

**Evaluation and Development
of Aquaponics Production
and Product Market
Capabilities in Alberta.
Phase II.**

Evaluation and development of aquaponics production and product market capabilities in Alberta. Phase II.

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1. Abstract

Evaluation and development of aquaponics production and product market capabilities in Alberta Phase II was a continuation of study started in 2003/2004. The major objective of the aquaponics project for stand-alone facility at CDC South was to select most the economically profitable crop for aquaponics production under Alberta conditions. Basil was selected for 2004/2005 project. Cucumber and tomato were also evaluated for their productivity in 2004. Based on this evaluation, yields of tomatoes and mini-cucumbers reached 20.7 kg plant⁻¹ year⁻¹ and 33.4 kg plant⁻¹ year⁻¹ and exceeded average values of commercial greenhouses in Alberta that employ conventional hydroponics technology. The yields considerably exceeded yields of the same crops produced during 2003. During the 2-year study, the yield of Genovese basil increased from 13 kg m⁻² year⁻¹ to 42 kg m⁻² year⁻¹. This increase was observed in spite of the lower nutrient levels in 2004 compared to 2003.

The Aquaculture Centre of Excellence (ACE) at the Lethbridge Community College is primarily a warm water applied aquaculture research facility with an attached seasonal greenhouse representing add-on aquaponics facility. Only part of the fish water is used for greenhouse production. The water was treated using fluidized sand filters and an ozonator to remove the bulk of organic material from the fish water, which led to consistent nutrient deficiencies. Therefore, nutrient supplements were necessary to ensure stable crop production. In 2003 and 2004, tomatoes and cucumbers were the main crops grown because of their high value and suitability for summer temperatures found in southern Alberta greenhouses. Four varieties of tomatoes (Chloe, Clarence, pear and grape) and three types of cucumbers (English, mini English and gherkin) were grown and fruit production was measured. The timing of fish sales in 2004 had a large impact on nutrient levels and amounts of supplement required. Air and water temperatures, timing of fish sales, and nutrient levels influenced growth. As nutrient levels in 2004 became low, production slowed down and leaves yellowed. Once the supplemental nutrients were added, the plants began to produce more rapidly.

The improved yields in 2004 in stand-alone aquaponics facility at CDC South in spite of the lower nutrient levels suggested a new factor in aquaponics production. In order to verify data produced in larger system, six crops (cucumber, tomato, basil, rosemary, *Echinacea* and lettuce) were grown in aquaponics and hydroponics nutrient solutions in model greenhouse experiments using raft hydroponics. Aquaponically produced plants attained a higher relative growth rate for both roots and shoots compared to plants grown hydroponically under non-limiting nutrient conditions. Root biomass was especially affected. Basil attained significantly greater height (35 vs. 30 cm), shoot weight (301 vs. 226 g) and root weight (111 vs. 68 g) in aquaponics nutrient solution compared to hydroponics nutrient solution, respectively. Similar results were obtained for rosemary, cucumber and tomato. The root diameter of *Echinacea* in aquaponics nutrient solution was 3.9 mm compared to 2.0 mm in hydroponics nutrient solution. Respective shoot and root weights of *Echinacea* were 2.4 and 1.3 g in aquaponics nutrient solution compared to 1.0 and 0.7 g in hydroponics nutrient solution. Nutrients were depleted faster in aquaponics nutrient solution than in hydroponics nutrient solution in the beginning of the experiments.

This study indicated that there was a factor stimulating nutrient uptake and assimilation by plants grown in aquaponics solutions where nutrients and many organic compounds were derived from fish feed. It was hypothesized that plant growth promotion (PGP) results from the interaction of nutrients, organic compounds and bacteria. Further research is needed to identify the PGP mechanism.

The second year study confirmed findings of the first year and proved the technical feasibility of the aquaponics technology in Alberta.

2. Introduction

The purpose of this project was to continue evaluating two aquaponics systems for crop yield, fish yield, the economic feasibility and the market potential for high value niche products in Alberta. The two systems being compared were: a stand alone, warm water system, with closely integrated fish tanks and greenhouse crop production (CDC South) and an add-on system, where a crop production facility was developed as an add-on to the existing aquaculture facility (Lethbridge Community College).

A grant was received from New Initiatives Funding Program for the 2003/2004 fiscal year. The funds were used to collect data on crops, fish and economic viability of a stand-alone aquaponics system at Brooks. In addition data was collected on crop production and economic potential of an aquaponics greenhouse operating as a seasonal add-on to an existing warm water aquaponics operation in Lethbridge.

Tilapia fish stocking densities and feed were increased to provide sufficient nutrient levels to grow a marketable greenhouse vegetable crop. Four crops including lettuce, basil, tomato and cucumber have been tested to determine their performance in the aquaponics environment. Within a short period of time the Brooks Aquaponics Facility was in full-operational and the first results on crop and fish yields were obtained.

The previous applied aquaponics demonstration at the Lethbridge Community College's (LCC) Aquaculture Centre of Excellence and data collected at the CDC South in 2003 indicated that crop yields were similar to a conventional hydroponics system. Further research at both locations, was required to diversify aquaponics crops and to measure plant and fish yields.

Economic feasibility and business opportunity information will continue being evaluated for this new technology for Alberta for a stand alone system at CDC South and an add-on system in Lethbridge to confirm and extend the result of the second year of operation.

The marketing study demonstrated acceptance of aquaponically-grown vegetables by consumers. Food safety involved extensive sampling at both locations including Brooks and Lethbridge. It showed no potential hazard for health (see the attached documents).

The result of this work will help contribute to the diversification of Alberta's plant and animal production sectors. Aquaponics may stimulate an opportunity for diversification for small and medium-sized greenhouse and fish farms.

Lethbridge Aquaculture Centre of Excellence – research purpose

The culture of warm water fish such as tilapia and grass carp in barns using recirculating aquaculture technology was becoming well established in Alberta. The focus of these farms was the year round production of fish under intensive, recirculating aquaculture conditions. Some farmers have built greenhouses on the side of their operations that are used in the warmer months of the year on a semi-commercial basis. Produce from these operations was sold at the farm gate, largely by word of mouth.

One producer has done a preliminary evaluation of evaluating aquaponics in the context of an add-on operation associated with his production of a cold-water species, rainbow trout. The other aquaponics project was at CDC South, Brooks where the focus was on evaluation, in an Alberta greenhouse context, of a balanced aquaponics system developed in the U.S. Virgin Islands. The project proposed for LCC would complement these two other studies.

3. Experiments

3.1. Maximizing production capacity of pre-commercial stand-alone aquaponics facility at CDC South, Brooks

Objectives:

- Second year-evaluation of the stand-alone warm water fish model under Alberta conditions.
- Optimizing fish yield and crop
- Evaluation of the stand-alone warm water fish model under Alberta conditions.
- Optimizing fish yield and crop yields for leafy vegetables including basil, and mini-English cucumbers and tomato.
- Complete a detailed cost of production for aquaponics based on the above fish and plant objectives.
- Conduct a marketing study of aquaponics products and opportunity for brand marketing.

3.1.1. Materials and methods

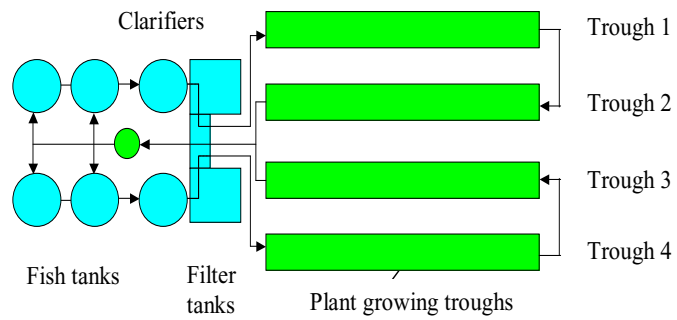
3.1.1.1. Recirculation system in Brooks

The recirculation system has also been described in the report 2004-679056201. The stand-alone aquaponics system at the CDC South, Brooks was based on the J. Rakocy model (Rakocy and Hargreaves 1993;Rakocy 2002;Rakocy, Shultz, Bailey, and Thoman 2004) adapted to greenhouse conditions (see Figure 1 A).

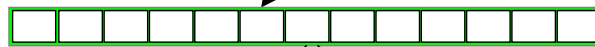
The facility consisted of three greenhouses (each 7.6 m wide x 15.5 m long) in a straight line separated by storage areas (each 2.9 m wide x 7.6 m long). One greenhouse contained the aquaculture equipment and the other two contained the plant trays. The aquaculture area held four fish tanks, two clarifiers, five settling/degassing tanks, one central sump tank and a base mixing barrel for a total system capacity of 71750 L. Fish were raised in four fiberglass culture tanks (2.4 m dia x 1.2 m deep, 5600 L capacity) arranged in two series of two tanks each. Fish tank effluent moved through two conical clarifier tanks (each 4500 L) that removed most of the solids through a series of baffles.

Figure 1. Pre-commercial aquaponics facility in Brooks.

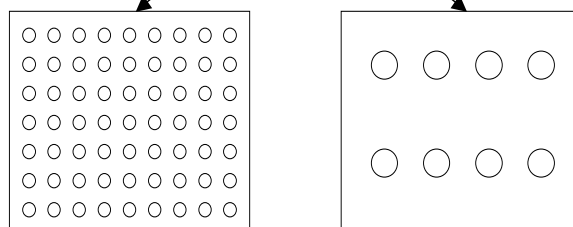
A. Aquaponics facility in Brooks. Plain view



B. Plant growing trough with Styrofoam sheets



C. Styrofoam sheet for basil (left) and for tomato and cucumber (right) production



Accumulated solids were drained from the clarifiers daily and stored in a holding tank for later application to field crops. Water moved from the clarifiers into two rectangular settling tanks (each 750 L) then into a joint degassing tank. These small tanks removed the rest of the solids and CO₂ from the fish effluent by filtration through plastic netting. The net filter provided extended surface area for residing ammonifying and nitrifying bacteria to mineralize organic waste.

Water from the degassing tank flowed into four plastic-lined, concrete plant troughs (each 0.9 m wide x 30.5 m long x 0.45 m deep, 9000 L capacity) arranged in two series of two. The outflow from the plant troughs moved into a small sump tank (1000 L) where a submersible pump continuously circulated the water back to the fish tanks via a mixing barrel. Fresh water was plumbed into the sump tank area, through a heat exchanger and boiler system capable of keeping the water consistently warm (~ 24.8°C for tilapia). A float valve in the sump tank lowers with the water level which triggered the addition of more fresh water; thus, the replacement rate adjusted automatically.

Water circulated through the system at 400 L min⁻¹. Each fish tank received a flow of 100 L min⁻¹ and each plant tray a flow of 200 L min⁻¹. Thus there was a turnover time of once per hour for the fish tanks and once every 45 minutes for the plant trays.

The greenhouse and recirculation system was under full-computerized control (Argus Control System Ltd). The computer collects some data on a daily basis using specific probes. Environmental parameters in the greenhouse such as temperature and humidity were maintained at stable levels by the computer using heaters/coolers and humidifiers. Irradiation in the greenhouse was also being monitored. The recirculation system was aerated using air blowers and diffusers and had a liquid oxygen backup. Water temperature, oxygen levels, electric conductivity (EC), and pH were monitored continuously by the computer control system

3.1.1.2. Fish culture

3.1.1.2.1. Aquaponics hatchery

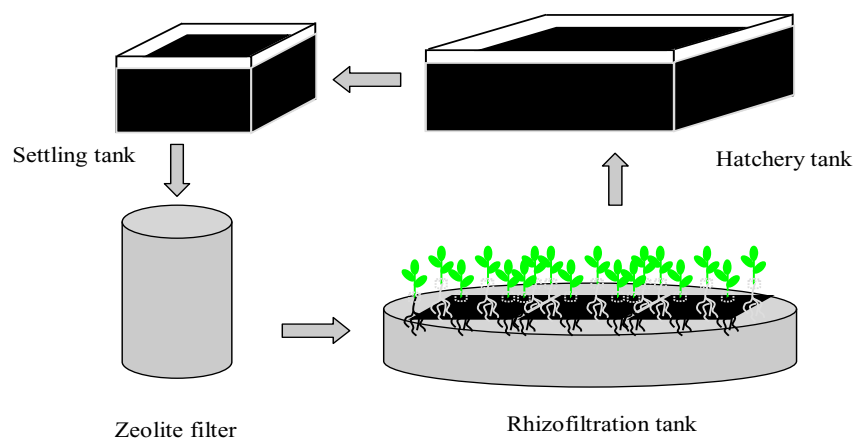
In summer 2005 the principles of aquaponics were successfully applied to build a fish hatchery at CDC South. The purpose of the hatchery was to grow 100 g fingerlings from 1 g fry in the aquaponics environment in order to minimize stress when transferring the 100 g fingerlings from a commercial aquaculture facility to the aquaponics system due to difference in water quality. The hatchery was also built in order to provide independent and continuous supply of the fingerlings to the pre-commercial aquaponics facility.

