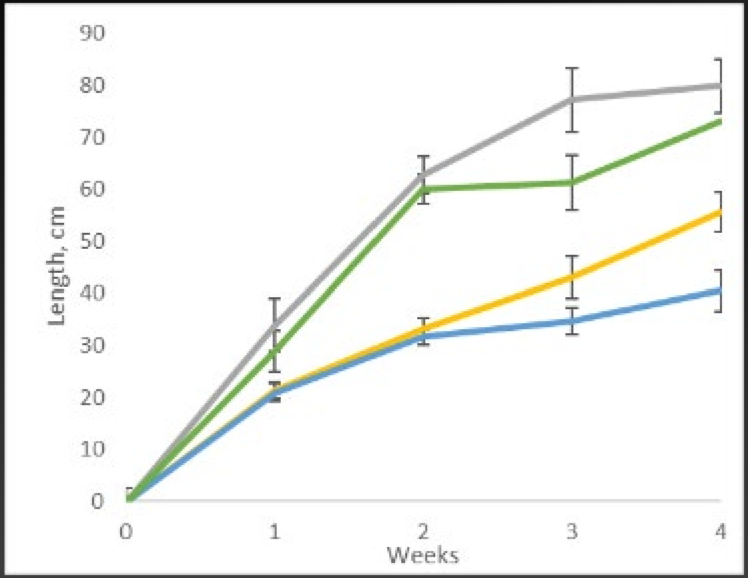
Bioreactor



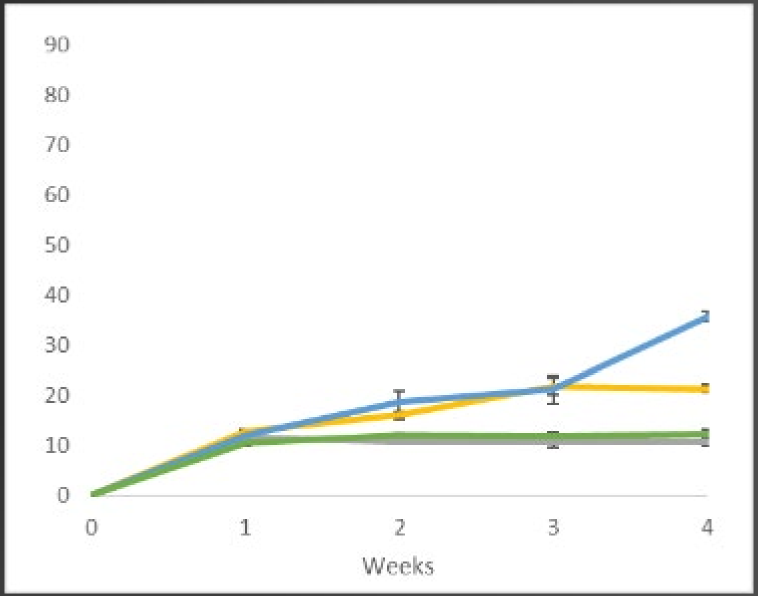
Red Kale
Genovese Basil
Dragoon
Win Win Choy

Root length (cm) of plants grown on different nutrient source in Warm Water Systems by Week

Aquaponics



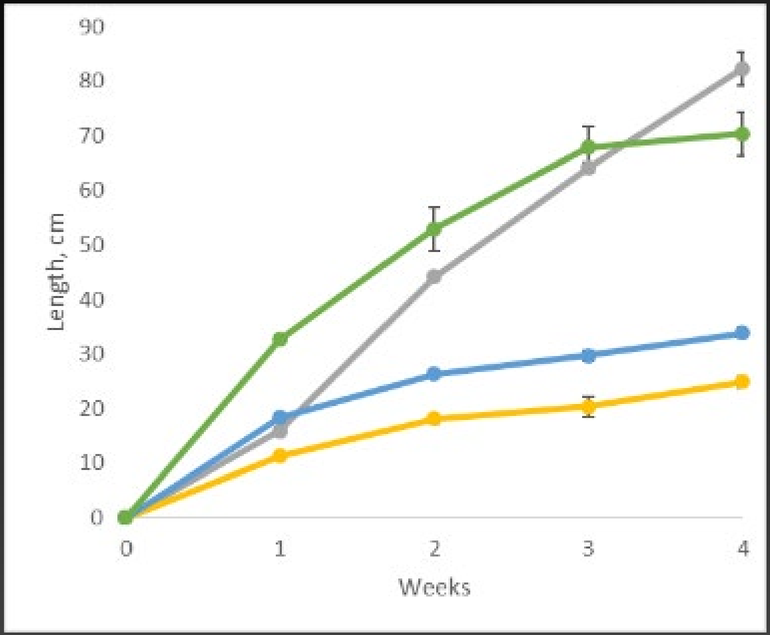
Bioreactor



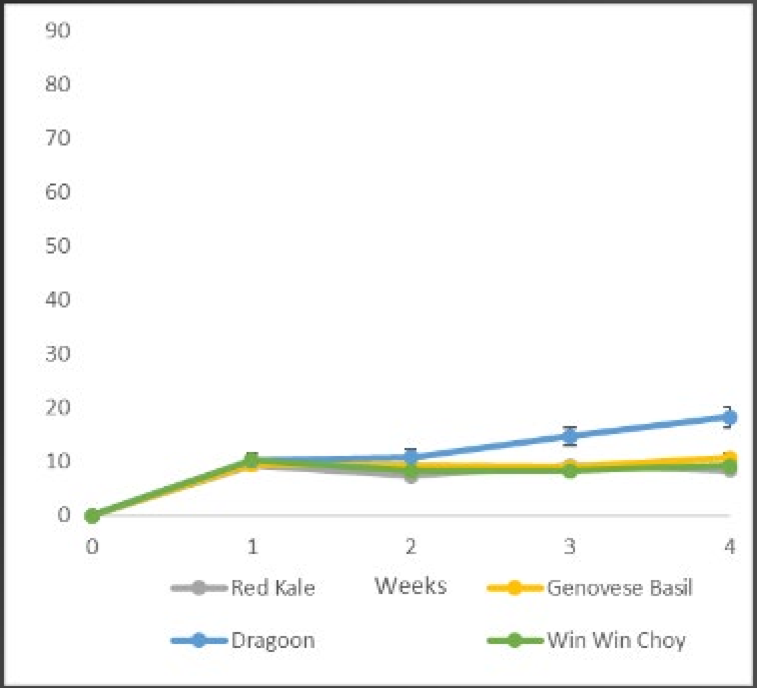
Red Kale
Genovese Basil
Dragoon
Win Win Choy

Root length (cm) of plants grown on different nutrient source in Cold Water Systems by Week

Aquaponics

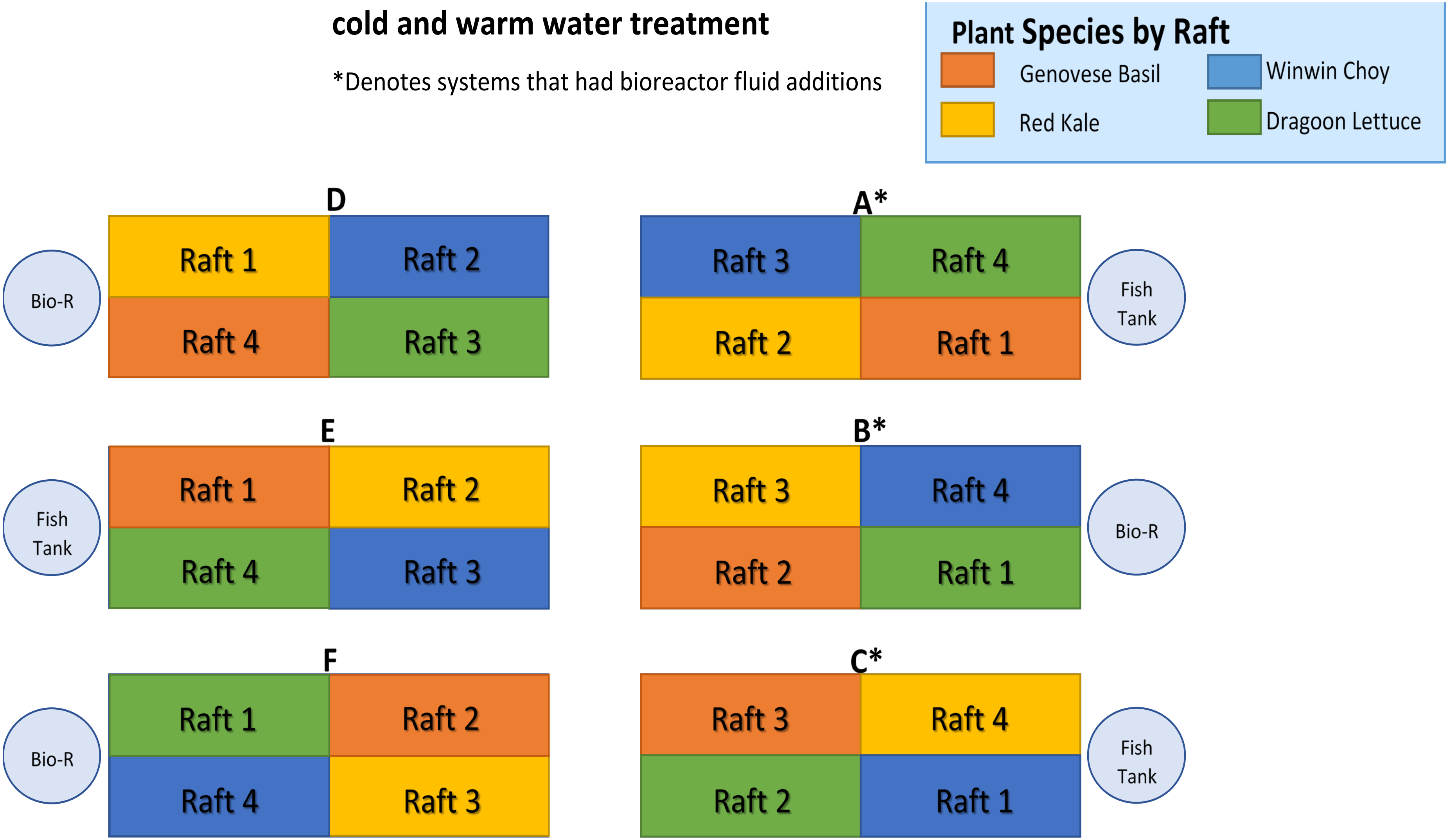


Bioreactor



Schematic diagram of aquaponic systems replicated for each cold and warm water treatment

*Denotes systems that had bioreactor fluid additions



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Warm Water

Cold Water

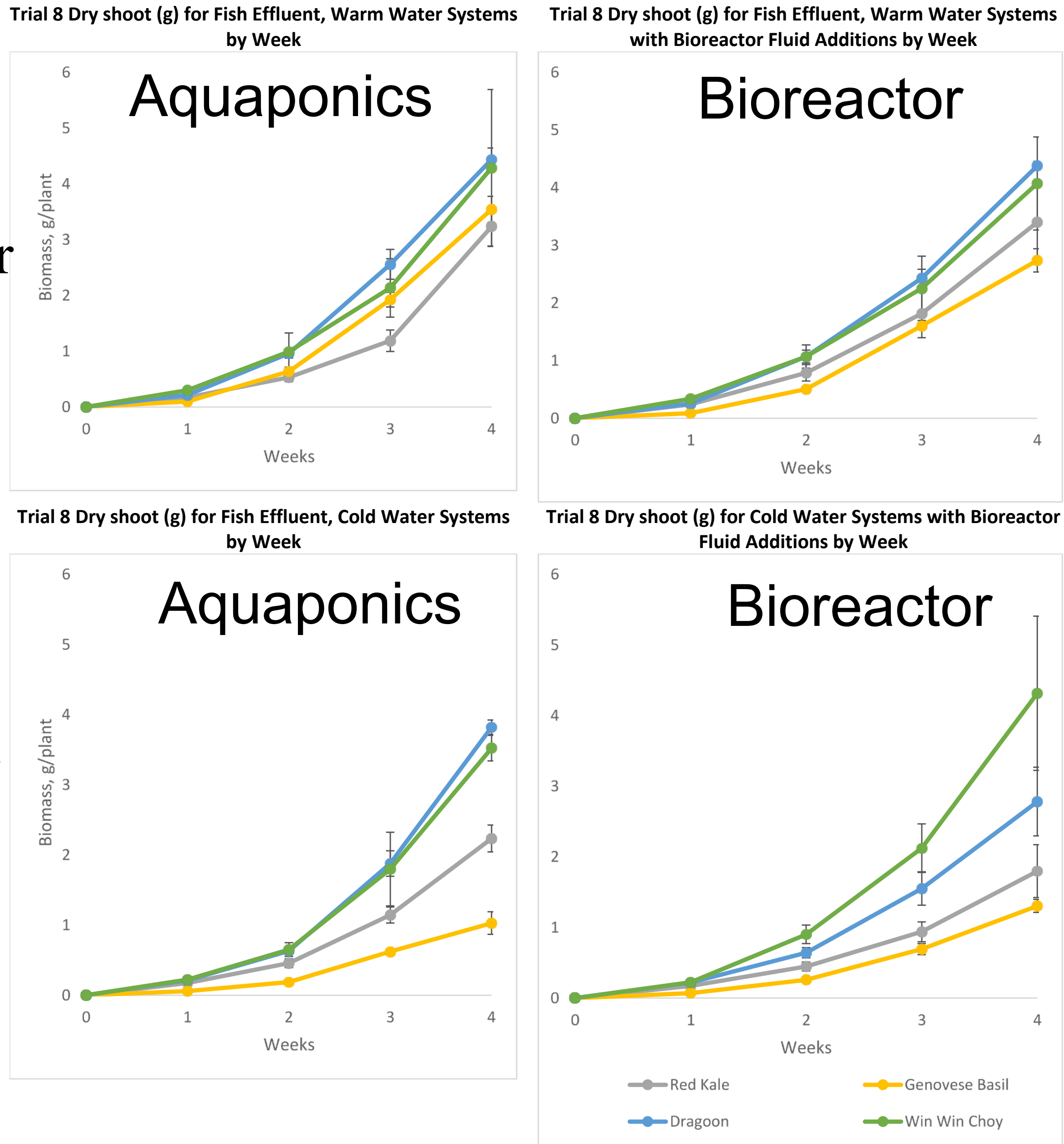
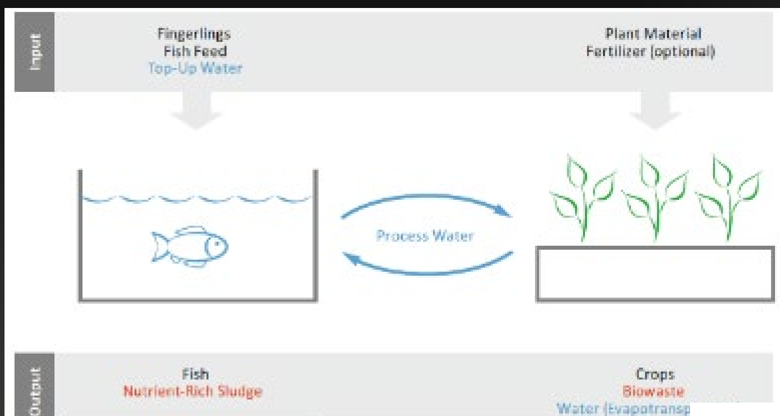


Figure 1. Trial 8 (June 19 to July 1, 2017) dry shoot (g) for different plant species grown in warm and cold water modular aquaponic systems whose nutrients are supplied from fish effluent compared to bioreactor fluid.