The hatchery consisted of two separate systems with total volume of 3.3 cubic meters. Each system consisted of two hatchery tanks (750 L total), one settling tank (250 L), zeolite filter (150 L), and plant tray (500 L) with total volume 1.650 cubic meter (see Figure 2). The food was provided manually. One-gram fry was received from MDM Aquafarms, Rumsey, Alberta. The fry was grown at 26.5 to 27.0°C. Ammonium level was maintained at lower than 2.0 ppm and DO level was not lower than 5.5 ppm, and pH was 6.5-7.0. Ammonium levels, EC, pH, and DO were monitored on daily basis.

3.1.1.2.2. Pre-commercial facility

Fish growth trials at the Brooks aquaponics facility were carried out at 24.8°C in a 24-week growth cycle with staggered production. Each tank initially received 600 tilapia of 100 g mean wet weight. The Alberta Fish Farmers Association supplied fish every 6 weeks. A research permit under the Provincial Fisheries Act has been obtained and renewed prior to each fiscal year. The expected food conversion ratio (FCR) was 1.3 at 90% feeding efficiency. Fish were fed 3.2 mm pellets up to a mean size of 300 g, and 4.8 mm pellets beyond 300 g. Food was provided through automatic feeders linked to the computer control system. Feeding rates started at 2.5% day⁻¹ for 100 g fish and was gradually reduced to 1.25% day⁻¹ for fish of 400 g. With this regime, fish were expected to reach a market size (700 g) in 24 weeks. At the end of the trials, all fish were returned to the Alberta Aquaculture Association (AAA). EC, pH, DO, and ammonium levels was monitored on daily basis.

Figure 2. Hatchery facility at CDC South, Brooks.



3.1.1.3. Plant culture

The plants grown during the second year of aquaponics project in 2004 were selected according to their commercial importance and the results produced in the previous study. Initially, three crops were selected including cucumbers mini, cv. Alamir, tomato, cv. Roma, and basil, cv. Genovese. Starting from June 2004, the experiments continued focusing only on basil as a high value crop.

Plant seedlings were grown in rockwool and transferred to the Styrofoam rafts floating in the plant troughs each containing 13 rafts with total area 25.8 m² (Figure 1 B). Each raft (1.98 m²) held 63 (basil) or 8 (cucumbers and tomatoes) plants (Figure 1 C). The plants were grown in the greenhouse at an air temperature of 22-25°C, an irradiation level $\geq 300\text{-}500 \mu\text{mol photons m}^{-2} \text{sec}^{-1}$ photosynthetically available radiation (PAR), and a 16:8 day:night photoperiod provided by natural and artificial lights. Water pH was maintained near 6.1-6.3 by the addition of either Ca(OH)₂ or KHCO₃ (alternate on weekly basis) to increase pH, or H₃PO₄ to reduce pH. This pH was considered optimal to maximize mineral uptake and plant growth and it was not harmful to the tilapia. As with the fish, plant growth trials were staggered so that the total plant production was balanced with fish production.

Each crop was rotated to avoid spikes of high mineral concentration from excessive fish waste input. Seedlings of cucumbers and tomatoes were transferred to the facility every three weeks. Each week three rafts with basil per trough were harvested and three rafts with young seedlings were placed to ensure uniform consumption of the minerals during the operation.

The crops were routinely monitored for pests and diseases. Biological crop protection was carried out as required through integrated pest management (IPM) practices. Various predatory insects and hyperparasites were used for chemical-free protection. Twenty two commercial products of biocontrol were tested (see Table 1). The plant growth trial protocol was standardized among the stand-alone and add-on facilities.

Table 1. Biocontrol products used in aquaponics project at Crop Diversification Centre South, Brooks.

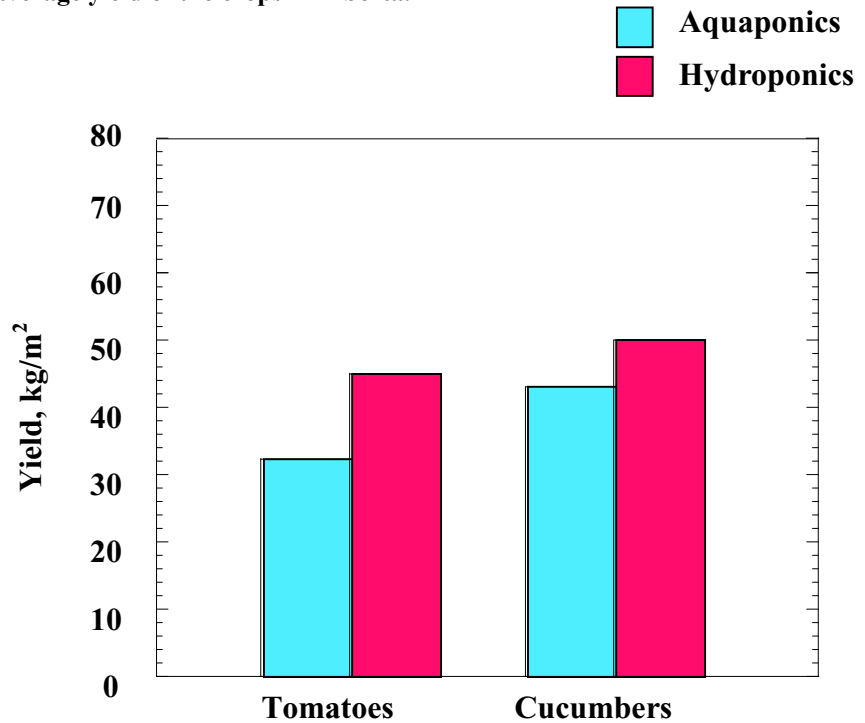
Bio Control Product	Organism	Target	Brand Name	Supplier
<i>Amblyseius/ Neoseiulus cucumeris</i>	Predatory mites	Thrips	Thripex	Koppert
<i>Amblyseius/ Neoseiulus cucumeris</i>	Predatory mites	Thrips		Westgro
<i>Amblyseius degenerans</i>	Predatory mites	Thrips		Westgro
<i>aphidus colemani</i>	Predatory wasp	Aphids	Ahipar	Koppert
<i>Aphidus ervi</i>	Predatory wasp	Aphids	Ahipar	Koppert
<i>Aphidus matricariae</i>	Predatory wasp	Aphids		Westgro
<i>Aphidoletes aphidimyza</i>	Predatory fly	Aphids		Westgro
<i>Delphastus pusillus</i>	Predatory beetle	Greenhouse whitefly		Westgro
<i>Dicyphus tamaninii</i>	Predator	Thrips/Greenhouse whitefly		Westgro
<i>Encarsia formosa</i>	Parasitoid	Greenhouse whitefly	Enstrip	Koppert
<i>Encarsia formosa</i>	Parasitoid	Greenhouse whitefly	Enstrip	Koppert
<i>Encarsia formosa/ Eretmocerus eremicus</i>	Parasitoid	Greenhouse whitefly	Enermix	
<i>Harmonia axyridis</i>	Predatory beetle	Aphids		Westgro
<i>Hippodamia convergens</i>	Predatory beetle	Aphids	Aphidamia	Koppert
<i>Hypoaspis aculeifer</i>	Predatory mite	Fungus gnats	Entomite	Koppert
<i>Hypoaspis mile</i>	Predatory mite	Fungus gnats/thrips		Koppert
<i>Orius insidiosus</i>	Predator	Thrips		Westgro
<i>Orius laevigatus</i>	Predator	Thrips	Thripor	Koppert
<i>Phytoseiulus persimilis</i>	Predatory mite	Thrips		Westgro
<i>Phytoseiulus persimilis</i>	Predatory mite	Thrips	Spidex	Koppert
<i>Stethorus punctillum</i>	Predatory beetle	Spider mites		Westgro

3.1.2. Results and discussions

3.1.2.1. Greenhouse crops production

The major purpose of the second year operation of aquaponics facility at CDC South was to reproduce the results of the first year, but also to maximize yield of crop and fish component through improved practice and accumulated experience of working with aquaponics technology. During the first year of Brooks Aquaponics Facility operation we showed technical feasibility of the Rakocy/UVI model adapted to the greenhouse conditions in Alberta (NIF 2003-679056201). Yields of two major greenhouse crops including tomatoes and cucumbers were considerably higher than average in organic greenhouse production based on soil, but still 15% - 25% lower than average yields in mainstream greenhouse vegetable production based on hydroponics.

Figure 3. Production of tomatos, cv. Clarence and cucumbers mini, cv. Alamir in aquaponics pre-commercial facility in 2003/2004 compared to average yield of the crops in Alberta.

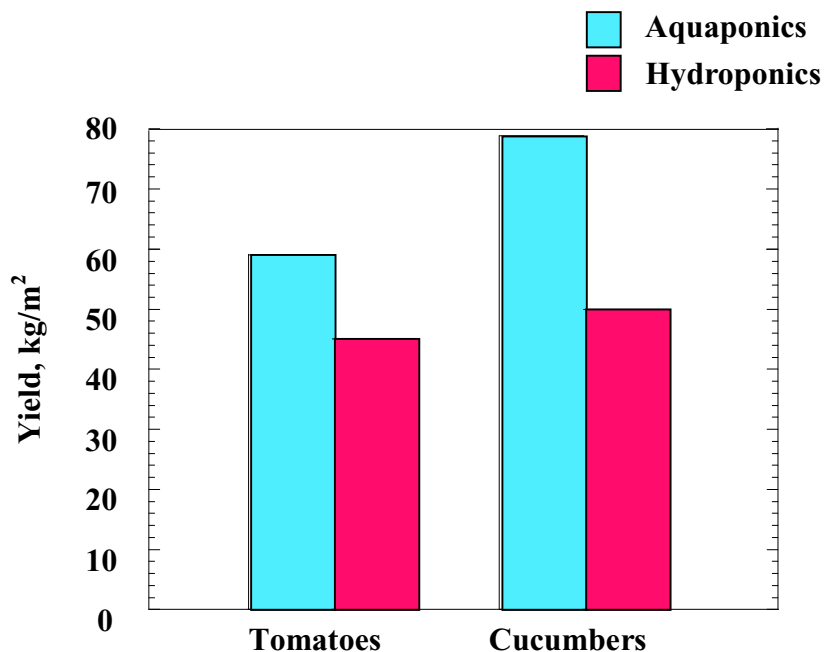


The lower average yield was mostly due to lack of experience resulted into a massive loss of plants caused by disease and pest infestation during winter period 2003-2004 (Savidov 2004). Therefore, a rigorous effort has been made to curb the losses. These measures included more diversified biocontrol agents (Table 1) and regular cleaning procedures. In addition to diversifying biocontrol organisms, the commercial biocontrol products supplier was changed which provided more stable results in pest control.

In collaboration with Plant Pathology Program at CDC South we found that the major cause of the plant loss was a local strain of *Pythium aphanidermatum*. This fungus survives in water and soil, releases swimming spores that penetrate into host tissue within 30 minutes, and grows approximately two inches per day in optimum environmental conditions (Kim, Kantzes, and Weaver 1974).

The occurrence of *Pythium* infection in aquaponics was reported previously (Stanghellini, Kim, Rakocy, Gloger, and Klinton 1998). Regular cleaning of the settling tanks and plant troughs deprives *Pythium* of the breeding ground and significantly decreases population of zoospores in the aquaponics water. The improved practice contributed to the yield increase of tomatoes and cucumbers in 2004/2005 compared to 2003/2004, which exceeded average yield in the industry (Figure 3 and 4).

Figure 4. Production of tomatoes, cv. Clarence and cucumbers mini, cv. Alamir in aquaponics pre-commercial facility in 2004/2005 compared to average yield of the crops in Alberta.



Basil was one of the crops chosen for 2003/2004 study. The results of the study demonstrated that basil adapted well to aquaponics environment and produced 21.8 kg m² of trough area or 8.7 kg m² of greenhouse area (Figure 5 and 6). Notably, basil production was steadily growing during the period from July 18, 2003 till May 23, 2004 despite of the gradual decline in EC and nutrient levels in the solution (Figure 6).

The average yield of basil, cv. Genovese, increased in 2004/2005 study 36.8% from 8.7 kg m² of greenhouse area to 11.9 kg m² (Table 2). A further growth was observed in the first 6 months of 2005/2006 fiscal year to 15.3 kg m² or for 75.9% (Table 3). As a result, the overall gross income from basil production grew from \$133.8 m² of greenhouse space in 2003/2004 to \$184.0 m² of greenhouse space in 2004/2005 and to \$236.2 m² of greenhouse space in 2005/2006. In other words, the gross income from basil production almost doubled for the period of two years without additional investments.

This result could be partially explained by the improved practice in 2004/2005 compared to 2003/2004. However, there was no a significant change in production protocol in 2005/2006 compared to 2004/2005. The growth in basil production also could not be explained by better nutrient supply as EC and the level of the major nutrients was maintained on approximately the same level (Figure 7 and 8). Therefore, it has been suggested that an additional factor could be involved rather than improved nutrient supply. In order to test this hypothesis, an artificial aquaponics solution containing the same level of mineral nutrients was used for model experiment.

Figure 5. Production of basil in pre-commercial aquaponics facility at CDC South.



Figure 6. Gradual increase of basil, cv. Genovese, production in aquaponics in 2003-2004. The yield is expressed in kg m^{-2} of trough area.

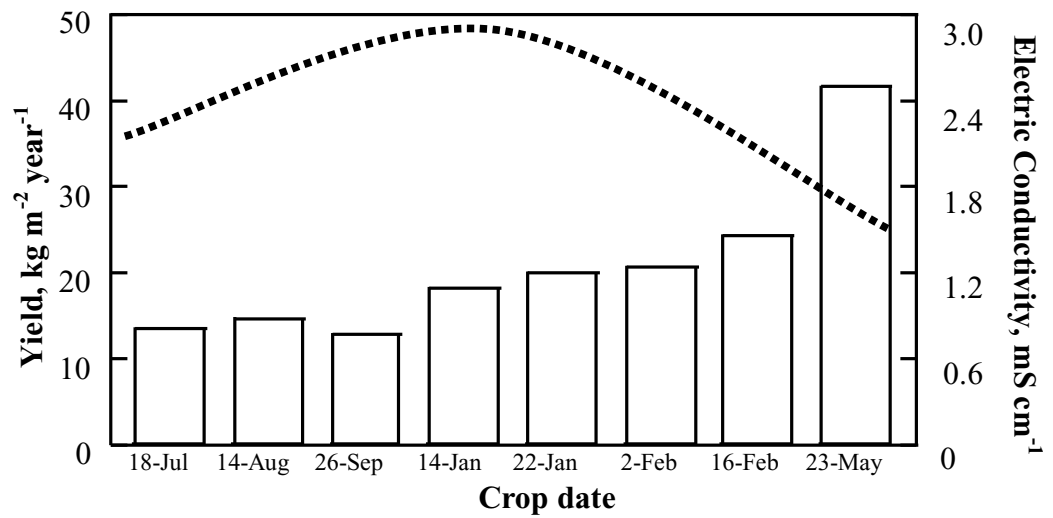


Table 2. Basil, cv. Genovese, production in aquaponics and gross return in 2004/2005 fiscal year. The yield is expressed in kg m⁻² of greenhouse area.

Trough #	Yield kg/m ²	SE	Gross return per year \$/m ²	S
1	10.5	0.7	161.5	11.3
2	12.6	0.5	194.1	8.2
3	13.4	0.5	205.8	8.0
4	11.3	0.5	174.7	7.9
Average for 2004-2005	11.9	0.6	184.0	9.9

*Standard Error (SE)

Table 3. Basil, cv. Genovese, production in aquaponics and gross return in 2005/2006 fiscal year. The yield is expressed in kg m⁻² of greenhouse area.

Trough #	Yield kg/m ²	SE	Gross return per year \$/m ²	S
1	14.3	0.5	220.7	8.4
2	15.4	0.5	237.7	7.2
3	17.7	0.8	272.0	11.7
4	13.9	0.6	214.6	9.8
Average for 2005-2006	15.3	0.8	236.2	12.9

*Standard Error (SE)

Figure 7. Levels of accumulated macro-elements in aquaponics solution compared to standard hydroponics solution for production of greenhouse cucumbers.

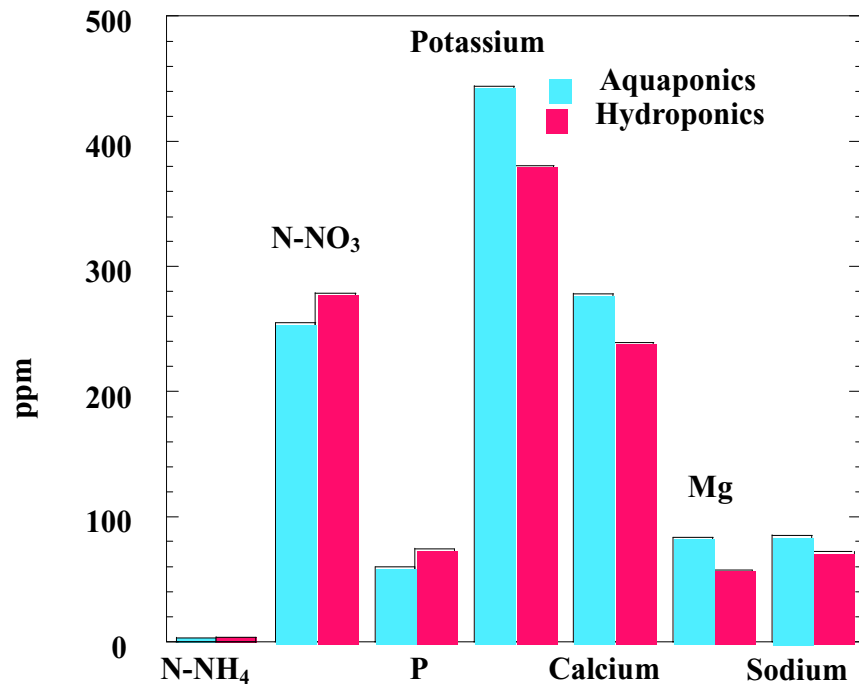
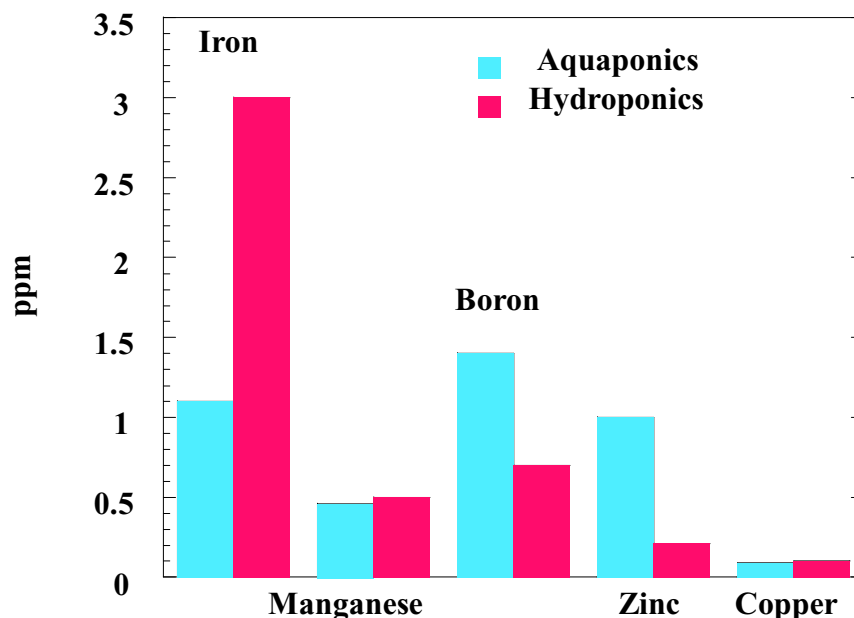


Figure 8. Levels of accumulated micro-elements in aquaponics solution compared to standard hydroponics solution for production of greenhouse cucumbers.



3.1.2.2. Fish production

The fish production was monitored through fish sampling every second week showing a steady increase in biomass production close to target levels (Figure 9). The fish mortality dramatically decreased compared to the same period in 2003/2004 indicating the stabilization of water quality due to well developed bacterial microflora oxidizing ammonium to nitrate. Analysis of water quality showed ammonium level less than 3 ppm during reported period. Better water quality and feeding practices led to a higher average of fish biomass at harvest and higher Food Conversion Ratio, FCR, compared to 2003 (Figure 10 and Table 4). Fish biomass increased for 28% from 0.50 kg to 0.64 kg. The average gross return \$1916 per harvest (Table 4). Higher return from fish sales provides a stable second income to aquaponics growers and contributes to economic feasibility of stand-alone aquaponics in Alberta.

Relatively high fish mortality in 2003/2004 was attributed to poor quality of fingerlings and lack of adaptation period of fresh fingerlings to aquaponics conditions (Savidov 2004). Therefore a hatchery was built using rhizofiltration principle in 2005 (Figure 2). The growth rates of the fish-fry was enough to provide a steady supply of 100 g fish to the large aquaponics facility. As a result, there was no fish mortality observed when the fingerlings were transferred to the larger facility.

Figure 9. Fish productivity in Brooks Aquaponics Facility.

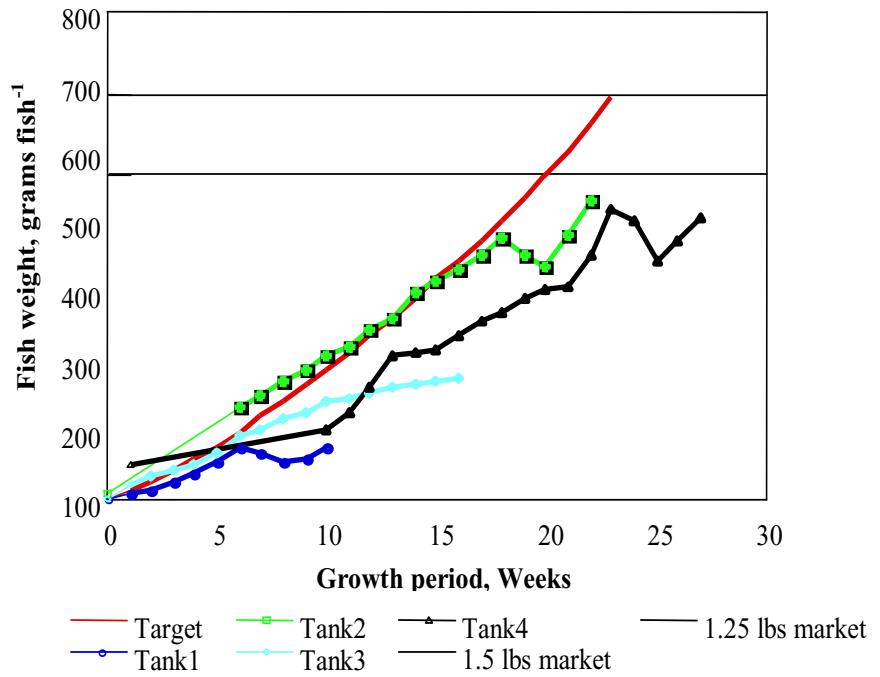


Figure 10. Fish production rate 2003.

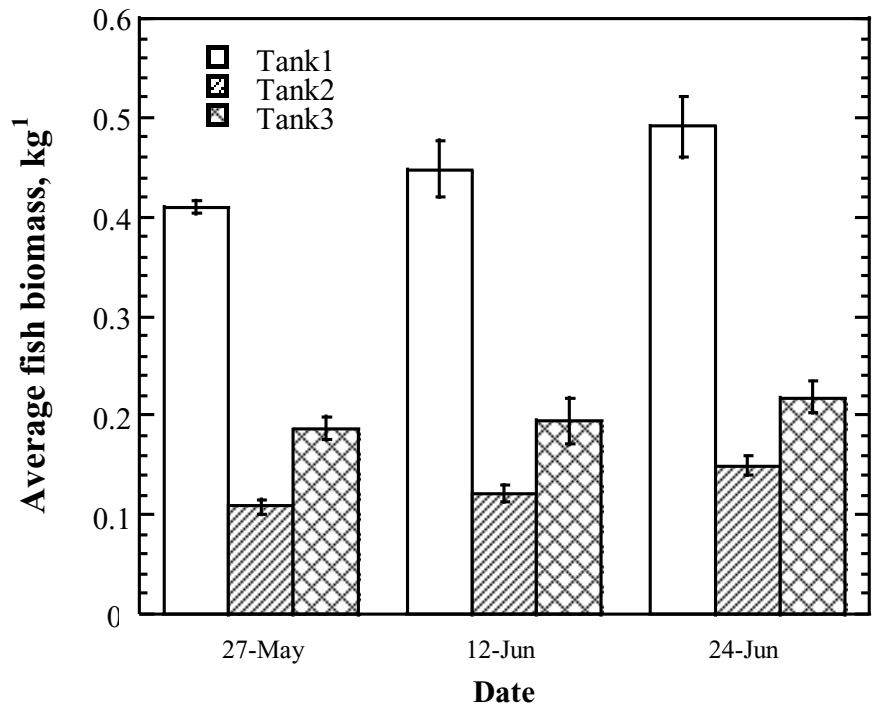


Table 4. Production and gross return of tilapia in 2004/2005.