“Coupled” vs. “Decopled”

- “Coupled” aquaponics is a recirculating system where the solution between RAS and greenhouse is directly exchanged without interruption and represents one loop



Goddak et al, 2019

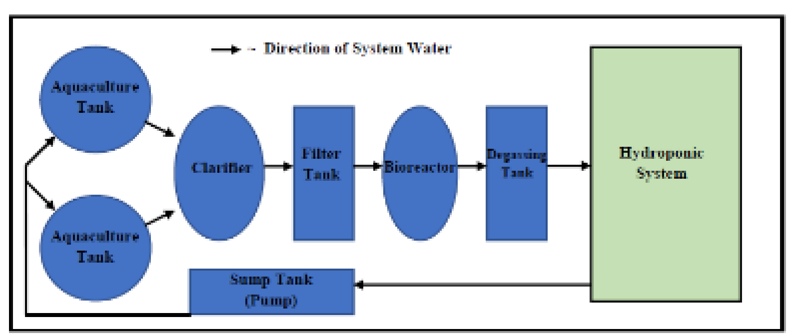
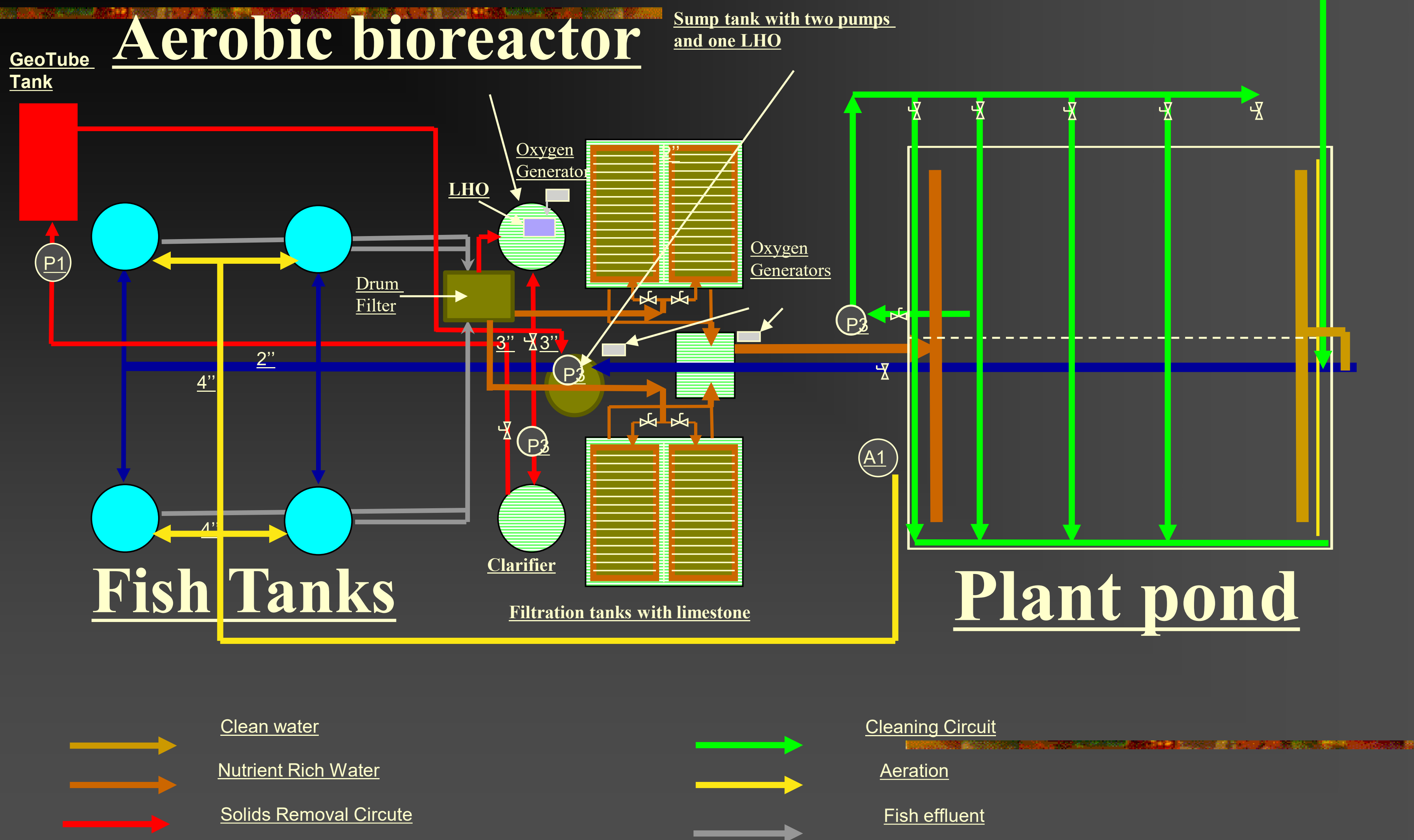


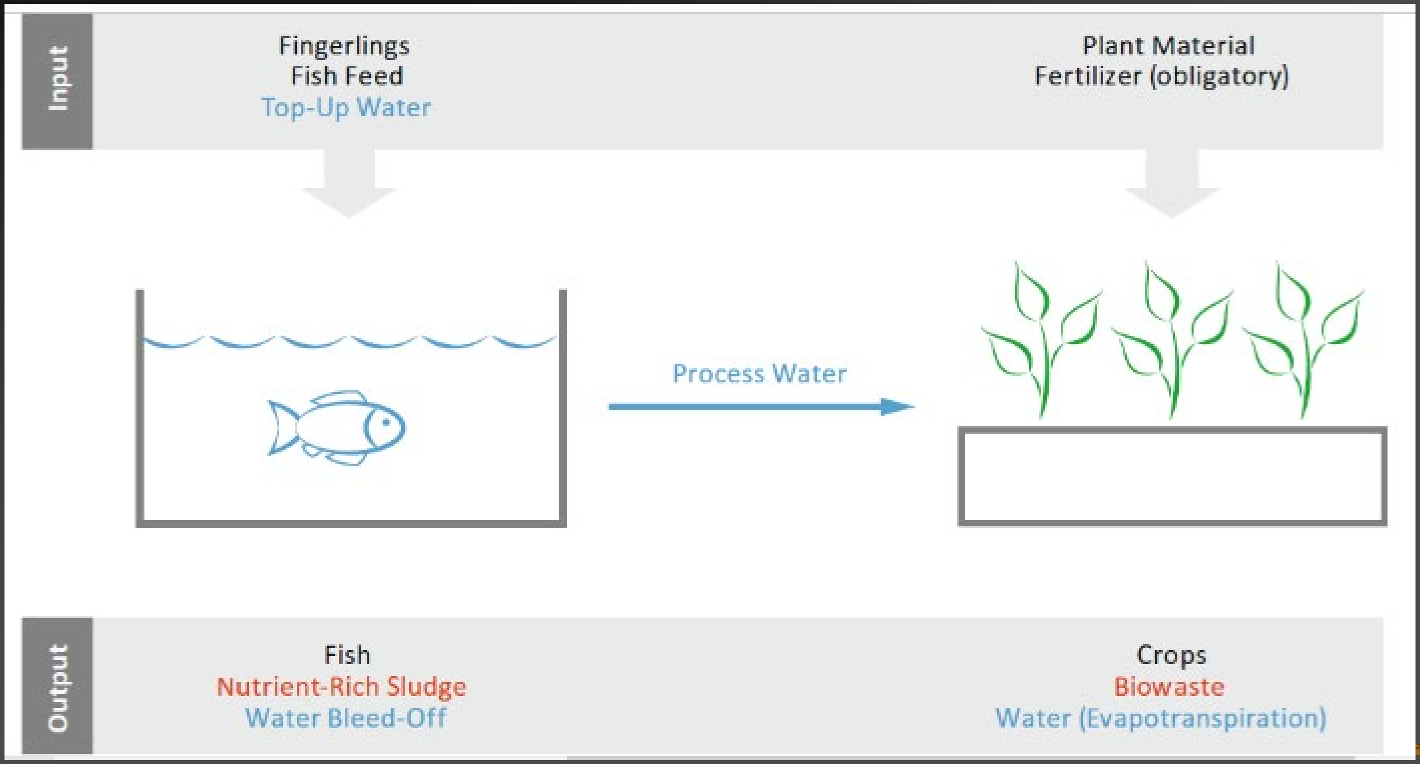
Fig. 2. Example of coupled aquaponic system. Design modified from the University of the Virgin Islands Commercial Raft System(Rakocy, 2012) and designs presented by (Palm et al., 2018) and Goddek et al., (2016).

Generation 4 aquaponics system, Brooks, AB, Canada, 2007



- This approach allows numerous microbes establish their communities, populate ecological niches and form food chains without interference and make the production system similar to a kind of ecosystem with the synergy between its components.
- That’s why we call it “ecosystem” approach

- “Decoupled” system is a non-recirculating system, where the effluent flows only in one direction from fish tank to plant growing facility and does not come back to RAS.



Goddak et al, 2019

- The main benefit of this approach is the possibility to use pesticides, synthetic fertilizers and other chemicals, which are used on a routine basis in hydroponic system, without harming fish.

- Those systems have been around for a long time, but only recently caught the attention from scientists with mostly hydroponic background.
- In fact, decoupled system is a kind of “organic hydroponics”, where organic material is mineralized in specially designed tanks and then used as a source of nutrients for plants.

- Use of the “decoupled” system allows artificial control of the water composition and its properties in each compartment on an arbitrary basis. However, this approach may interfere establishment of the natural aquaponic microbiome, which is typical for mature aquaponic systems.
- This microbiome is the main factor of a synergy in aquaponics, which results in a significant increase in productivity when the process is not interrupted.

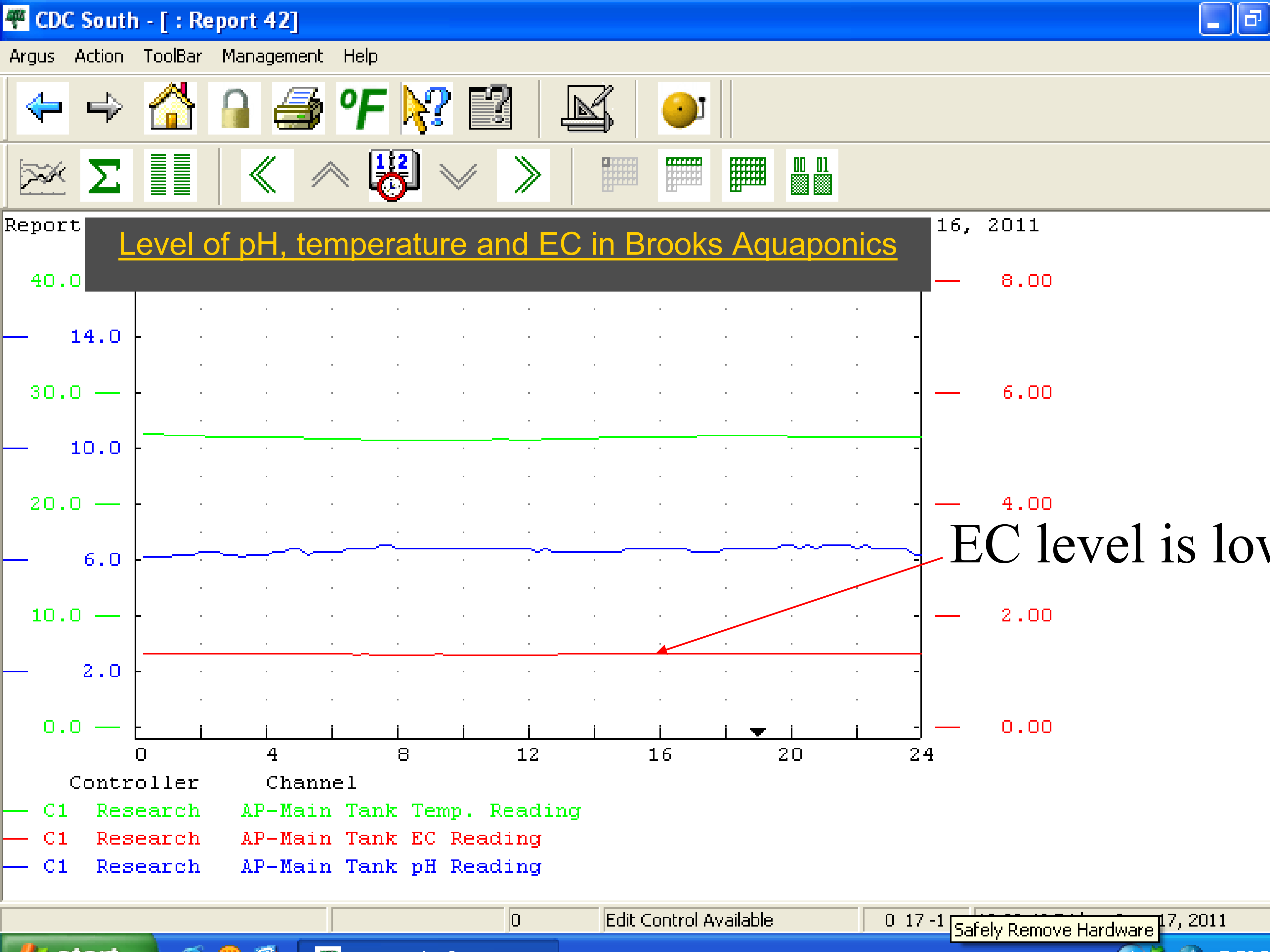
- The main purpose of the “organic hydroponic” approach is to establish manageable, risk-free greenhouse production
- The drawback of this approach is removing the plants as an important component of the system’s biofilter for remediation of fish effluent
- The benefit of this approach is easier establishment and control of startup aquaponic operations

- There is a fundamental difference between “hydroponic” and “ecosystem” approaches in the way the nutrients are supplied to the plants.

- In hydroponic approaches, all nutrients are provided in an available form to the plants.
- The grower has “target levels” of nutrient concentrations in the feed solution and adjusts the concentrations according to the target levels by adding supplemental fertilizer.
- This approach works very well in commercial hydroponics.
- The drawback is that the nutrients are supplied in excess and often wasted.

- In aquaponics, only a small part of the nutrients is in available form to the plants. Plants mostly depend on the *continuous* release of nutrients by fish and microbes.
- In many respects it mimics the situation observed in natural ecosystems. For example, in soil the bulk of the nutrients is “locked” in organic form.

- The continuous supply of the nutrients released due to biological activities in nutrient-rich soil ensures that the plant receives adequate amount of nutrients even despite of *the considerably lower* concentration of the nutrients in soil solution compared to hydroponics.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16, 2011
Level of pH, temperature and EC in Brooks Aquaponics
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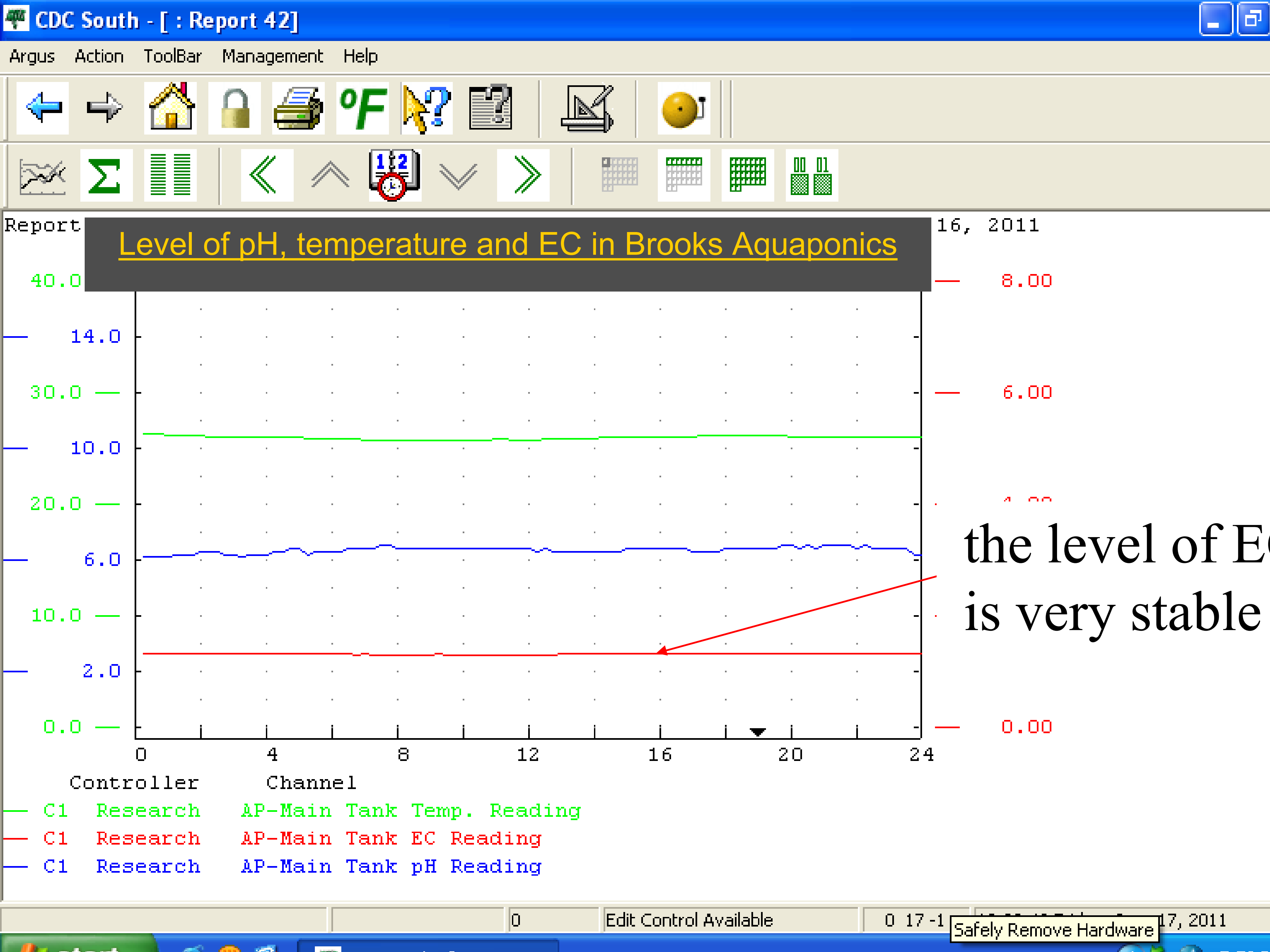
Safely Remove Hardware

- These plants were grown on aquaponics solution with 645 µS cm^{-1}

- The plants evolved and are well adapted to acquire nutrients from *a very wide range* of nutrient concentrations in the environment
- It is *the total amount* of nutrients supplied to the system, such as fish feed, which is relevant for optimal plant growth.

- In this case, “the target” levels of nutrients become irrelevant and considerably lower levels of nutrients in aquaponics can result to similar and even higher yields compared to commercial hydroponics.
- At the same time the level of nutrients and pH in mature aquaponics stays very stable despite of the intensive nutrient uptake by plants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Safely Remove Hardware
17, 2011

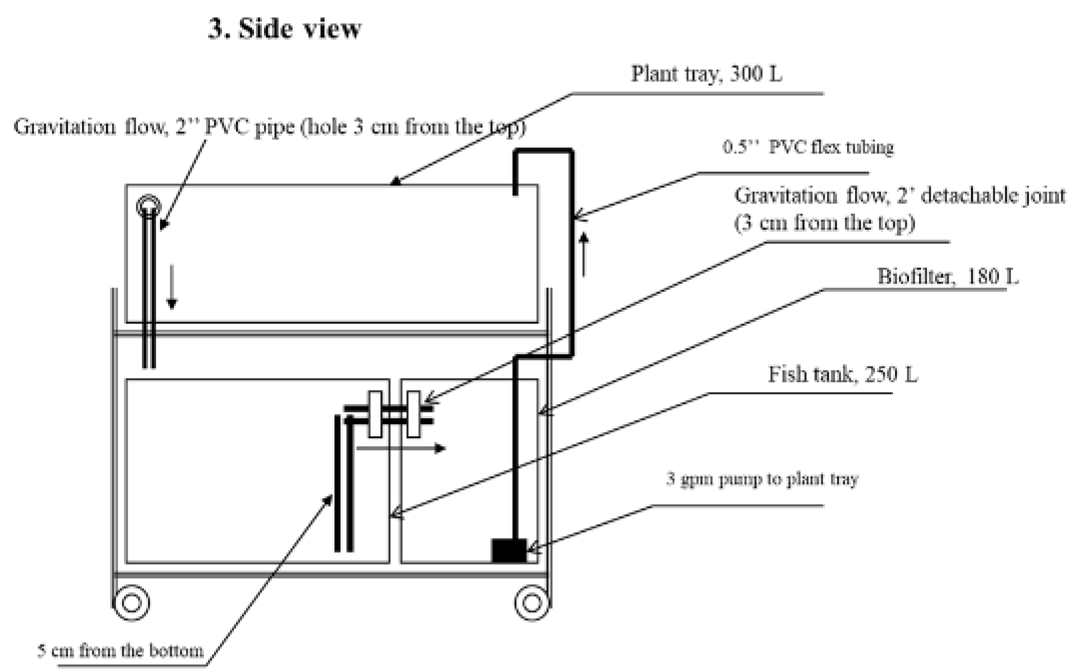
- There is a similar approach in hydroponics, which is called “Relative Addition Rate” or RAR.
- The relative addition rate (RAR) technique allows the nutritional control of plant relative growth rate (RGR) by the *continuous* release of nutrients in small amounts upon the plant growth demand instead of supplying the entire amount (Stadt et al, 1992)
- This method allows to avoid waste of considerable amount of fertilizers.

- Due to this unique mechanism of nutrient supply and its “multitrophic” nature, aquaponics is the only food production system, where 100% use efficiency is achievable without compromising yield.
- To the contrary, 100% nutrient use efficiency in hydroponics is not achievable

What about the claim that “a known drawback (of the “coupled” system) is that a compromise away from optimal growing conditions for plants and fish must be achieved to produce both crops and fish in the same environmental conditions” (Simon Goddek et al Water 2016, 8(7), 303)?

- There are well documented studies with mature “coupled systems” conducted at the University of Virgin Islands, USA, by Dr. James Rakocy, Dr. Wilson Lennard in Australia and in Canada.
- These studies demonstrated that mature aquaponic systems can achieve similar or even higher crop productivity compared to hydroponics.
- The water in those systems had been recirculating for years without interruption.

Aquaponic experimental modules were designed and built for collaborative work with the University of Alberta in 2004



Since then, the same water has been recirculating without change in a “coupled aquaponic” system for 16 consecutive years.

2005

2008

2020

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Enhanced growth of basil in Brooks aquaponic facility

(the plants on the right are just 1 week older than plants on the left)

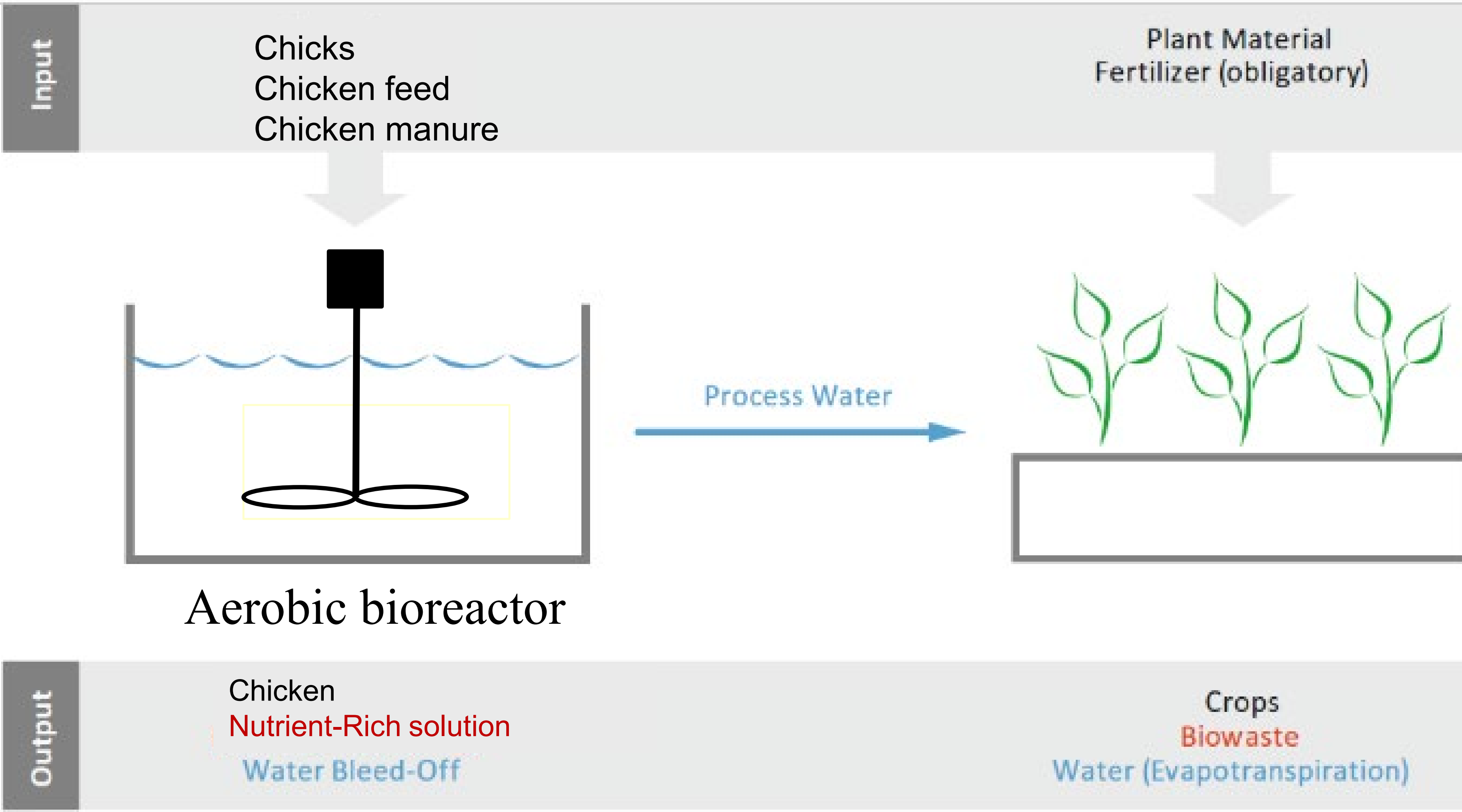
Effect of aquaponics water on basil production. Commercial trials at Red Hat Co-operative Ltd , April 18, 2013

4-week old aquaponic plants

6-week old hydroponic plants

- Decoupled systems are an important development as they show an example of nutrient recycling for other livestock industries

Decoupled “Poultryponics”



- Testing aerobic bioreactor technology to produce greenhouse crops at Crop Diversification Centre North

- Chicken manure was used as a organic feedstock for bioreactor instead of fish manure in experiments, which started in 2011


Bioreactor ~1200 liters
- agitated and oxygenated
Probiotic Reservoir ~5000 liters
- oxygenated and water-cycled
- feed tank for substrate culture

Aerobic Bioreactor at CDC North


Poultry Manure 1000 L Bioreactor
the addition of ~ pure oxygen
makes this an **odorless** process!

Typical composition of liquid aerobic digestate generated from chicken manure

	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5
Nitrate and Nitrite	2,140	3,060	1,560	2,180	1,660
Ortho -P dissolved	108	335	288	118	212
Potassium	2,130	3,190	2,270	2,280	2,180
Calcium	300	627	368	263	320
Magnesium	200	212	122	184	139
Sulfur	150	232	88	171	117
Boron	1.02	1.60	0.56	1.17	0.69
Iron	0.58	1.40	2.39	3.35	0.16
Manganese	4.84	4.27	2.52	3.59	1.68

- Nutrient-rich solution containing soluble organic and mineral components is produced as a result of aerobic biodigestion of poultry manure

Only mineral component of poultry manure is left after the process including sand and oyster shells