Tilapia harvests	Fish number	Average lb (kgs)	Total weight lbs (kgs)	Production kg/m ³	Gross return \$
1	550	1.40 (0.63)	769 (348.8)	64.6	1768.7
2	601	1.47 (0.66)	881 (399.6)	74.0	2026.3
3	578	1.53 (0.70)	887 (402.3)	74.5	2040.1
4	629	1.26 (0.57)	795 (360.6)	66.8	1828.5
Average	590	1.42 (0.64)	833 (378.0)	70.0	1916.0
Standard Error	16.8	0.06 (0.03)	29.9 (13.6)	2.5	68.9

3.1.2.3. Comparison of water use efficiency in hydroponics and stand-alone aquaponics systems

Hydroponics is far more efficient in water usage than field crop production due to minimum wastage of water and nutrients delivered by means of drip irrigation system (Table 5, (Smith 2005).

Table 5. Water use efficiency in agriculture.

Agricultural sector	Liters of water per \$100 of output
Rice	470,000
Cotton	160,000,
Dairy-milk	147,000
sugar	123,900
Beef cattle	81,200
Vegetables	37,900
Wheat and grain	24,500
Hydroponic crops	As low as 600

A negligible amount of water is removed from the system with solids in aquaponics system. For example, about 15 liters are removed every day from a system containing 71,000 liters, comprising about 0.02%. Water loss through evapo-transpiration will be the largest in aquaponics. However, it rarely exceeds 0.7% a day in greenhouse conditions in Alberta. Calculation show 497 liters of daily loss or 181.4 cubic m annually + 5.4 cubic m removed with solids. With average gross revenue of \$47,440 (\$11,040 from tilapia sales and \$36,400 from basil sales) means a 394.3 liters per \$100 of output, which is for 65.7% more efficient than in the best hydroponics systems (Table 5).

Most common soilless technologies for vegetable production are based on the use of solid substrates such as rockwool, peat, perlite, coir, etc. In open hydroponics systems, which make most of commercial hydroponics operations, water and nutrients are lost from the 25%-40% overdrain. This means a grower has to apply 25%-40% more nutrient solution beyond the plant needs in order to maintain appropriate concentration of salts in the root zone. The main reason for

increase of salt concentration in the root zone is that the plants use water faster than nutrients. The remaining salts should be washed out by excess of nutrient solution in order to prevent inhibition of root growth. It is a serious problem for the industry, especially, in the areas with high concentration of greenhouse operations. The environmental impact can be high. Therefore, cutting down the water and nutrient wastage from overdrain is one of the most urgent problems arising from expansion of the industry during the last decade. Most advanced hydroponics facilities use recirculation technology, which allows cutting down the wastage of water large using collecting tanks for the leachate. The solution in the collecting tanks is then re-supplied to the plants along with the fresh nutrient solution. However, diseases and unbalanced nutrient composition are among the major obstacles for wider adoption of the recirculation technology. Accumulation of toxic organic compounds, such as phenols, is another challenge for long term recirculation system in hydroponics (Politycka and Wojcikwojtkowiak 1991; Kreij, Runia, and Burg 2004)

However, even with recirculation technology, the solution has to be partially or completely removed from the system on regular basis. Aquaponics represents an example of recirculation system for greenhouse crop production, which does not require renewal of the recirculating nutrient solution. This result cannot be achieved with any other existing hydroponics technology including recirculating bagged hydroponics; nutrient film technique, NFT; deep flow technique, DFT; or aeroponics.

The present study revealed that the key difference between aquaponics and other known recirculation hydroponics systems is the absence of observed toxicity of accumulated organic compounds on plant growth. Moreover, since the stimulating effect of aquaponics solution was observed only after extended period of approximately one-and-a-half years, it is hypothesized that the organic compounds accumulated in the old aquaponics water were important for growth of beneficial bacteria. This phenomenon needs to be studied so the results could be implemented in recirculation hydroponics systems.

3.2 Comparative study of aquaponically and hydroponically grown plants in model system

Objectives:

- 1.Design a model system for comparative study in order to determine effect of organic component of aquaponics solution on growth and development of greenhouse plants;
- 2.To study effect of aquaponics solution on plant shoot and root yield of six greenhouse crops.

3.2.1. Materials and methods:

3.2.1.1. Plant material

Six plants were selected for comparative study based on their commercial importance and their difference in relative growth rates. Plant species included (in the order of increasing growth rate): Echinacea, rosemary, lettuce, basil, tomato, and cucumber.

The seeds of cucumber cv. Alamir; tomato cv. Clarence; basil, cv. Genovese; lettuce, cv. Redoak, Atlantis, and Concord; and *Echinacea angustifolia* were

planted in medium size rock wool plugs in growth chambers on different dates. The cucumbers and lettuce plants were one week old; tomato, basil and *Echinacea angustifolia* were three weeks old, and the rosemary cv. Rex cuttings were rooting for four weeks at transplanting. Seeds of *Echinacea angustifolia* and cuttings of rosemary were obtained from CDC South.

The plugs with seedlings were placed onto 35 L plastic tanks lined with plastic liner, and each tank was provided with air through glass rods with attached plastic diffusers (Figure 11). Each tank had a Styrofoam raft with 6 holes of 5 cm diameter size cut in each raft. Six plants per tank were transplanted. The plants were grown in the greenhouse at an air temperature of 22-25°C, an irradiation level $\geq 300\text{-}500 \mu\text{mol photons m}^{-2} \text{sec}^{-1}$ photosynthetically available radiation (PAR), and a 16:8 day:night photoperiod provided by natural and artificial lights.

The treatments included aquaponics solution obtained from pre-commercial aquaponics facility at CDC South and made-up hydroponics solution containing the same levels of macro- and micronutrients. The aquaponics solution has never been changed during two years of operation of the facility and contained significant level of organic soluble material. Each treatment was replicated five times and experiment was setup in a completely randomized design. Cucumber, tomato and basil plants were grown for one month, and rosemary plants were grown for two months.

3.2.1.2. Preparation of hydroponics solution for comparison trials

To prepare comparable hydroponics solution, the concentration of various elements was determined in the aquaponics water, hydroponics solution was prepared using the salts given in Table 6. The hydroponics and aquaponics solutions were added in plastic tanks. The solution volumes were kept constant by adding distilled water on daily basis, and pH was monitored and adjusted to 6.2.

The aquaponically-grown lettuce were compared with plants grown on standard hydroponics solution (Table 7).

Figure 11. Setup of the experiment for comparative study of aquaponically grown plants.

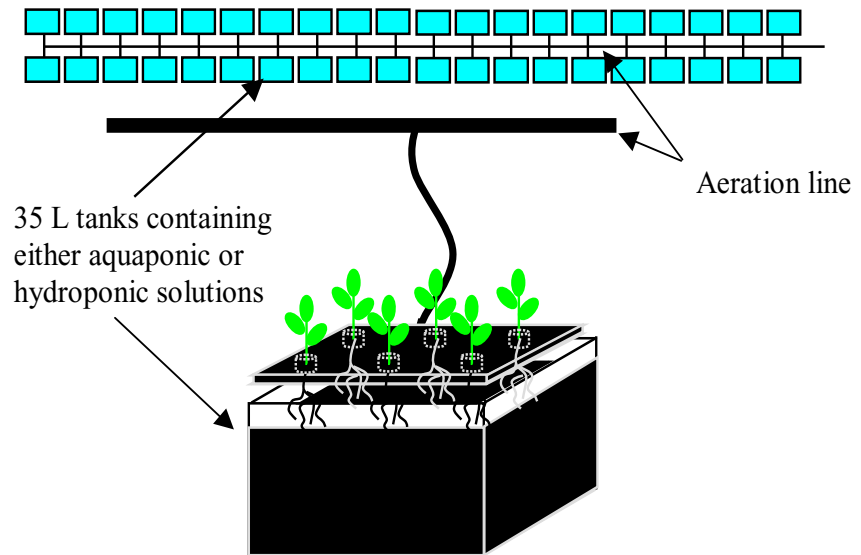


Table 6. Nutrient composition of comparable hydroponics nutrient solution.

Element	Determined concentration (ppm)	Salts used
Ca	85	Ca(NO ₃) ₂
N	124	KNO ₃
K	249	K ₂ SO ₄
P	35	Na ₂ HPO ₄
Mg	56	MgSO ₄ ·7H ₂ O
Na	94	NaSO ₄ ·7H ₂ O
Cu	0.34	Chelate
Zn	1.3	Chelate
Fe	6.4	Chelate
Mn	1.1	Chelate
B	2.8	Na ₂ B ₄ O ₇ ·10H ₂ O

EC 1.7 mS cm⁻¹
pH 6.2

Table 7. Nutrient composition of a standard hydroponics solution used in lettuce experiment.

Element	Determined concentration (ppm)	Salts used
Ca	135	Ca(NO ₃) ₂
N	158	KNO ₃
K	217	K ₂ SO ₄
P	44	Na ₂ HPO ₄
Mg	49	MgSO ₄ ·7H ₂ O
Cu	0.07	Chelate
Zn	0.13	Chelate
Fe	2.1	Chelate
Mn	0.35	Chelate
B	1.19	Na ₂ B ₄ O ₇ ·10H ₂ O

EC 2.2

pH 5.8

3.2.1.3. Water sample collection and analysis

Hydroponic and aquaponics water samples were collected every third day for the first week and every second day during the rest of the sampling period from each container, a total of 360 samples were collected. The water samples collected will be analyzed for the macro- (N-NH₄, N-NO₃, PO₄, K, Ca, Mg, Na, SO₄, Cl) microelements (Fe, Mn, Zn, B, Cu, Mo).

3.2.1.4. Plant sample collection and analysis

Plant samples were collected before transplanting and after the experiments were completed. The samples were analyzed for macro- (N, P, K, Ca, Mg, and Na) and microelements (Fe, Mn, Zn, B, Cu, Mo).

The experiment was repeated twice, with the exception of the rosemary plants, which were continued into the second experiment.

3.2.2. Results and discussion

The idea of the model experiment was to exclude mineral salts as a factor controlling plant production in aquaponics and answer a question: “Is an unknown component of organic nature responsible for enhanced plant growth in aquaponics, rather than mineral component?” To answer this question, the contents of all major minerals were determined in the aquaponics solution. A hydroponics solution containing the same levels of nutrient was made using pure mineral salts (Table 6).

The content of nutrients in “artificial aquaponics” solution was verified by independent analysis, which turned out to be nearly identical to content in the sampled aquaponics solution ($\pm 5\%$) (data not shown). Five crops (cucumber, tomato, basil, rosemary, Echinacea) were grown in aquaponics and hydroponics nutrient solutions in the system described in Materials and Methods (Figure 11) in order to determine if the observed effect of aquaponics water was plant-specific. Lettuce was grown on aquaponics solution and a standard hydroponics solution used in the industry.

In the beginning of the model experiment, aquaponically produced plants attained a higher relative growth rate for both roots and shoots compared to plants grown hydroponically under non-limiting nutrient conditions. Root biomass was especially affected.

Basil attained significantly greater height (35 vs. 30 cm), shoot weight (301 vs. 226 g) and root weight (111 vs. 68 g) in aquaponics nutrient solution compared to hydroponics nutrient solution, respectively (Table 8). Similar results were obtained for rosemary (Figure 12), cucumber (Figure 13), and tomato.

The root diameter of Echinacea in aquaponics nutrient solution was 3.9 mm compared to 2.0 mm in hydroponics nutrient solution (Figure 14). Respective shoot and root weights of Echinacea were 2.4 and 1.3 g in aquaponics nutrient solution compared to 1.0 and 0.7 g in hydroponics nutrient solution. EC and pH was monitored in the course of the experiment.