- Tomato trial at CDC North started in December 2013

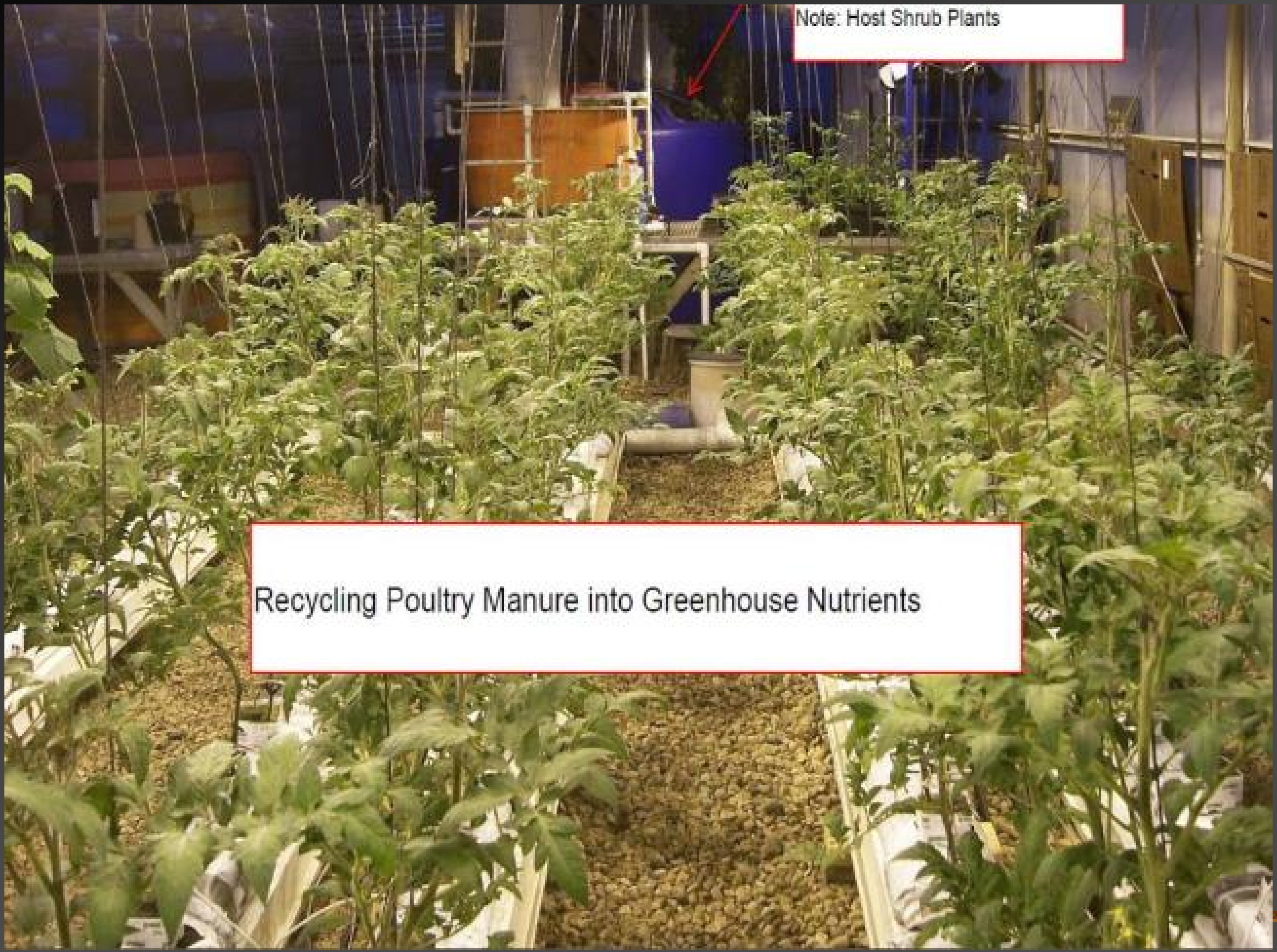
  Biochar was repeatedly used for the 4th year. Fresh coconut coir was used as a control

Layout of tomato trial with poultry manure digestate

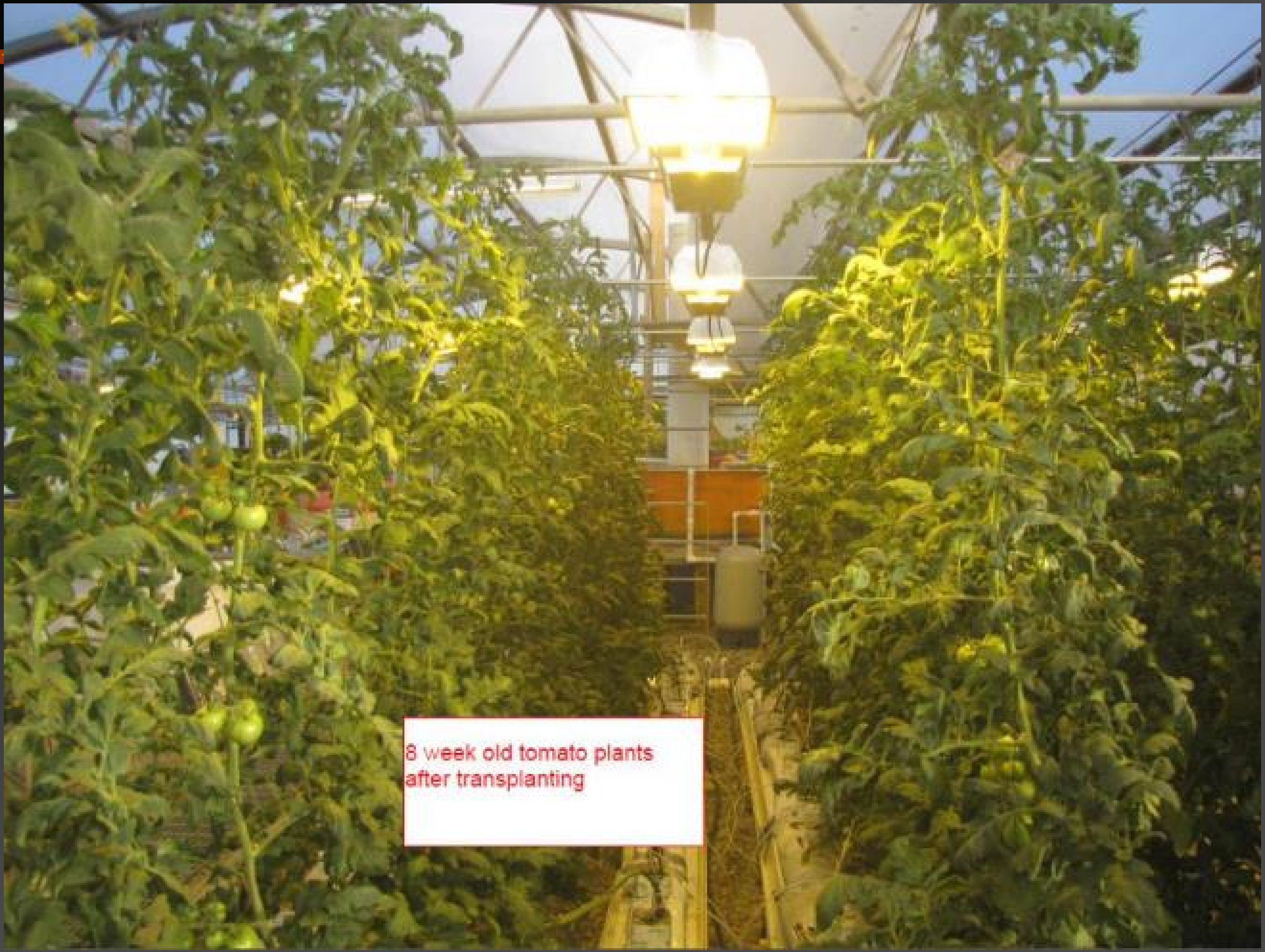
3 C	4B	1C	2B	4B	3C	1C	2B
1C	2B	4B	3C	1C	2B	4B	3C
4B	3C	2B	1C	4B	2B	3C	1C
2B	1C	3C	4B	3C	1C	2B	4B

1 C	Coir
2 B	Biochar
3 C	Coir + Fish Emulsion
4 B	Biochar + Fish Emulsion

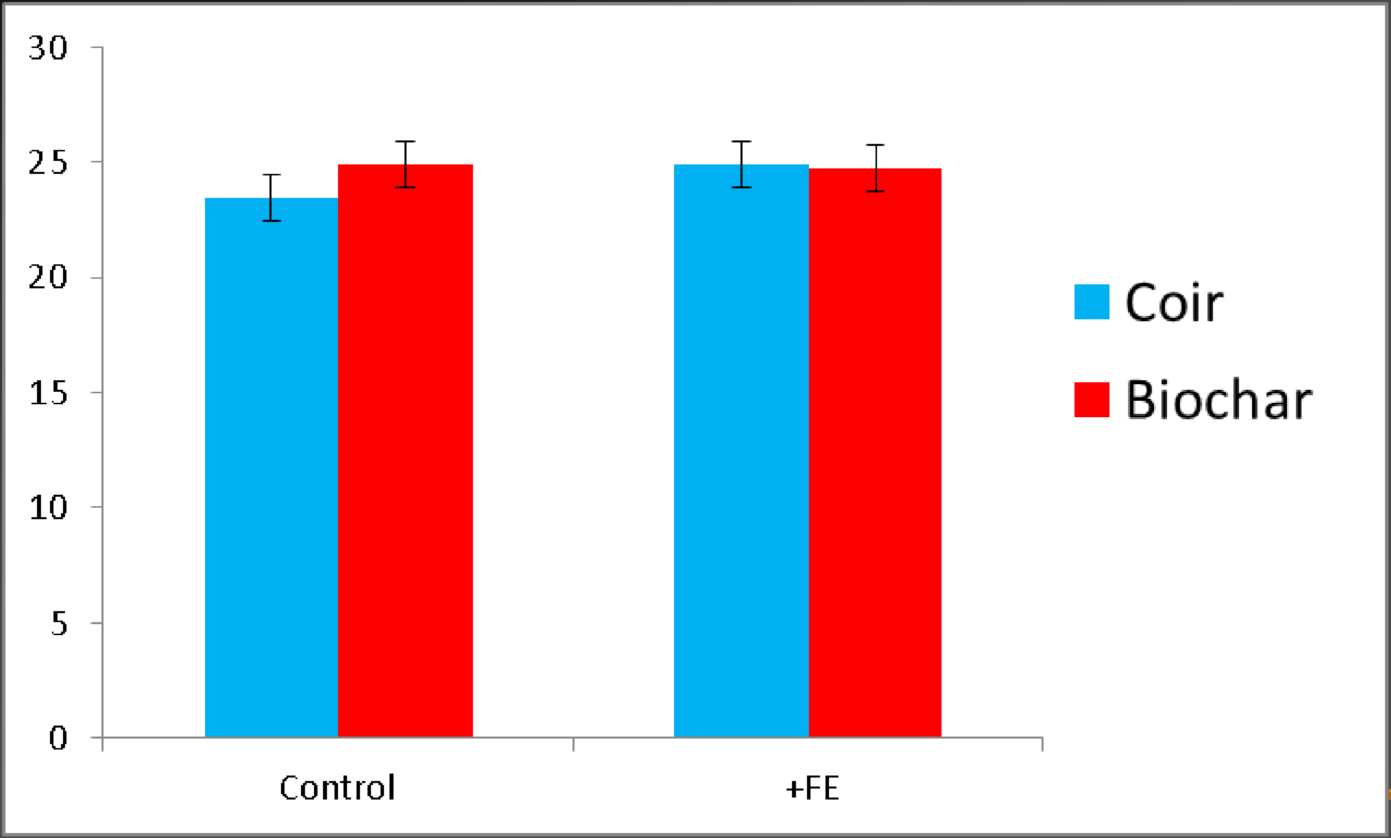
- Tomato plants 2 weeks after transplanting



- Tomato plants 8 weeks after transplanting

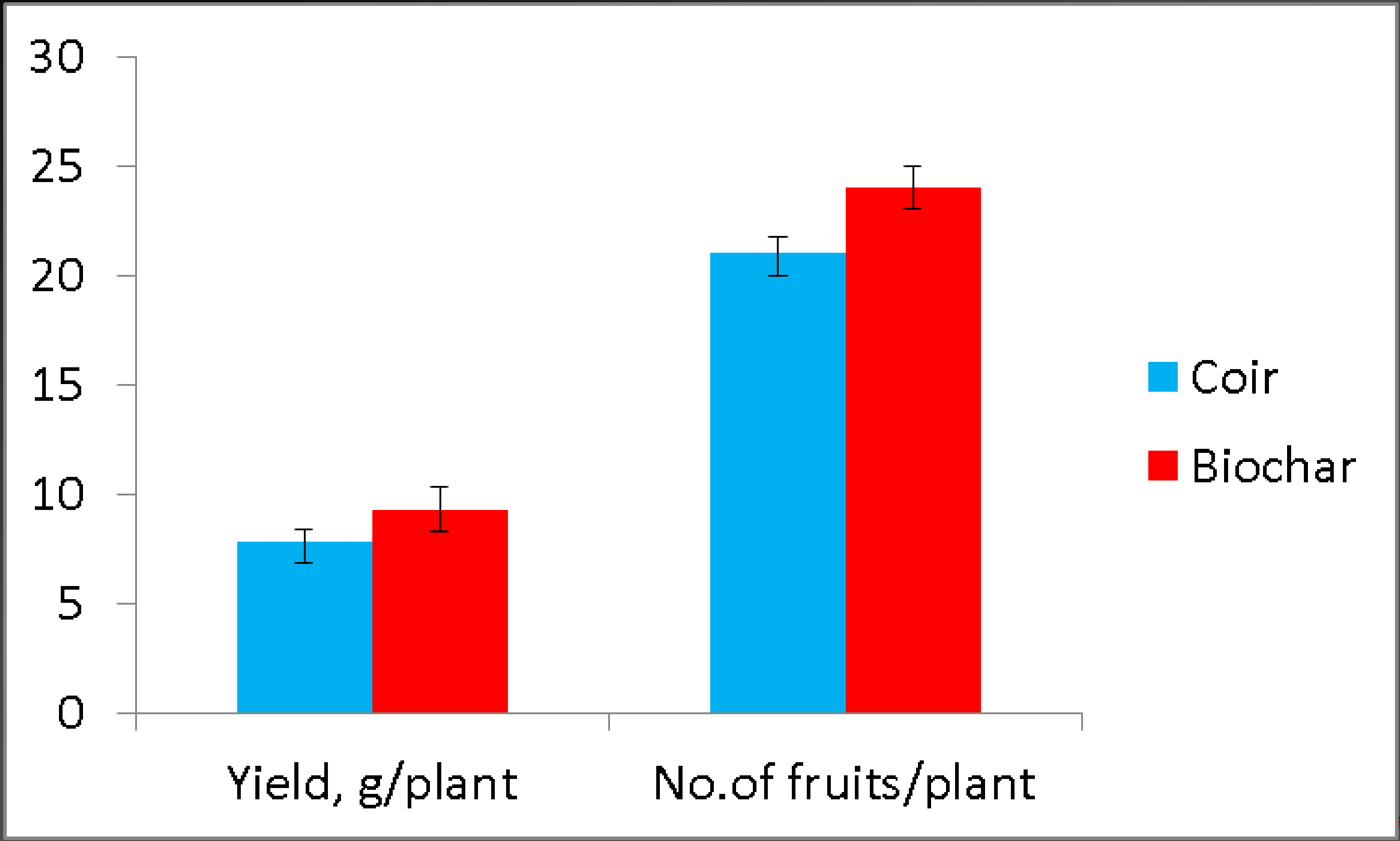


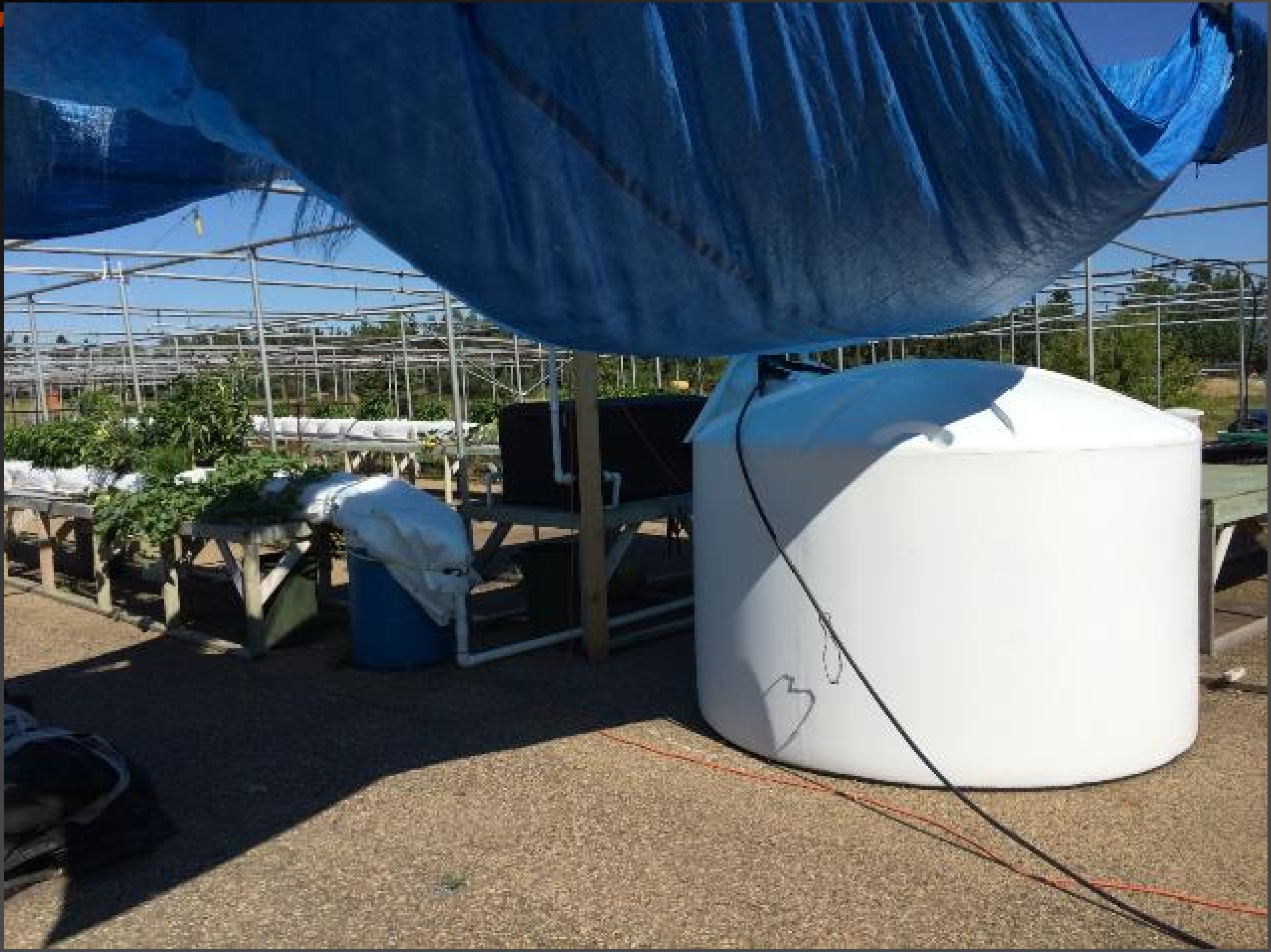
- Yield of tomato, cv. Torero, grown on poultry manure digestate, kg/plant



Cucumbers grown on poultry digestate

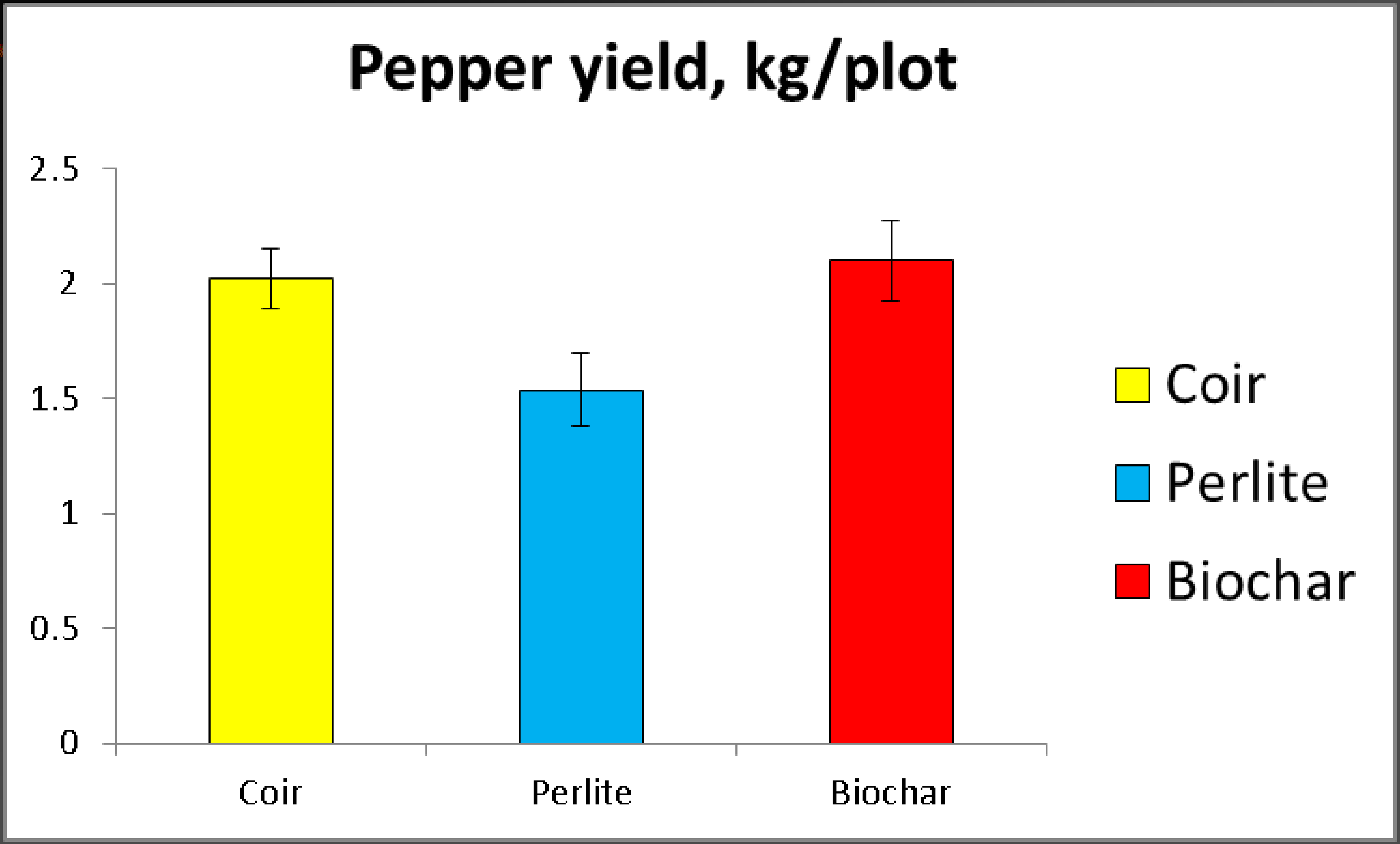
- Yield of long English cucumber, cv Kasja, grown on poultry manure digestate



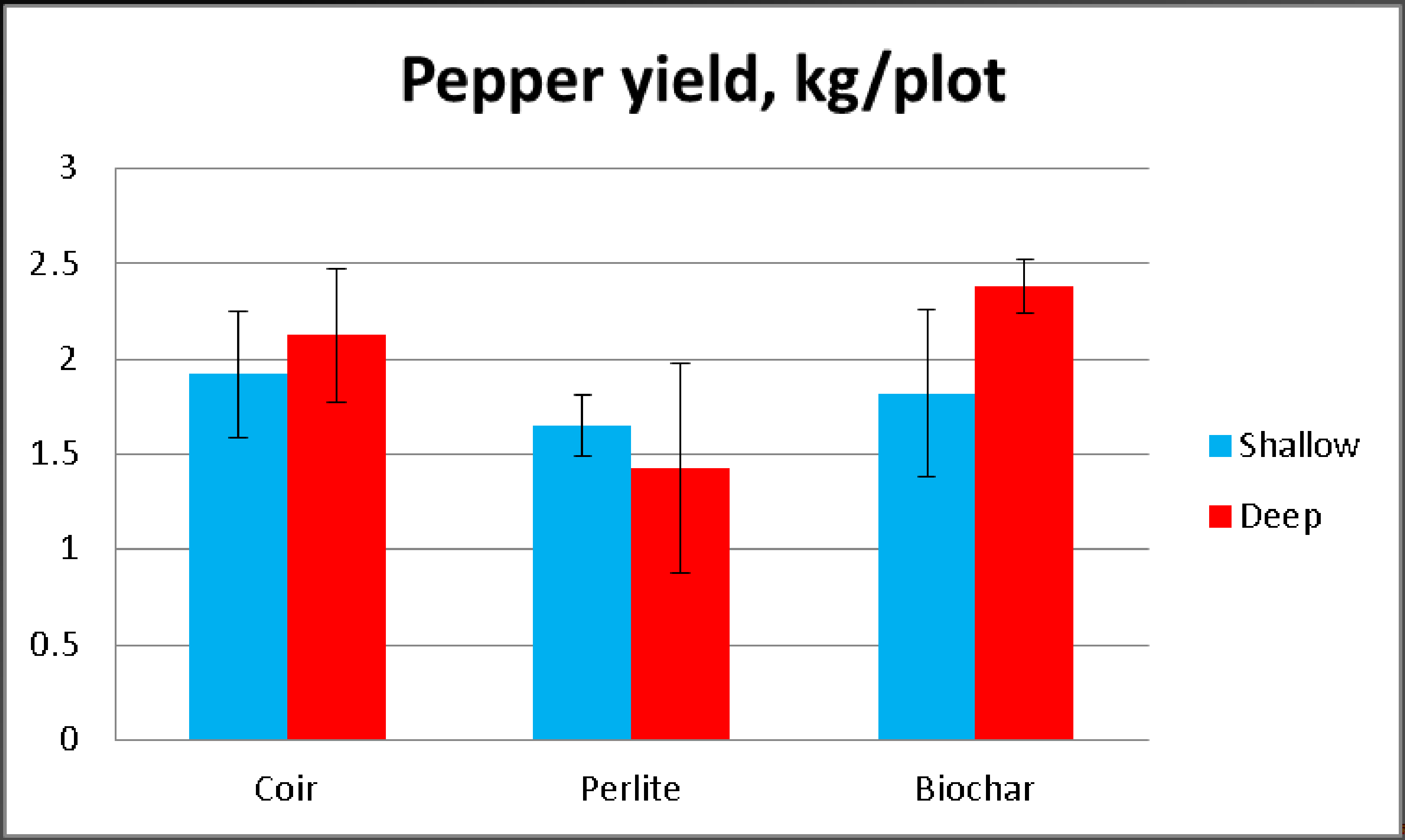


After 6 weeks…

- Yield of pepper crop grown on poultry digestate



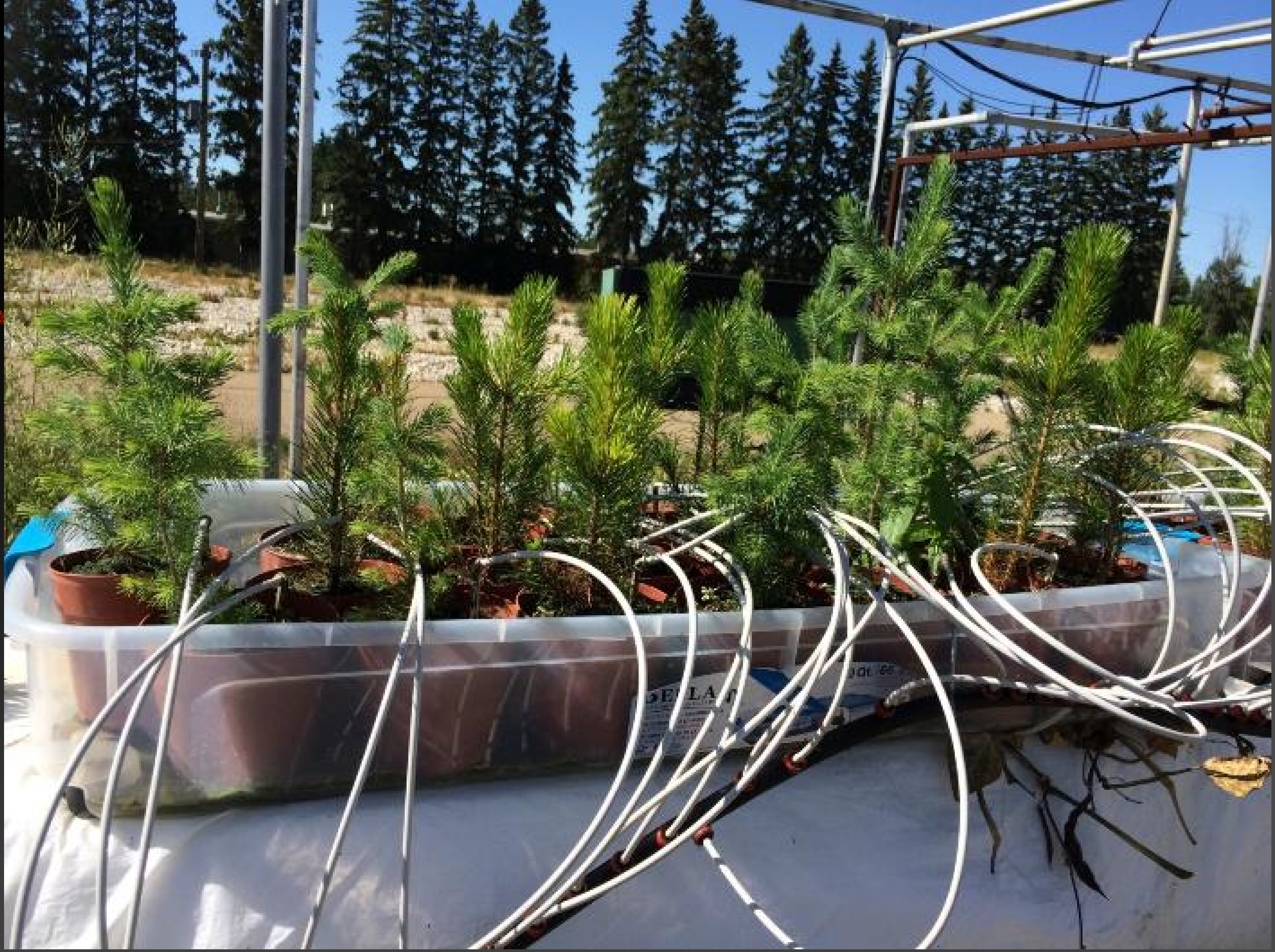
- Effect of the trough depth on pepper yield grown on poultry manure digestate



- Fig tree production using mineralized poultry manure

- Organically-rich solutions were trialed to grow tree seedlings in summer 2014.

- White spruce, *Picea glauca*, lodgepole pine, *Pinus contorta* var. *latifolia*, aspen, Populus tremuloides, and hybrid poplar were among tree species tested in the experiments.



Seedlings of lodgepole pine and white spruce grown on biologically active aerobic digestate. The seedlings were transferred in mid-July and doubled in height after two months.