It has been observed that attaining higher plant biomass was concomitant to faster drop in EC (data not shown). Since only soluble mineral component contributes to water EC, it has been concluded that mineral component were depleted faster in aquaponics nutrient solution than in hydroponics nutrient solution in the beginning of the experiments. The faster depletion of the mineral component in aquaponics system stipulates faster nutrient uptake by aquaponically grown plants compared to those grown hydroponically. However, the faster depletion of nutrients led to growth inhibition and, finally, to a complete stop in the growth if the plants were allowed to deplete the solution. In the end of the experiment, the plant biomass in both aquaponics and hydroponics treatments was nearly identical indicating no difference in initial nutrient contents between the treatments.

A different setup was used in the experiment with lettuce plants, where standard hydroponics solution was used instead of “made-up” hydroponics solution based on analysis of aquaponics solution (Table 7). In the last case, EC and mineral salts were higher in the hydroponics solution compared to aquaponics solution. In spite of the richer mineral content, aquaponically grown plants attained higher biomass, than hydroponically grown plants (Figure 15). However, the final biomass was higher in hydroponics, when the nutrient solution was allowed to deplete. The experiment was conducted with three different varieties of butterhead lettuce. The experiments were repeated with the same results.

Thus, one may assume that the plants grown on aquaponics consumed nutrients faster in the conditions of unlimited nutrient supply. As the result, they accumulate higher biomass for the same period of time. The plants grown in hydroponics accumulate similar biomass, but two-three weeks later. This means that the aquaponics plants will have earlier start of production period (Figure 16), which can benefit commercial growers due to higher wholesale prices. This assumption was confirmed by the observation that aquaponically grown lettuce plants started flowering for at least one week earlier compared to hydroponically grown plants. Cucumber and tomato plants flowered up to 5-10 days earlier in aquaponic solution compared to hydroponics solution.

This study indicated that there was a factor stimulating nutrient uptake and assimilation by plants grown in aquaponics solutions, where nutrients and many organic compounds were derived from fish feed. It was hypothesized that plant growth promotion resulted from the interaction of nutrients, organic compounds and bacteria.

The phenomenon of plant growth stimulation is well known in plant science and it is attributed to Plant Growth Promoting Rhizobacteria (PGPR) (see published reviews: (Alka, Murali, and Tilak 2000; Cordier, Lemoine, Lemanceau, Gianinazzi-Pearson, and Gianinazzi 2000; Loredo-Osti, Lopez-Reyes, and Espinosa-Victoria 2004; Mantelin and Touraine 2004; Gray and Smith 2005). The stimulatory effect has been observed on many crops including canola and the bacteria will be isolated and identified (Bertrand, Nalin, Bally, and Cleyet-Marel 2001). PGPR promote growth through:

- Nitrogen fixation
- Phytohormone production
- Improving plant mineral nutrition
- Suppression of plant pathogens

In soilless culture the effect of indigenous bacterial communities on suppression of plant pathogens including *Pythium* and *Fusarium* has been studied previously (Postma, Willemsen-de Klein, and van Elsas 2000; Folman, Postma, and Van Veen 2001). Genuses of bacteria found to have stimulating effect on plant growth included *Azospirillum*, *Azoarcus*, *Pseudomonas*, *Bacillus*, *Delftia*, *Phyllobacterium*, and *Achromobacter*. In one of the studies, the evaluation of the indigenous microorganisms in soilless culture based in different greenhouse substrates was conducted (Koochakan, Ikeda, Jeanaksorn, Tojo, Kusakari, Okada, and Sato 2004). In this study, the results indicated the unique indigenous microorganism population in each soilless system. Also, it revealed that aerobic bacteria could be dominant over fungi in inorganic substrate culture. With further research of beneficial microorganisms to horticultural plants, biological control with reduced fungicide application in soilless culture would be feasible.

It has been assumed that stimulatory effect of Plant Growth Promoting Rhizobacteria in aquaponics is the first reported example of the phenomenon observed in hydroponics conditions. They have a potential to decrease level of agro-chemicals applied for crop production. Thus, PGRB can be an important factor of environmentally sustainable agriculture.

Figure 12. Accelerated growth of rosemary in aquaponics solution compared to hydroponics solution: plain view, A; shoots, B; and roots, C.

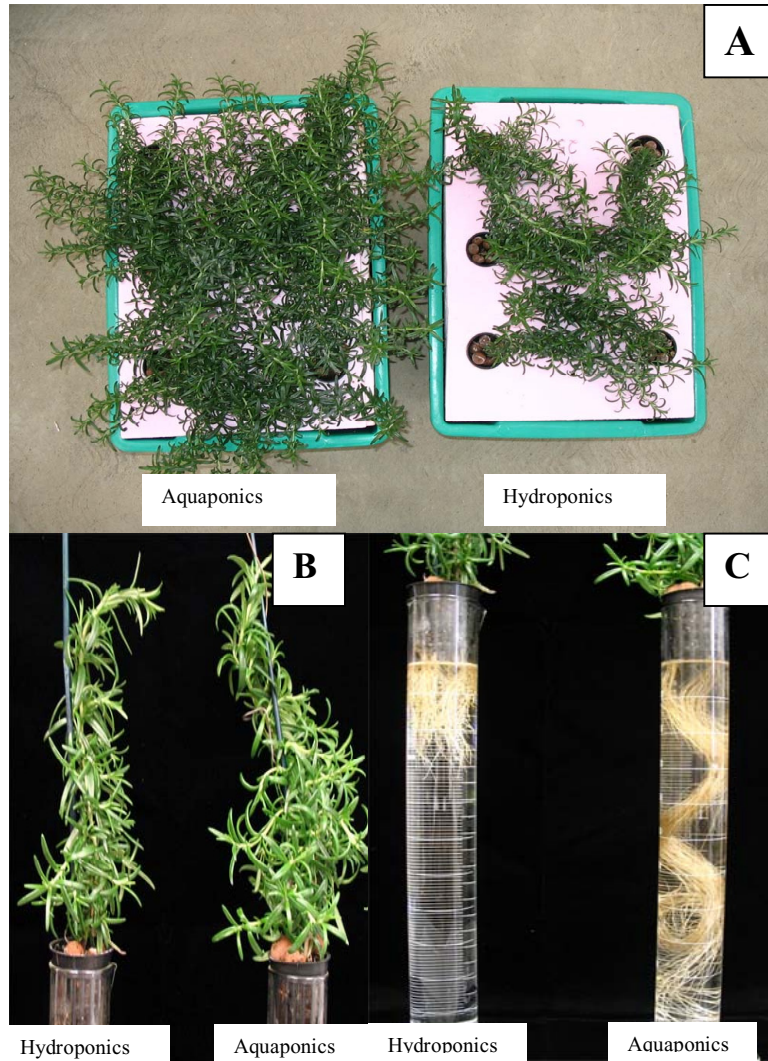


Figure 13. Accelerated growth of cucumbers mini, cv. Alamir, in aquaponics solution compared to hydroponics solution.

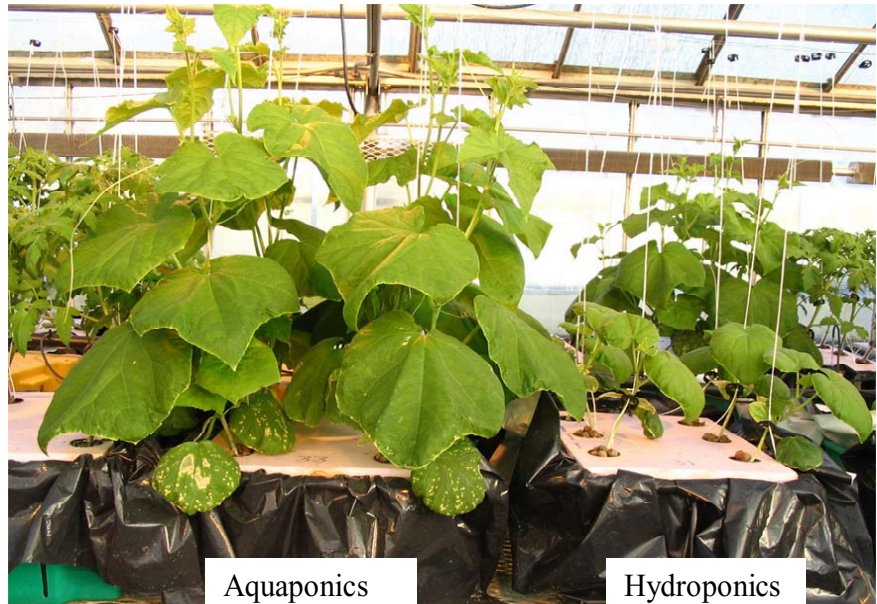


Figure 14. Accelerated growth of Echinacea angustifolia in aquaponics solution compared to standard hydroponics solution.



**Root diameter
2.0 vs 3.9 mm**

**Root biomass
0.7 vs. 1.0 g**

Figure 15. Accelerated growth of three variety of butterhead lettuce in aquaponics solution compared to standard hydroponics solution.

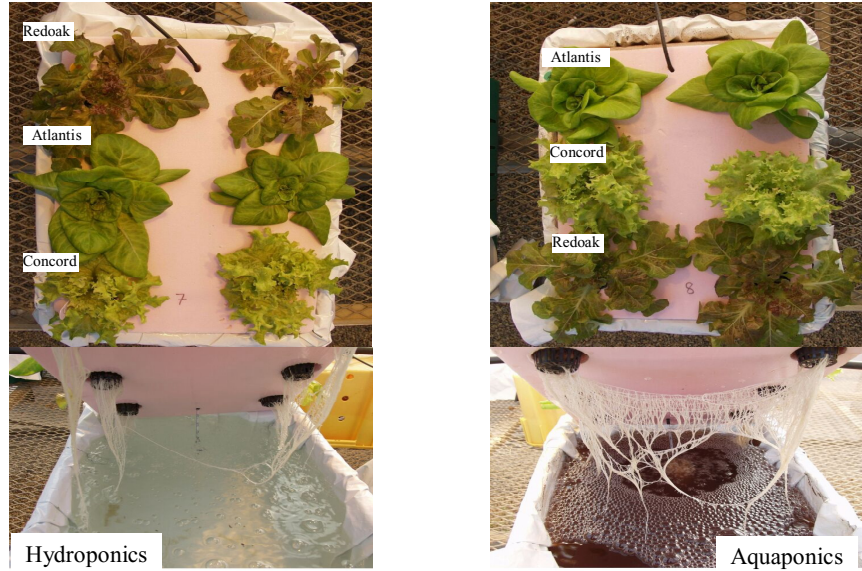
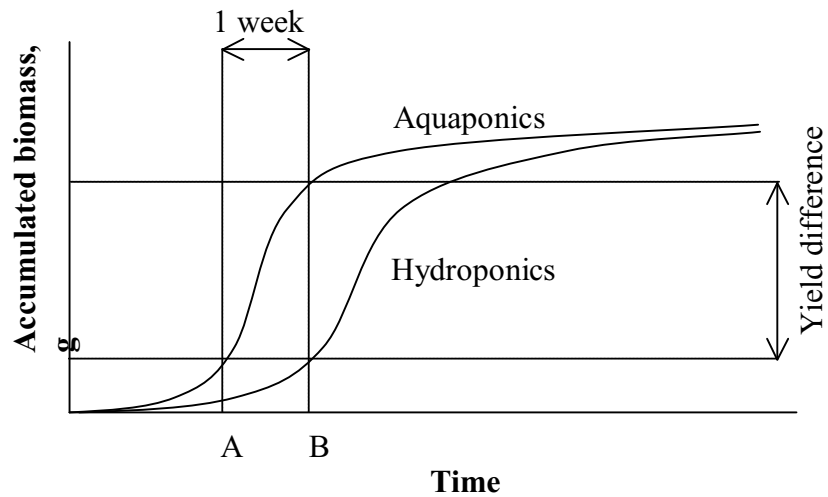


Table 8. Plant growth of four crops in hydroponics and aquaponics nutrient solutions.

Crop Plant	Hydroponic			Aquaponic		
	Height (cm)	Shoot (g)	Root (g)	Height (cm)	Shoot (g)	Root (g)
Basil	30	226	68	35	30	11
Rosemary	31	141	119	35	22	29
Cucumber	138	1180	219	156	1580	27
Tomato	110	1616	198	114	1841	27

Figure 16. Effect of aquaponics and hydroponics solutions on the plants relative growth rate.