- Main conclusion:

"Decoupled" systems can be an important development, a way to produce food integrating other livestock industries, such as poultry, beef and cattle with plant production

Use of biochar for filtration and greenhouse production in aquaponics

Biochar is produced as a result of dry carbonization of organic material in anaerobic conditions, which starts at 200°-300° of torrefaction stage and completes at 450°C-550°C

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Specifications of bamboo charcoal used in the experiments

a) No pollution on surface, no impurities
b) Particle size: 5-7mm, uniformly blended;
c) Moisture content: ≤9.0%;
d) Ash content: ≤4.50%;
e) Fixed carbon: ≥85%;
f) Unit surface area: 250-300m^2/g;
g) pH value: 7-8;

- h) Density: 0.50-0.55g/cm^3.

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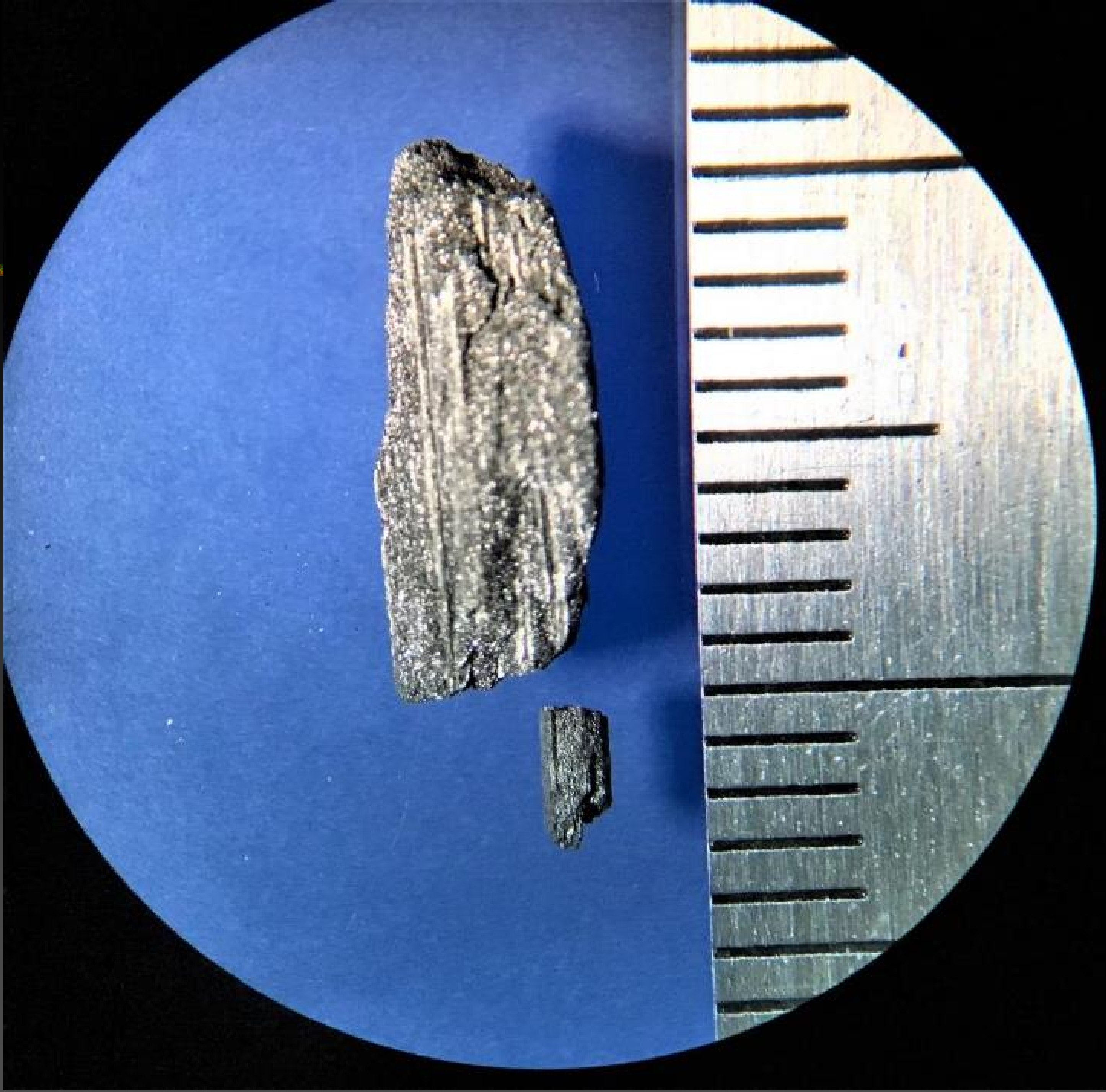

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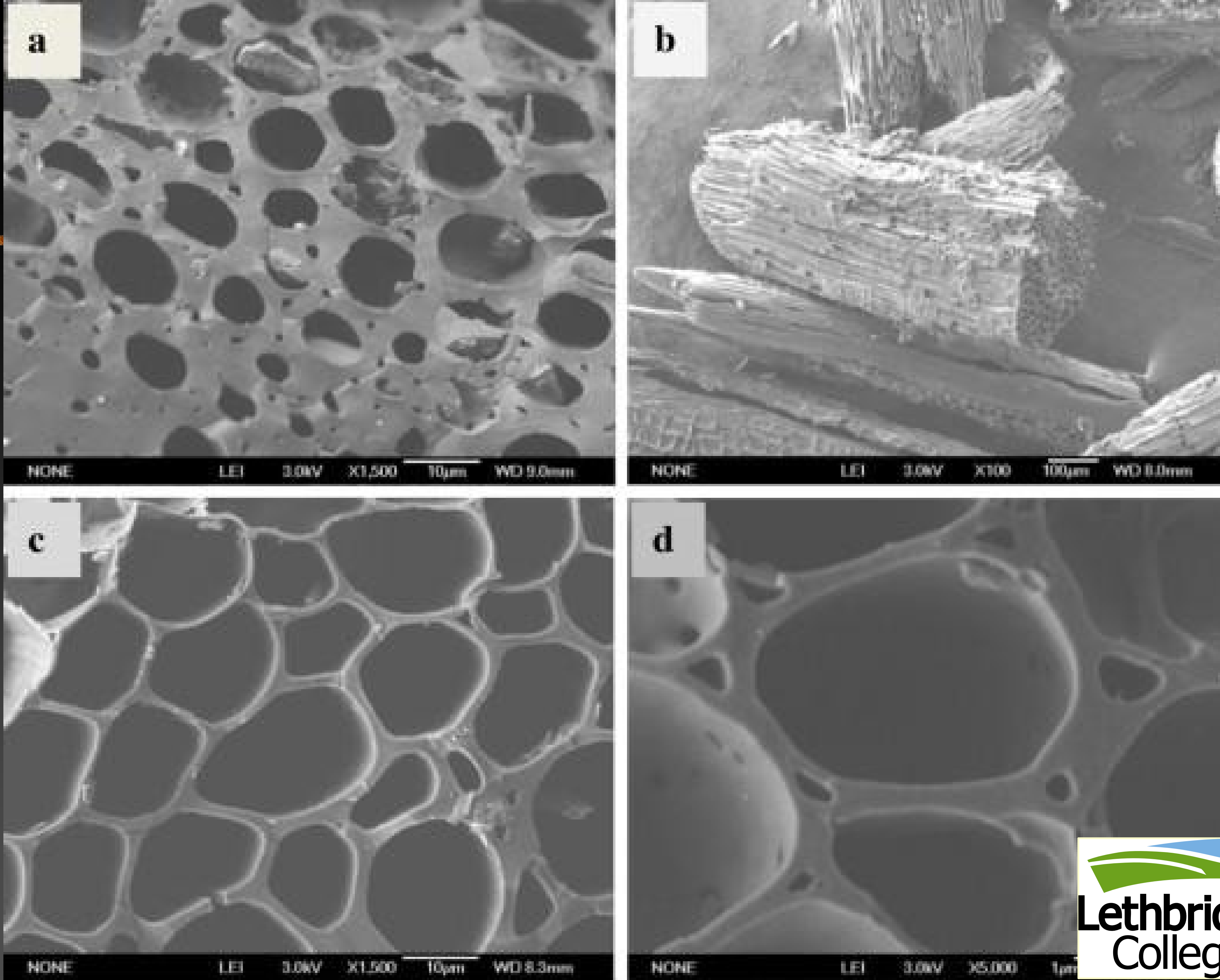

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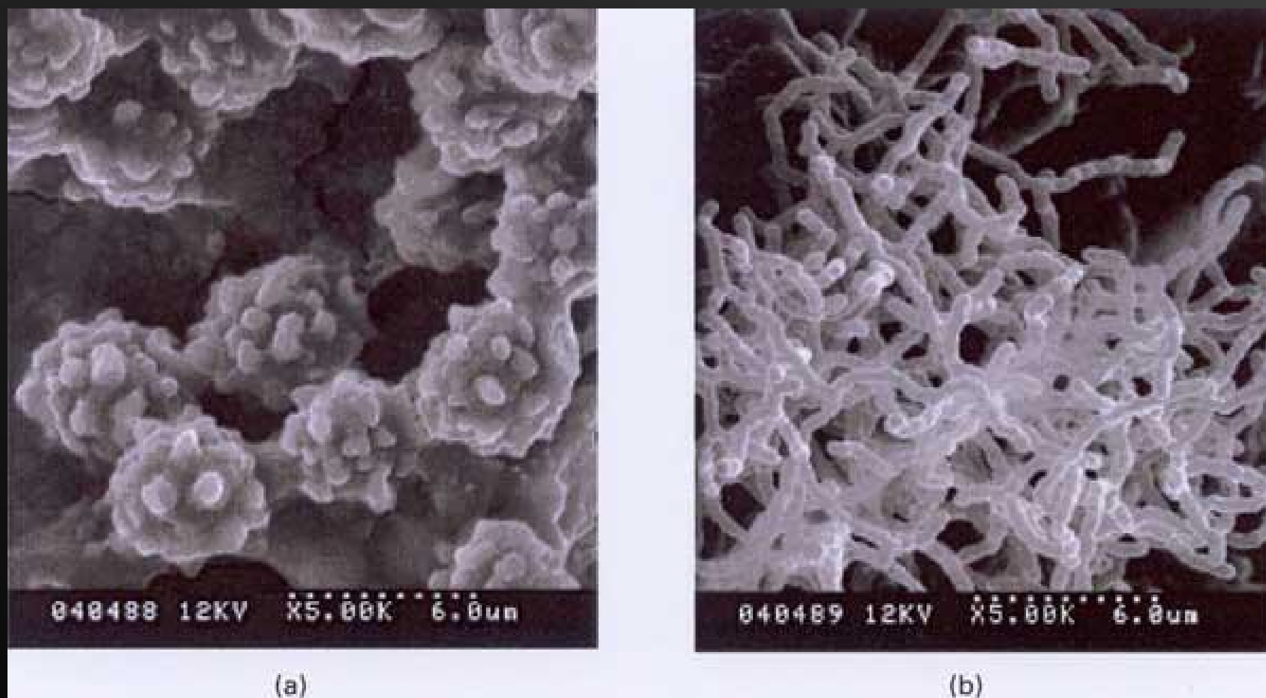
The bamboo biochar pores also allow to use it as highly efficient biofiltration media



SEM photographs of the different type of microorganisms
the mixture surface of bamboo charcoal and rice

Yoshizawa Shuji and Satoko Tanaka, Food and Fertilizer Technology Center (http://www.fftc.agnet.org/library.php?func=view&id=2015010714

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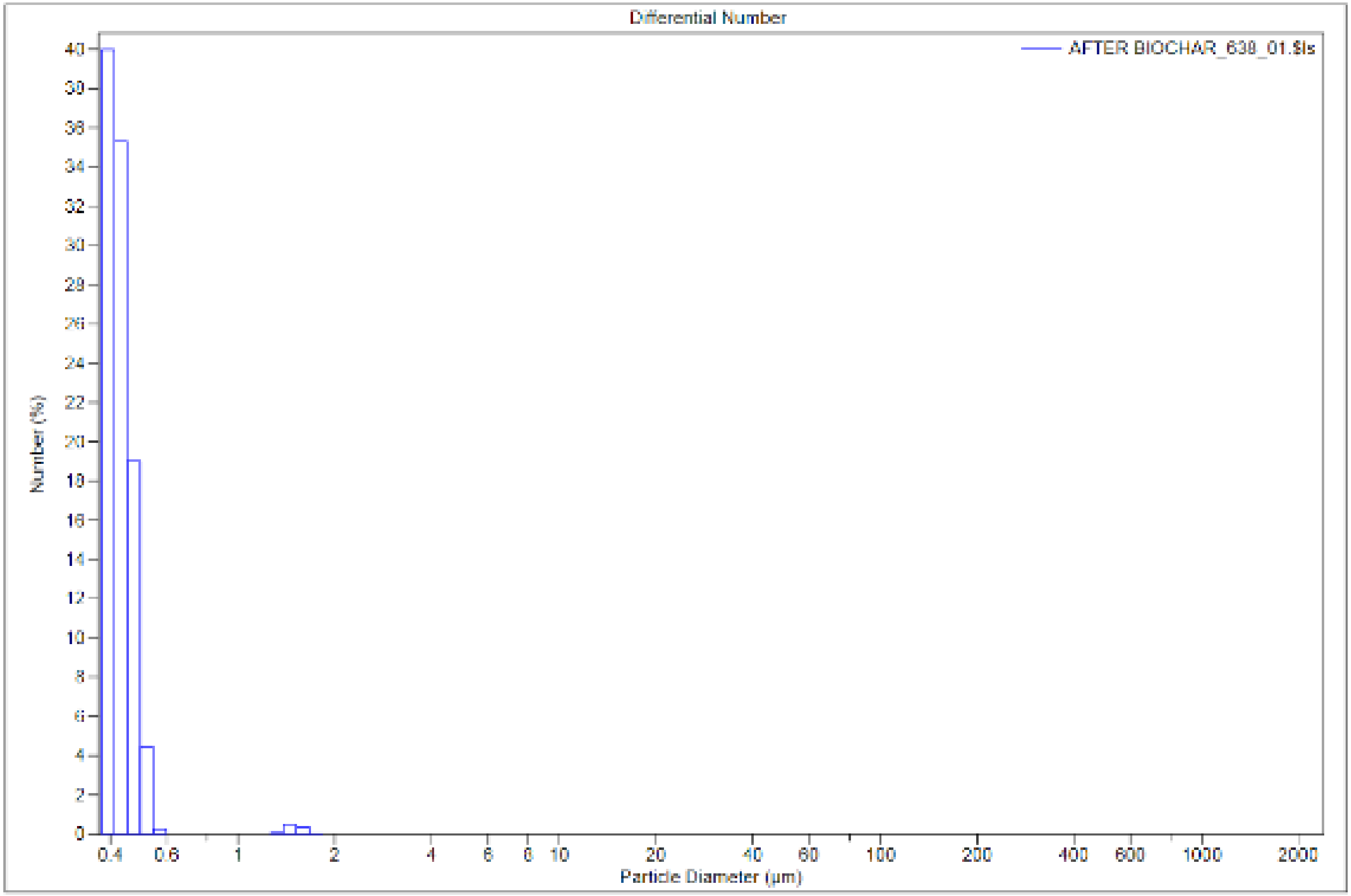
Using Biochar as a water polishing filter dramatically decreased amount of particles between 0 to 30 micron in aquaponics

LS Particle Size Analyzer

3 Jun 2020 13:35

Beckman Coulter LS 13 320



TSS in fish tanks is not detectable in RAS with biochar filters even at high fish stocking density