A – start of production for aquaponics
 B – start of production for hydroponics

3.2.3. Future Research

To investigate the nature of the stimulating effect on plants: bacteria or chemical or both and introduce the isolate into a hydroponic system to evaluate the impact on greenhouse crops production.

The greenhouse industry in Alberta faces increasing market challenges from the emerging Mexican and US greenhouse industries. In addition to market challenges, high natural gas prices have resulted in reduced profit margins for greenhouse growers. In order to stay on the competitive edge, new approaches have to be developed to increase crop productivity per square meter of greenhouse space in Alberta.

Over the last two years, we demonstrated a stimulating effect of aquaponics water on plant growth, which promoted early crop development attributed to Plant Growth Promoting Rhizobacteria. Early crop production is estimated to bring additional \$10-15 million dollars in revenues to the growers due to higher prices in early season.

Long English cucumbers dominate the Alberta greenhouse vegetable crop production with a staggering 65% of total acreage. It has been suggested to use this crop for future research involving Plant Growth Promoting Rhizobacteria. Economic analysis shows that break even point for greenhouse cucumbers is 100 cucumbers per square meter at the existing gas price. Since an average productivity of long English cucumbers in Alberta is close to this value, the industry will not be economically viable if the productivity is not improved for by at least 10%.

Recent results produced in aquaponics culture indicate that the productivity of greenhouse crops grown in soilless conditions can be significantly improved using specific Plant Growth Promoting Rhizobacteria. The root biomass will be increased by two or more times, leading to increased upper biomass productivity of 20%-30% translating to higher cucumber yield.

An increase in productivity from 100 to 120 cucumbers doubles the profit margins and ensures at least \$10 million cash flow to greenhouse growers. Earlier crop production is essential for the industry to stay competitive as the prices are high in early season and to replace imported produce. The wholesale price for a case of large size long English cucumbers dropped from \$17.94 in February to \$7.03 in April 2005. Thus, the shifting the production season to the earlier date using the bacteria alone will be translated to additional \$2-4 million of gross revenue in the greenhouse industry per year.

Objectives:

1. To isolate and identify Plant Growth Promoting Rhizobacteria from rhizosphere of plants grown aquaponically, and from aquaponics solution;
2. To develop a biotest to study effect of Plant Growth Promoting Rhizobacteria on plant growth;
3. To demonstrate the plant growth promoting effect of isolated bacteria in model in vitro experiments;
4. To develop pilot scale method for Plant Growth Promoting Rhizobacteria application in commercial greenhouse conditions.

Deliverables:

1. Methods for isolating and propagating Plant Growth Promoting Rhizobacteria for hydroponics culture;
2. Specific Plant Growth Promoting Rhizobacteria strains, which can improve plant growth and crop productivity;
3. Methods of Plant Growth Promoting Rhizobacteria application in commercial greenhouse conditions;
4. Extension and scientific publications for the greenhouse industry;
6. Higher productivity of greenhouse crops in Alberta at the same cost of production
7. Improved competitiveness of the greenhouse industry in the domestic and export markets

Aquaponics as a Seasonal Add On to an Existing Warm Water Re-circulating Aquaculture Operation

Penny Takahashi, Ryan Meaver, and John Derksen

3.3.1. Introduction

The Lethbridge Aquaculture Centre of Excellence uses 95,000 liters of water in the recirculating unit that supports the aquaponics greenhouse. The water in this circuit passes through the greenhouse growth trays 2.5 times a day. Of the 95,000 liters in this circuit, 2500 to 5000 liters are replaced/added. The plant roots act as a bio-filter that provides surface area for the bacteria (*Nitrosomas* and *Nitrobacter*) that convert ammonia to nitrate.

The ACE Aquaponics facility is not operated year round due to the high costs of heating and short and low light levels in the winter months, the aquaponic greenhouse is not operated for approximately three months, from early November through mid February. Because the aquaponic facility is not operated on a year round basis, cucumbers are seeded every four months within the operating season to provide two cycles while tomatoes are seeded only once during the growing season.

The production of vegetables within the Lethbridge Community College Aquaculture Centre of Excellence demonstrates to fish farmers the potential for growing produce using aquaculture effluent. Many people on tours within the facilities were impressed with the technical knowledge in recycling between the fish and the plants to maximize growth in vegetable production.

Objectives:

- Evaluate vegetable production in an aquaponics system as an add on to an existing warm water aquaculture facility
- Marketing evaluations, and complete interim economic evaluations.

3.3.2. 2003 Study

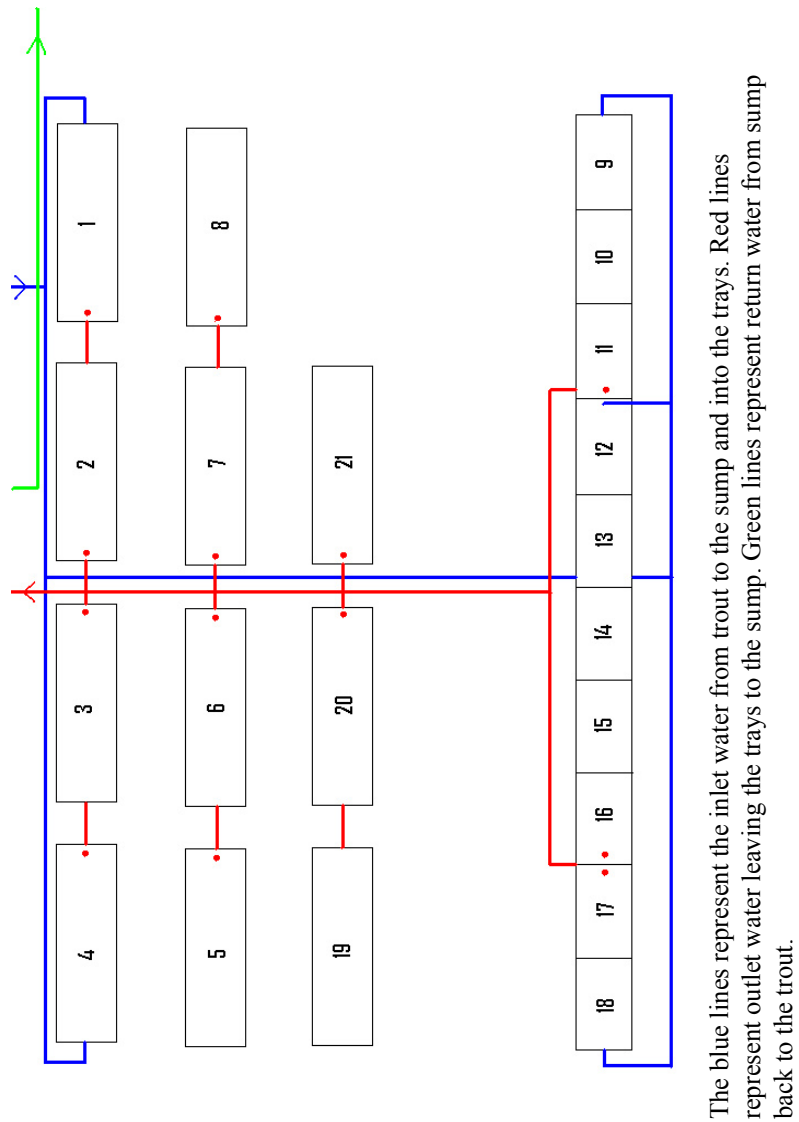
3.3.2.1. Materials and methods

The Aquaculture Center of Excellence greenhouse is 30' wide by 90' long. The facility houses 21 trays of 3 different sizes. All of them are equipped with 5 cm (2") thick Styrofoam sheets that float in the water and hold the plants in position. There are 10 trays on the north wall of the greenhouse (#s 9-18), which are 244 cm x 56 cm and 10 cm deep (8' x 2' x 4"), these trays are the smallest in size and are elevated three feet off the ground. Nine of these 10 trays have 33 potting holes in their styrofoam sheets that are 5.08 cm in diameter. Tray #10 has 6 potting holes that are 15.24 cm in diameter. The 8 trays on the south side of the greenhouse, numbered 1 through 8 are 487 cm x 122 cm x 11 cm (16' x 4' x 4"), 4 of the trays on the south wall are also raised 3 feet. The remaining 4 trays are on the gravel floor of the greenhouse. There are three trays 487 cm x 122 cm x 15 cm deep (16' x 4' x 6"), numbered 19 through 21 in the middle of the greenhouse that are also located on the ground. All of these 11 hydroponics trays have 20 holes per tray that are also 15.24 cm (6") in diameter. These 21 hydroponics trays to yield 78.9 square meters of growing area. (See Figure 17).

Up to 100g of fish food daily will sustain 1 square meter of plant area (Eric Hutchings). In 2003 the fish, grass carp, that supported the aquaponics facility were fed 8 kg of food daily. The total number of grass carp in the Aquaponics system ranged from 3200 to 6000 five to sixteen inch fish. This number fluctuated due to sales, grading and mortalities.

In this study 3 cultivars of cucumber; long English, Alamir and gherkin and 4 cultivars of tomato; Chloe, New Yorker, pear and grape were grown. Plants were seeded in growth chambers and transplanted into the aquaponics system 20 to 30 days later. There were exceptions with the New York, grape and pear tomatoes; these plants were transplanted from soil into the system. Plants ranged from 30 to 50 cm in height when transplanted.

Figure 17. Diagram is a lay out of the large greenhouse at the Aquaponics Centre of Excellence.



3.3.2.2. Results and discussions

The greatest overall production in net weight was for cucumbers in general, and specifically gherkin (36.42 kg/m²) and English (24.6 kg/m²). The best tomato production was shown by New York (15 kg/wk/ m²) and Chloe, with about 12 kg/wk (Table 9). The most productive herbs were Basil and Dill, with 2.19 kg/wk and 0.29 kg/wk respectively.

Table 9. Aquaponics produce and their weekly harvest (in kg) for 2003.

Cucumber species presented in green, herbs in blue, and tomatoes in red. Data for cucumbers represents the production of the 2nd cultivar only.

	English	Mini-English	Gherkin	Basil	Thai Basil	Italian Parsley	Dill	Chives	Oregano	Chloe	New York	Pare	Grape
Date													
7/6			10.91										
7/13			50.26	10.07									
7/20	11.11		63.08							2.31		0.12	
7/27	17.63	3.46	58.53		0.29	0.33	0.34	0.03	0.21	12.20	2.76		0.15
8/3	20.75	2.41	27.95	2.86	0.52	0.52	0.12	0.21		12.85	21.84	0.22	0.54
8/10	18.10	25.05	42.72	0.03	0.08					23.22	17.72		0.69
8/16	26.99	34.45	48.12	0.04		0.01	0.02			13.04	26.39	0.34	0.89
8/23	33.80	27.73	18.97							17.23	9.92	0.06	0.86
8/30	39.04	26.87	22.86	1.19	0.02	0.01	0.03	0.01	0.01	10.35	13.99	0.66	0.31
9/6	35.58	41.47	30.07	0.93	0.10	0.06	0.07	0.01		2.67	14.06	0.18	0.73
9/11	18.29	25.40	27.14	0.21	0.21					4.46	14.33	0.31	2.73
Total	221.27	186.84	400.60	15.32	0.32	0.95	0.86	0.58	0.26	98.32	121.0	1.87	6.89
Mean	24.59	23.35	36.42	2.19	0.11	0.19	0.29	0.12	0.06	10.92	15.12	0.27	0.86

Cucumber

Trends in weekly production for cucumbers revealed that gherkins had rapid onset of production, with the greatest weekly production in the 2nd, 3rd and 4th weeks of harvest. Both English and Mini-English productivity increased gradually, peaking in the 7th week (Fig. 18). From an overall productive capacity (kg of product/plant) or (kg of product/area (m²)), English cucumbers were superior to both mini-English and gherkin (Fig 19 and 20). This productive capacity gradually increased peaking on the 9th week to 4.5 kg/plant and 9kg/m². Mini-English demonstrated a similar increase in productivity over the weeks, peaking to 5 kg/plant and 0.45 kg/m² in the eighth week. Gherkin production peaked in the 7th week, with 3 kg/plant and 1.55 kg/m².

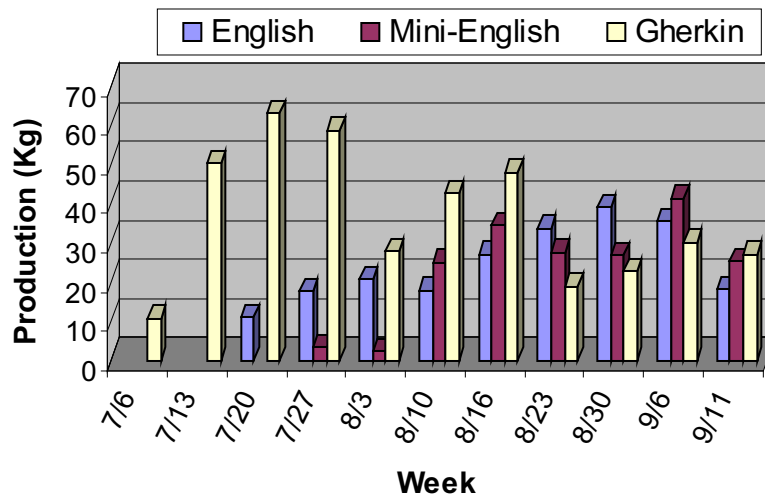


Figure 18. Weekly cucumber production for 2003 Aquaponics. All data represents the weekly harvest of the respective species taken from the 2nd planting of the season. The trend of productive capacity with respective cucumber cultivar using a Monday, Tuesday, and Wednesday harvest schedule and summing the three days harvest for weekly production is illustrated above.

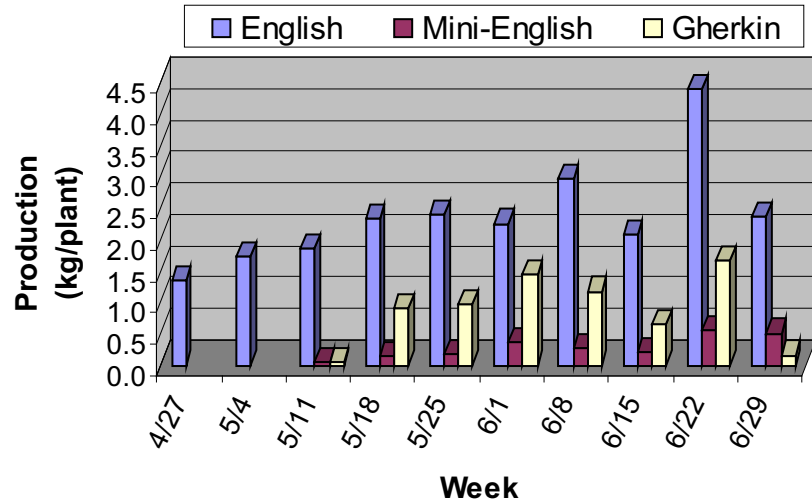


Figure 19. Relative plant productivity of cucumber cultivars in 2003. Data represents the weekly harvest of the 3 species of cucumber from the 1st planting of the season. Average weekly plant production: English – 2.36 kg/plant, mini-English – 0.28 kg/plant, gherkin – 0.88 kg/plant.

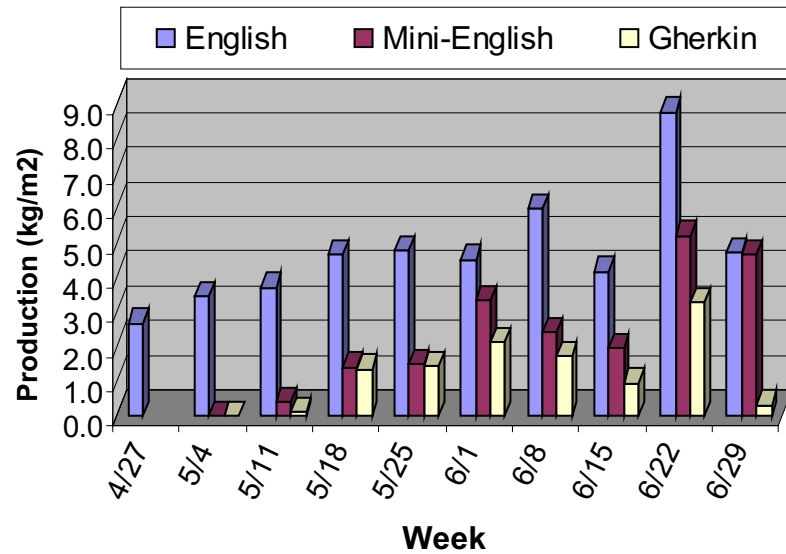


Figure 20. Relative aquaponics productivity of cucumber cultivars, in 2003, based on planted area. Data represents the weekly harvest from the 1st planting of the season.

Average size and weight of cucumbers harvested was determined for each cultivar and plotted in Figures 21, 22, and 23. Average size for English cucumbers was approximately 340 mm, mini-English 140 mm and gherkin 105 mm. No sizes were recorded for tomato harvest.

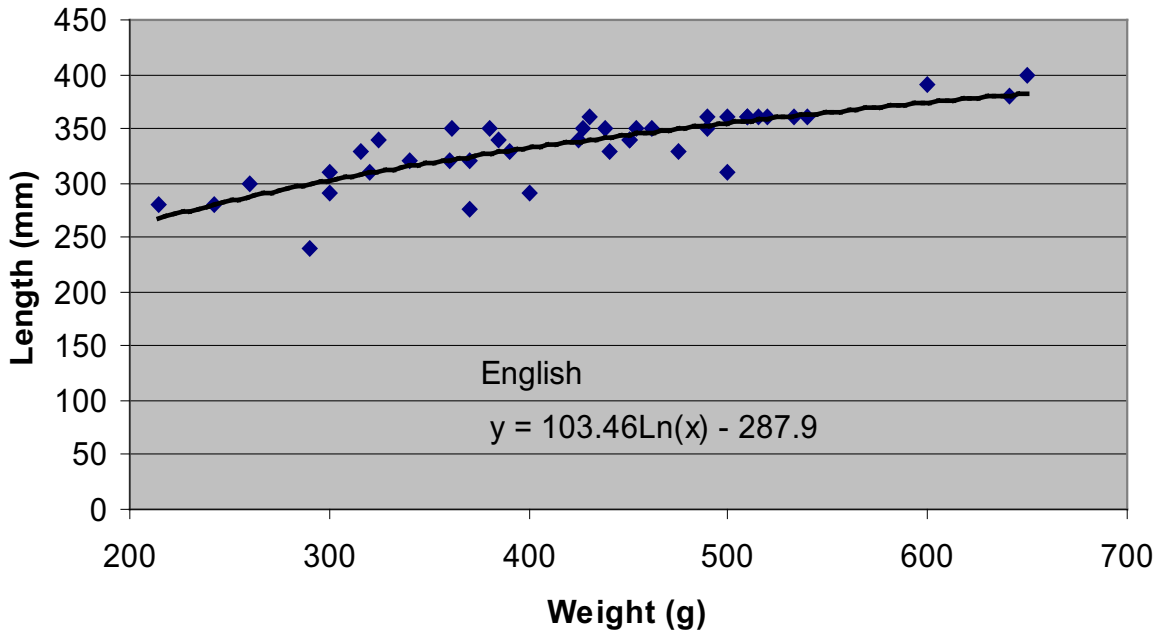


Figure 21. Relationship of length and weight for English cucumbers harvested in 2003, aquaponics.

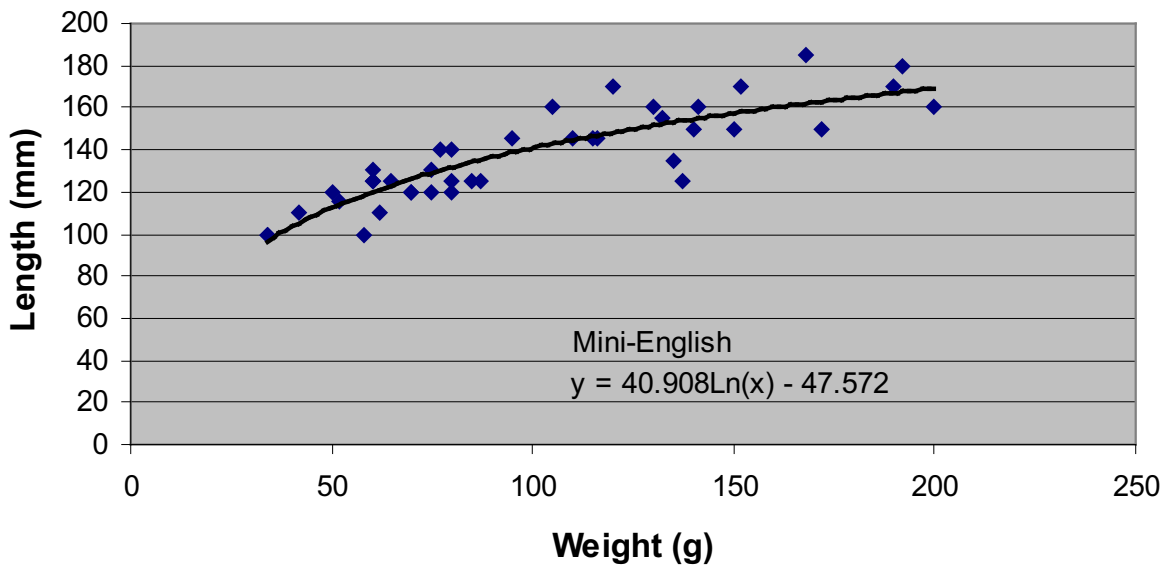


Figure 22. Relationship of length and weight for mini-English cucumbers harvested in 2003, aquaponics.

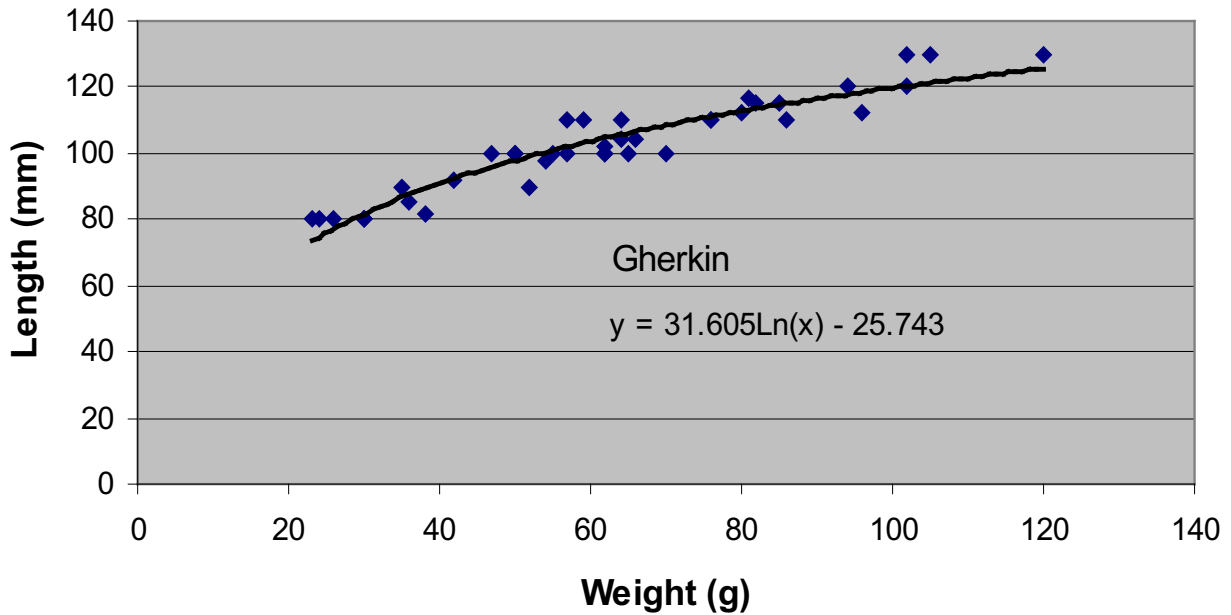


Figure 23. Relationship of length and weight for gherkin cucumbers harvested in 2003, aquaponics.

Tomato

Four varieties of tomatoes were tested for their productive capacity using aquaponics, New Yorker, Chloe, pear, and grape. Weekly tomato production revealed peak production was achieved in the 4th week for Chloe and New York species. High production of New York tomatoes was initiated quickly, with reduced, but stable production in later weeks (Fig. 24). Chloe tomatoes showed dramatically reduced production after about 7 weeks. Pear and grape tomatoes showed low and variable production over the production cycle (Fig. 24).