Two different configurations of biochar filters were used

Total filtration flow was close to 100 L per minute

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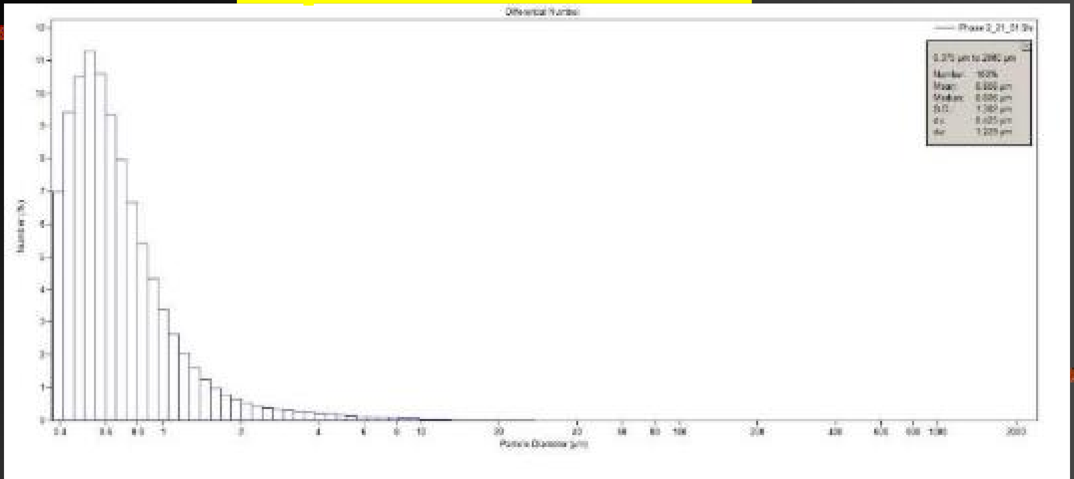
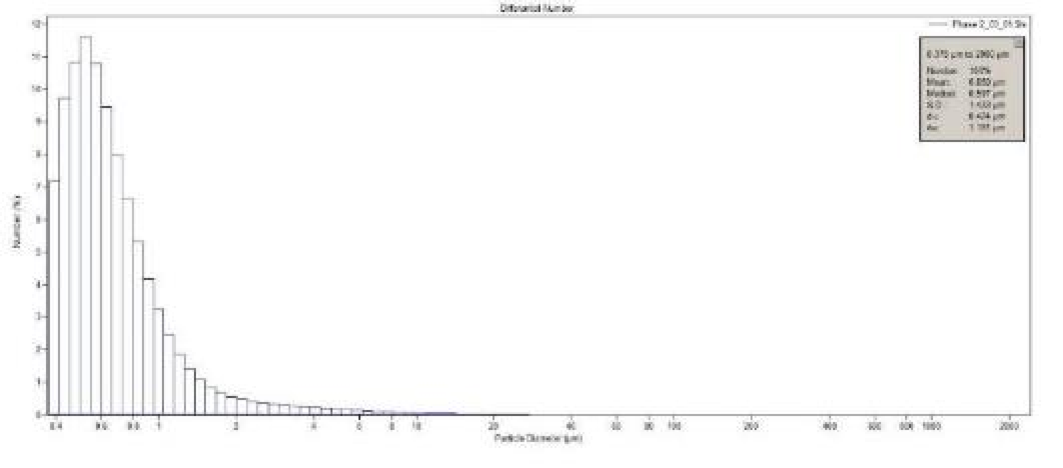
GD
GE
GB
GC

Start of the experiment

Control

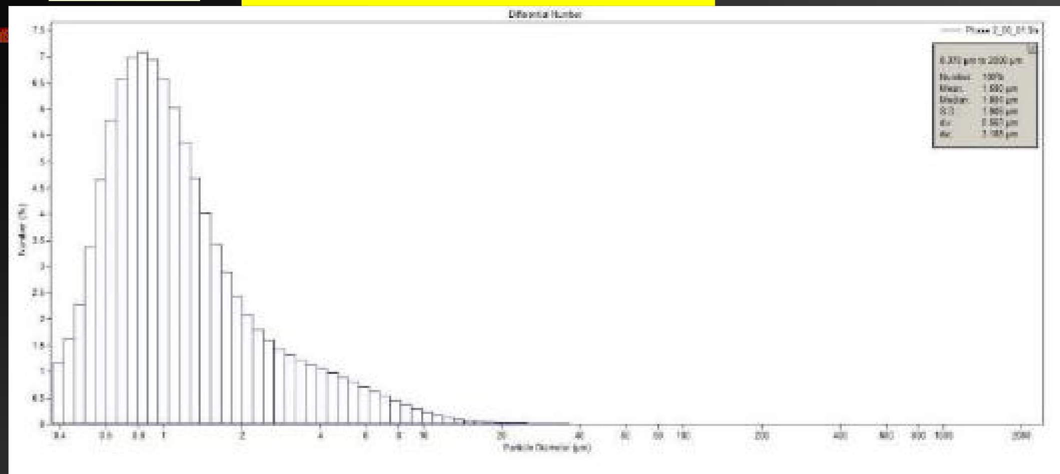


Biochar, 8 cm

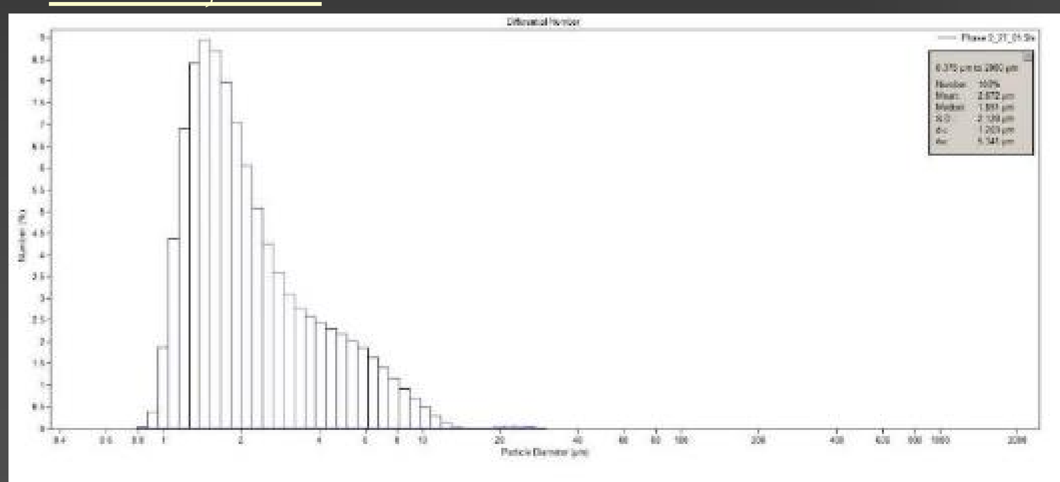


After 1 hour of filtration

Control



Biochar, 8 cm



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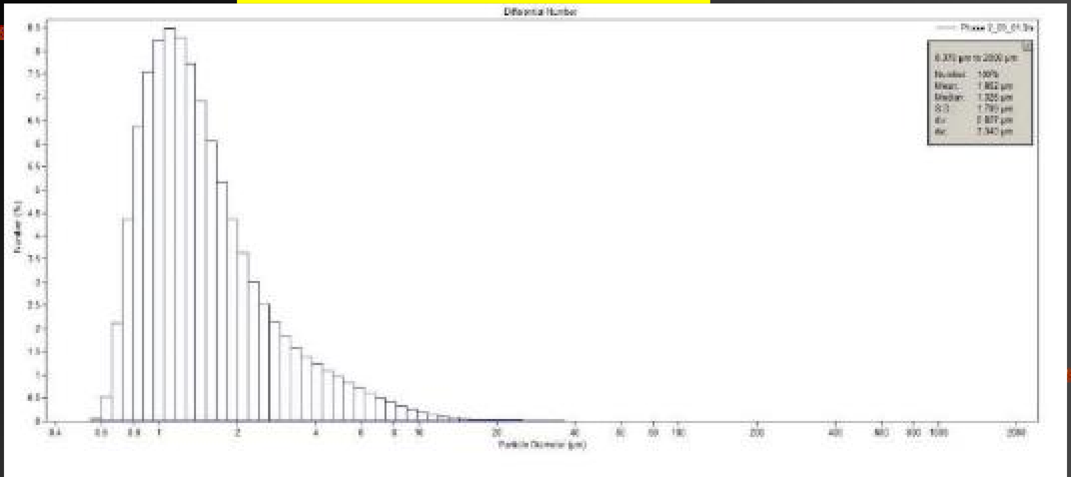
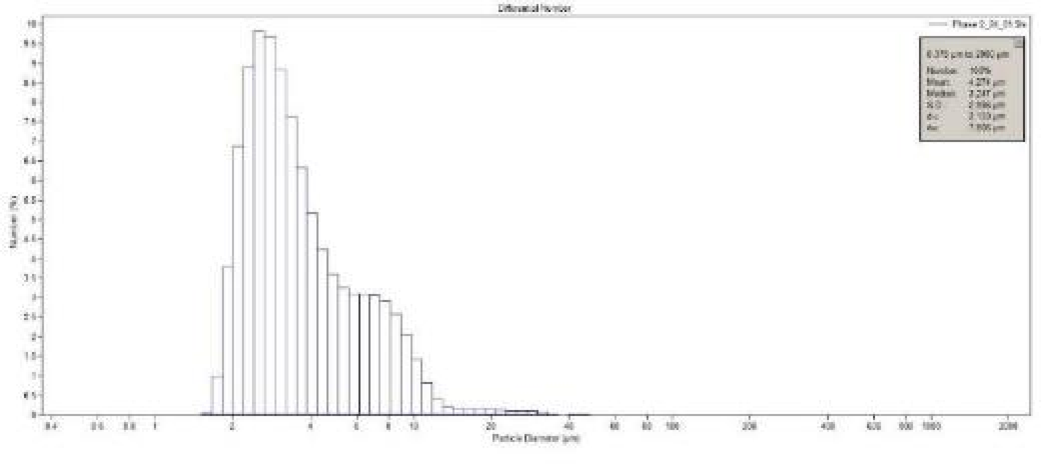
After 2 hours of filtration

Control

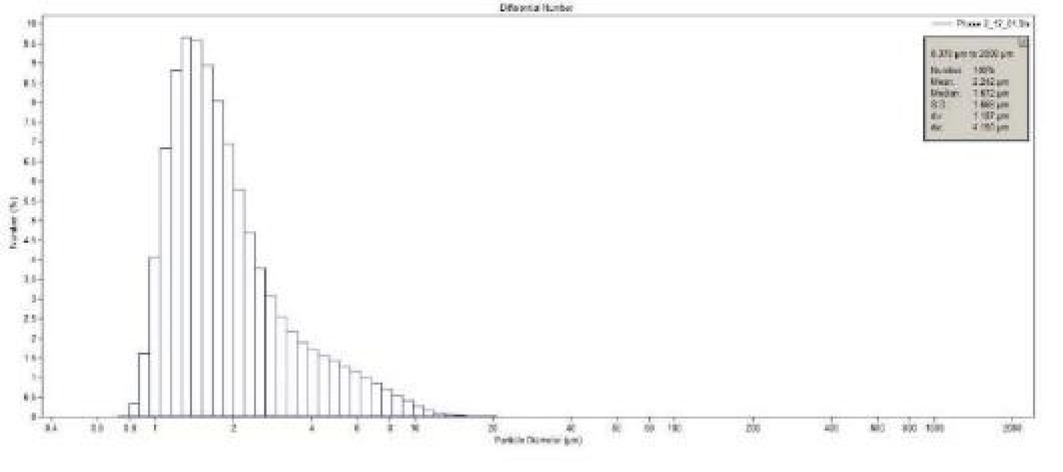


Biochar, 8 cm

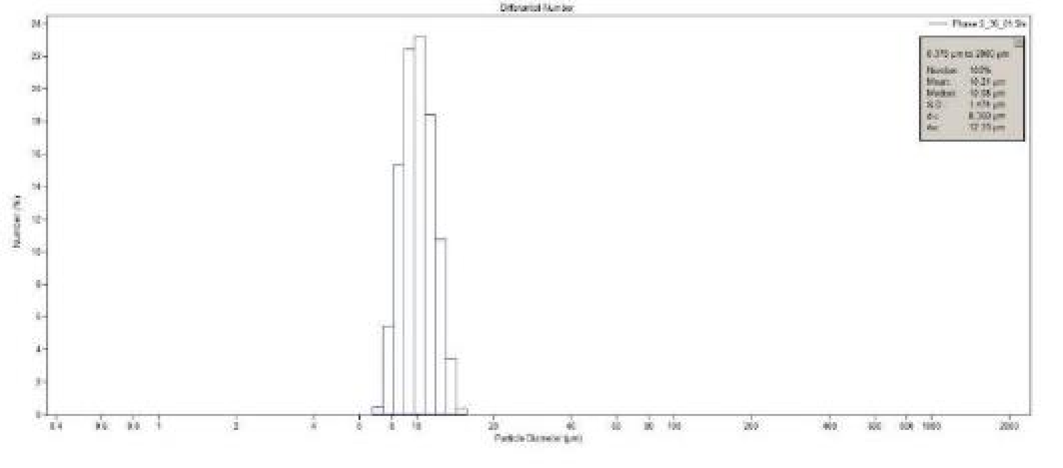


After 3 hours of filtration

Control



Biochar, 8 cm



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Use of biochar as a plant growing medium

Shrinkage of coconut coir after 2nd year of use

Coconut coir

Biochar

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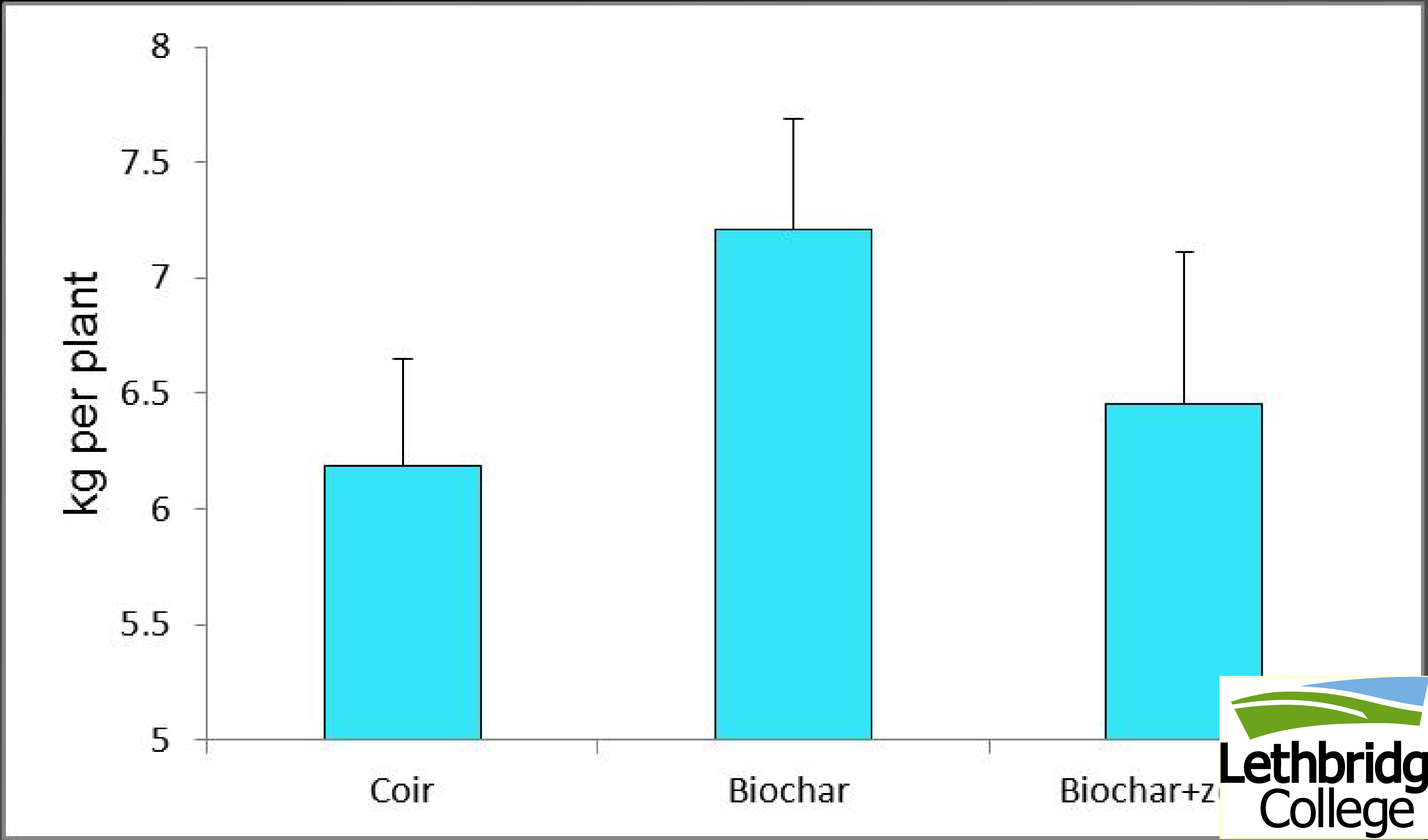
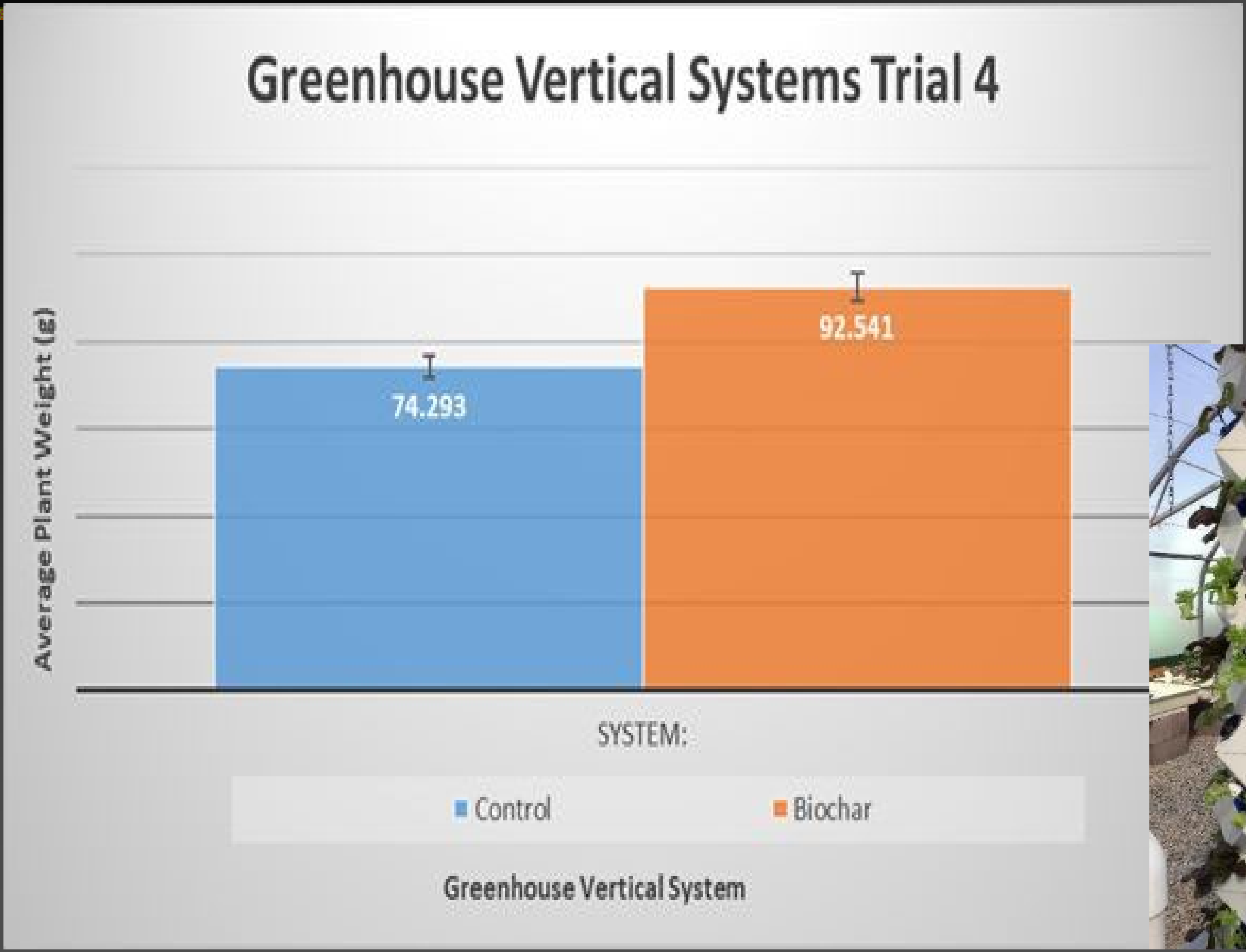
Effect of substrates on yield in the 2nd experiment with cluster tomato, cv. Tradiro



Effect of biochar on aquaponic lettuce production



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The Conclusions

Bamboo biochar represents a highly efficient relatively low-cost filtration solution to remove finer particles (1-100 micron) for aquaponics and aquaculture.

The biochar filter use will be most appropriately as a water polishing step after removal of larger particles (30-1000 micron) using sedimentation tanks or drum filters

Results also indicated that the performance of biochar-based filtration depends on the operational conditions (biochar media size, biochar filter bed height and loading rate).

Biochar also has a potential as a highly efficient biofilter housing beneficial bacteria and considerably exceeds the potential of other known biofiltration media

Integrated Agriculture Technology and Technology Access Centres

Total Budget - $4.2M

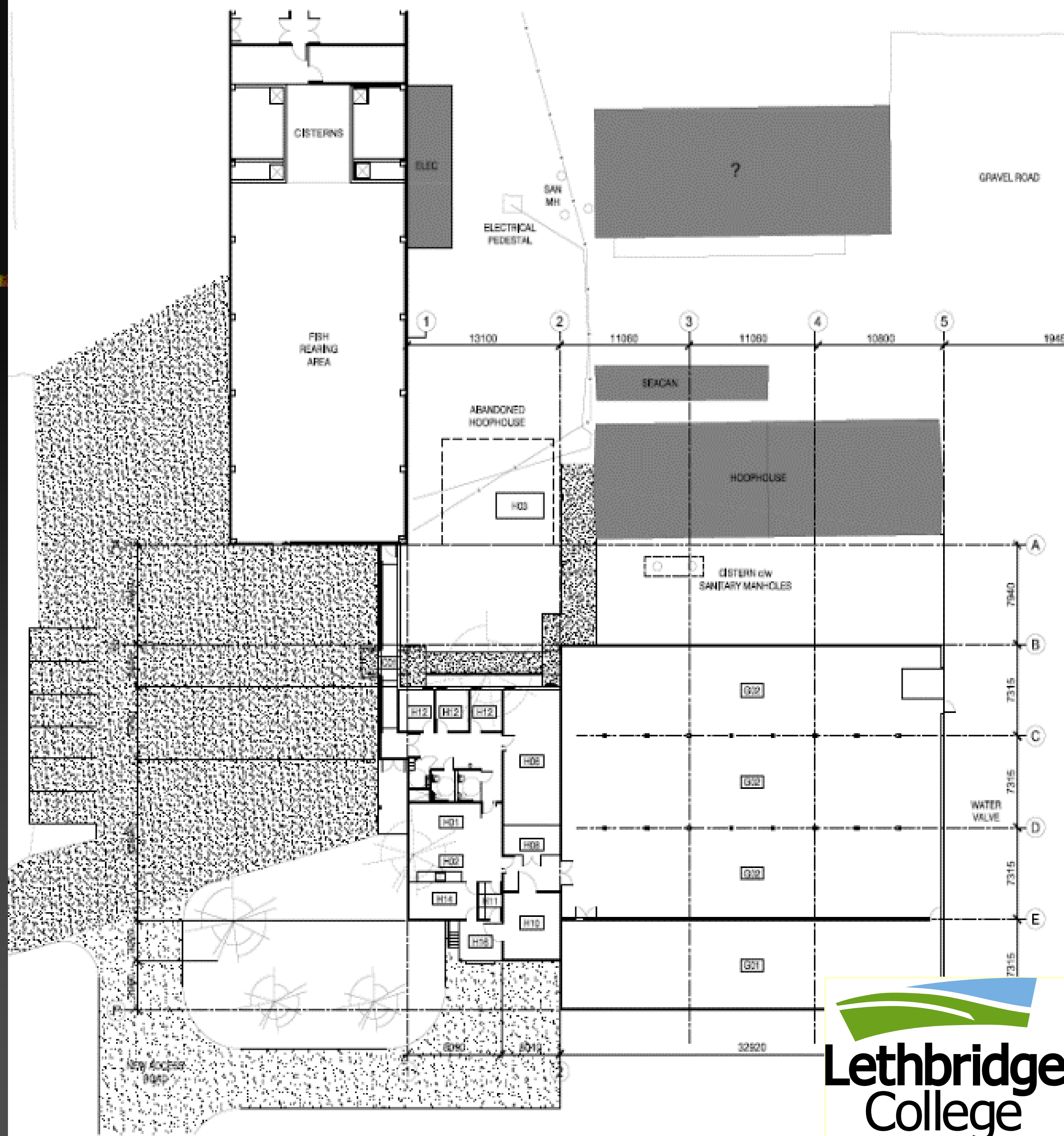
The following services will be provided by the TAC:

- Applied Research & Development;
- Technical Services & Consulting;
- Training and Education.

IATC Research Facility

In Lethbridge

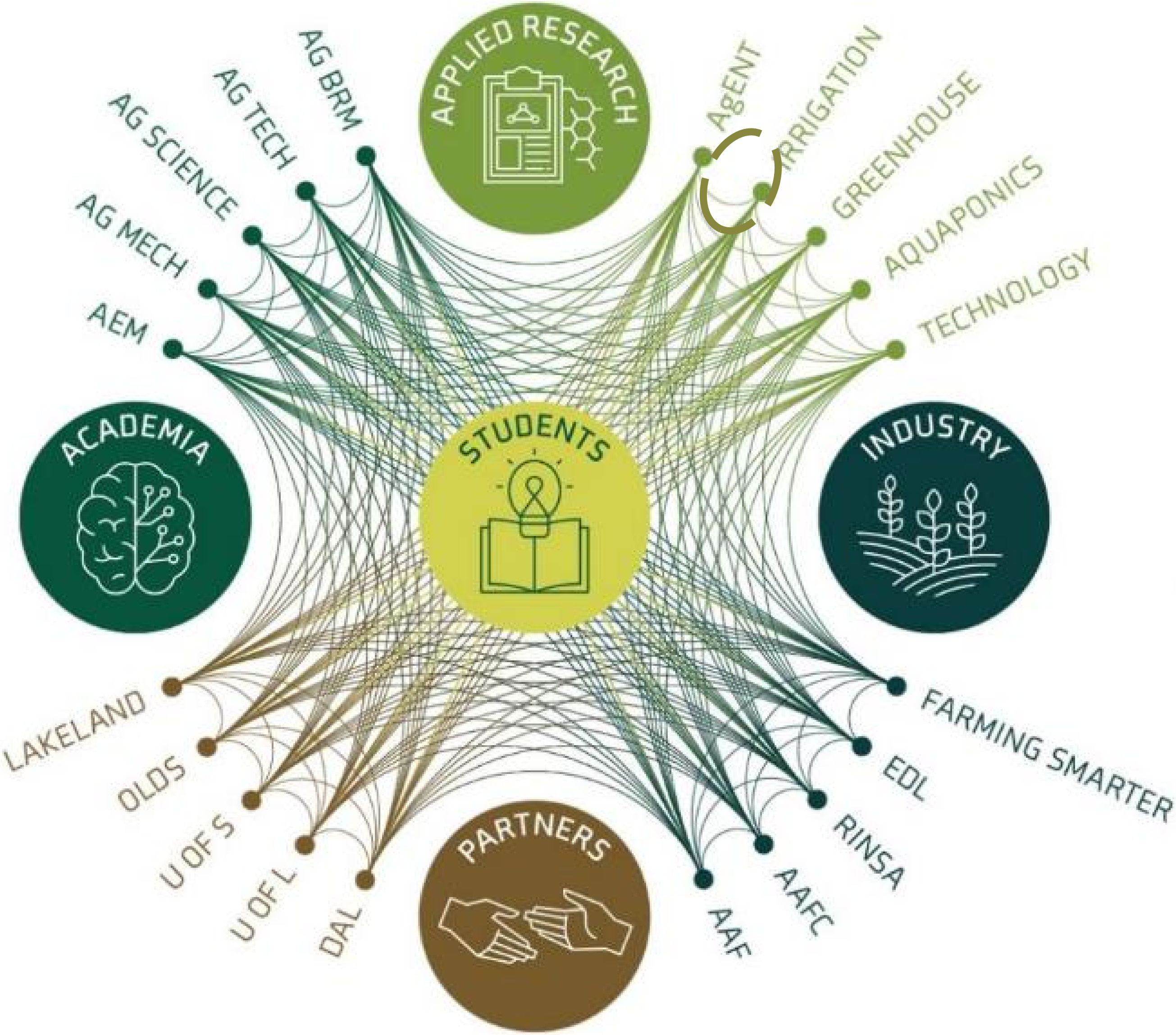
Total area: 10,000 sq.f (under construction)




Tyvek

IATC Research Facility In Brooks

Total area: 50,000 sq.f



COLLABORATIVE
CENTRE *of* EXCELLENCE
in AGRICULTURE

The main objective is to enhance the ability of local businesses to solve problems and become more innovative and competitive through access to technology, expertise, and equipment.

There are over 60 aquaponic experimental modules available for research. Another 40 units will be made with over 100 units of aquaponic research capacity

There are over 60 aquaponic experimental modules available for research. Another 40 units will be made with over 100 units of aquaponic research capacity

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12 DFC systems, 2,000 L

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41 Nutrient Film Technique, systems, 80 L

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Lethbridge College

Lethbridge College

9 DFC, systems 700 L

Over 16 years of operation using the same water

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