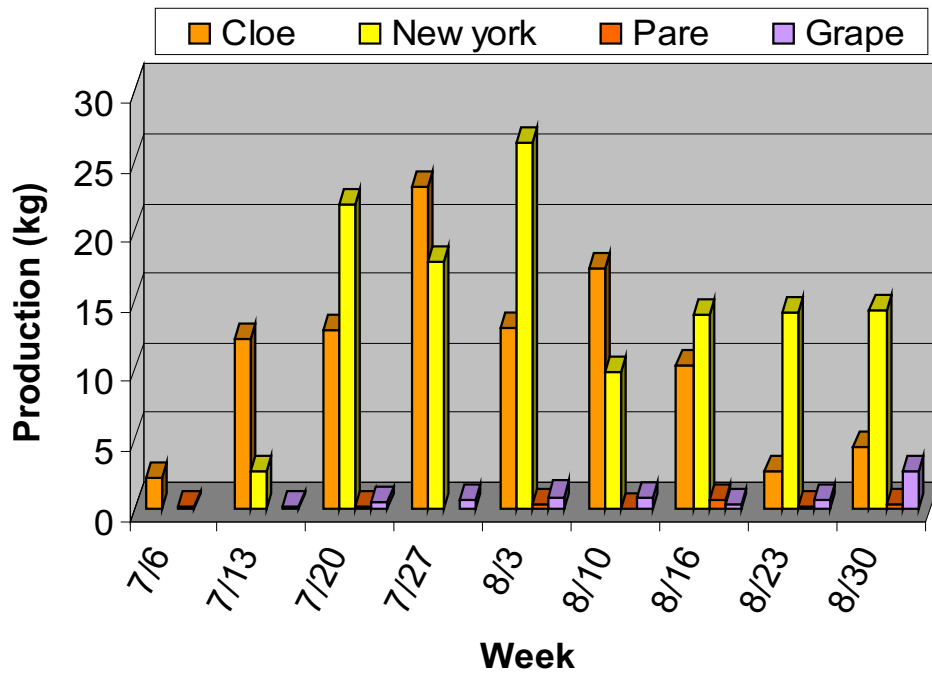


Figure 24. Weekly tomato production for 2003. Data represents production from the 1st planting of the season. Tomato cultivars/varieties were tested for feasibility in aquaponics for Southern Alberta greenhouses. Weekly harvest equals the total of a three harvests per week schedule (Monday-Wednesday-Friday).

Seeds for the first planting were started on the first of March 2003. Sixteen plants of two cultivars, English and mini English cucumbers were started. The English cucumbers were introduced into tray 8 of the system on the 22 of March, and the Alamir were placed into tray 7 on the same day. (See Figure 17).

On the first day of April 30 Chloe tomatoes and 15 gherkin cucumbers were seeded. The gherkin cucumbers were transplanted into the aquaponic system on April 15 into tray 6. Chloe tomatoes followed with 15 transplanted on the 22 of April into tray 1 and 15 on April 28 into tray 2. Four additional Chloe tomato plants were placed into trays 1 and 2 of the aquaponic system.

Fruit was harvested from the tomatoes and cucumbers bi-weekly on Mondays and Thursdays. The cucumbers were harvested from the plants at a range of lengths. English cucumbers were harvested at lengths of between 240 cm and 400 cm. Alamir cucumbers were harvested between 100 cm to 185 cm. gherkin cucumbers were harvested when they ranged from 80 cm to 130 cm long. Pear and grape tomatoes were harvested as soon as they became ripe. Chloe tomatoes were sampled between 45 cm and 70 cm diameter. New Yorker tomatoes were harvested at a range of 50 cm to 90 cm in diameter. Harvests were quantified by weight and numbers of fruited. Cucumbers and tomatoes were counted out and weighed in groups. Total numbers and weight were recorded for each sample date.

On May 7th 20 gherkin cucumber plants were seeded. 24 *Latin* New Yorker tomatoes were purchased from Dan's Greenhouse, Lethbridge, Alberta on the 16th of May. These tomatoes were transplanted from soil into trays 3 and 4 of our system, 12 in each. The 20 gherkin cucumbers that were seeded on May 7th were transplanted into tray 5 of the system on the 20th of May.

3.3.3. 2004 Study

3.3.3.1. Materials and methods

The dimensions of the large greenhouse and tray location were the same as in 2003 with no additions or renovations occurring within the 2004 season. The trays on the North wall were the same depth and length but varied with regard to the number of holes in the Styrofoam on the top due to the different types of plants grown in these trays during the 2004 season.

The amount of feed given to the fish differed as the number of rainbow trout ranged from 0 to 25,000 six to seven inch fish. This number fluctuated due to sales and mortalities due to mechanical failure.

The cultivars of study in 2004 were 4 types of tomato; Chloe, Clarence, Cherry, and Roma and 2 types of cucumbers, mini English and gherkin. Because ACE is seasonal facility, plant selection was based on their ability to grow fast and resist disease.

Plants were seeded in coconut base in trays and germinated under lights inside a heated building. After germination they were transplanted into 1" rock wool cubes. When they were large enough they were transplanted into rock wool within 6 inch baskets in the aquaponic greenhouse.

Long English cucumbers were started and transplanted into the aquaponic greenhouse but they were not grown for research purposes but rather for customer preference. Clarence tomatoes were started and transplanted into the aquaponic greenhouse to be used for research purposes.

The cucumber plants were 30 to 50 cm long before being transplanted into the aquaponic greenhouse. The long English cucumbers were held in water in trays for over a month before being transplanted into trays in the aquaponic greenhouse. They had to be strung up because of their rapid growth and the stalks did not become thick and sturdy as rapidly as other cucumbers.

Table 10. 2004 Seed and Transplant Dates.

Cultivars	Number	Tray #	Date Seeded	# of days from seeding to transplant	# of days from transplant to first day of production	# of days from first day of harvest to last day of production
Chloe	18	1	Feb 23/04	30	100	107
Chloe	18	2	Feb 22/04	16	91	116
Roma	40	3	Feb 9/04	42	91	119
Roma	40	4	Feb 9/04	40	87	124
Clarence	20	7	May 14, 04	31	67	56
Clarence	20	8	May 14/04	30	68	57
Cherry	106	5	Jan. 20/04	62	89	68
Cherry	20	6	Jan. 20/04	62	84	63
Cherry	20	7	Jan. 20/04	62	84	9
Cherry	20	8	Jan. 20/04	62	NA	NA
Gherkins	24	19	Apr 26/04	35	20	64
Gherkins	24	20	Feb 23/04	37	19	114
Gherkins	24	21	Feb 23/04	37	19	113
M. Eng.	20	19	Aug 4/04	21	28	31
M. Eng.	20	5	Aug 4/04	21	28	21

Table 10 displays the number of each plant species seeded and the tray in the greenhouse in which they grew. The number of days from seeding to transplant date is recorded for each plant species. The number of days from first harvest to last harvest for each plant species is recorded.

From the centre of the large greenhouse and towards the south, the ceiling is covered with a greenhouse shade cloth. The centre and North side is not covered. The water in the trays along the north wall had a consistently warmer temperature than the other trays.

Harvest methods varied. Harvesting occurred 3 times a week and decreased gradually to once a week depending on the rate of growth. The rate of growth was affected by amount of daylight hours, air and water temperatures, and nutrient levels. The research produce was weighed and measured and placed in plastic bags ready for market.

The seeds that were planted in the ACE greenhouse were a combination of commercial seed and retail seed. The commercial seed plants all developed healthy stalks and fruit. The cherry tomatoes were purchased in soil from Canadian Tire. Out of the one package, three different varieties were produced. Trays 5 and 6 showed three distinct varieties that were developing.

In a marketing survey completed by Lethbridge Community College, there is an

indication that the majority of those polled were interested in all natural produce and that a very high percentage indicated that having locally grown produce was fairly important or very important. In a recent report by Nick Savidov, Senior Biologist Brooks Crop Research Centre, Brooks, Alberta, he states, “that aquaponically grown produce did not contain the most common pathogens and had less chances of contamination than field grown produce.” (Savidov 2004).

3.3.3.1.1. Pruning

Several methods of pruning tomato plants were used to gain maximum production. The Chloe, Clarence, and Cherry are determinate tomato plants and secondary heads and extra branches that were not required for fruit bearing were removed. The plants were secured from the bottom by clips to a string that was tied along a ceiling tension wire. This provided some control in the direction of its growth. When the vines came within reach of the ceiling tension wire, the vines were laid down in a clockwise or counter clockwise direction.

The cherry tomatoes were extended over the ceiling heater and to the ceiling tension wire on the North wall. The shortest vine on the cherry tomatoes was 8 meters long and the longest was 10 meters long.

The Roma tomatoes were indeterminate and did not have a single head but grew branches in every direction. In pruning the plant, we tried to leave flowering branches and removed a portion of the branches that were not flowering to relieve the weight of the plant on the ceiling tension wire.

Long English, mini English and gherkin cucumbers were all pruned the same way. Clips attached the plant to a string that was tied to a ceiling tension wire. This provided the plants with direction and stability in its development. The cucumbers were pruned so that there were three arms per plant bearing produce. At the beginning of the study the number of fruit bearing arms varied.

Sweet basil and Thai basil were grown on the North wall in two separate trays. They were pruned so that the plant did not grow a single stalk but rather so that the plant would branch out thick and bush like. There were a total of 3 major harvests that were sold to a local restaurant and some smaller harvests for smaller scale sales.

3.3.3.1.2. Bio-Control

Bio-control was used to control pests within the aquaponics greenhouse. Five Richardson ground squirrels were caught within the greenhouse before April 19, 2004. After that date, no more Richardson ground squirrels entered the Aquaponics greenhouse facility. There was a dog on site after that date that was a deterrent to the Richardson ground squirrels.

April 21, 2004 the first aphids were recorded in the greenhouse. The main source of aphids appeared to be in the water Iris. In the beginning of the season, a mild soapy solution was used to spray the aphids. Fifty ml of sunlight soap was added to 10 liters of water but was unsuccessful in eliminating the aphids in the greenhouse. The water irises were trimmed back to the water surface to slow down the multiplication of the insect.

Bio-control was purchased from Holland and there were two different applications of the lady bugs that were used to control aphids. After the second application of 100,000 ladybugs, the aphids were gone with in a three-

week period. They did not appear again until the end of the season and were embedded deep within the inner vegetation on the Roma tomatoes.

Whitefly was observed August 4, 2004 on tomato, cucumber, lettuce and pepper plants. Encarsia was brought in from Brooks to help control the whitefly. The whitefly multiplied at a very rapid rate and within a month was observed on the majority of plants within the greenhouse. The Encarsia was placed in the ACE facility on leaves and distributed on four sections where whitefly was very apparent. The Encarsia was observed to be successful in multiplying but not at the rate the whitefly reproduced. Where the Encarsia had time to multiply, the leaves were free from whitefly. Where the whitefly was particularly thick, there was a sticky substance left on the produce.

Mildew was observed on the long English and Mini English cucumbers and was treated by an ECA solution beginning September 7, 2004. The application was routinely applied 3 times a week. The mildew did not go away but was controlled.

Mold was observed on the Clarence, Chloe and Roma trays of tomatoes. The leaves were first evident by a browning coloration and then the tomatoes later showed mold as well. Because the mold developed within the last three weeks of operation, no biocontrol was used.

Spider mite appeared on the Long English cucumbers on the North wall in July and rapidly spread along the tops of the plants. *Phytosiulus perimilis* was used as a bio-control but the Spider mite rapidly spread. The leaves appeared to have a light colored substance on the top and the leaves soon discolored and died. This shortened the lifespan of the long English cucumbers.

On August 30th,³ Clarence plants were removed from tray 7. *Pythium* only appeared on tray 7 for the 2004 season. The reason for *Pythium* on this tray only was not known and these plants were removed from the tray.

3.3.3.2. Problems encountered

There were 5 different power outages this past season ranging from 5 hours to 48 hours. Power from a portable generator was used to connect a fan inside the greenhouse. With hot indoor temperatures, the fans were used to cool and distribute air so the plants did not die in excessive heat build up.

3.3.3.3. Results and discussion

The first plants seeded for the 2004 season were seeded January 20. From April 19 to October 15, 2004, samples were tested from gherkin and mini English cucumbers, and Clarence, Chloe, Roma and Cherry tomatoes. Air and water temperatures, timing of fish sales and nutrient levels influenced growth.

Figure 25. Weekly gherkin cucumber production for the first planting in 2004 as a function of plant production (kg/m²). The low productions indicated in August were due to the termination of gherkin trays in preparation for the transplant of new plants.

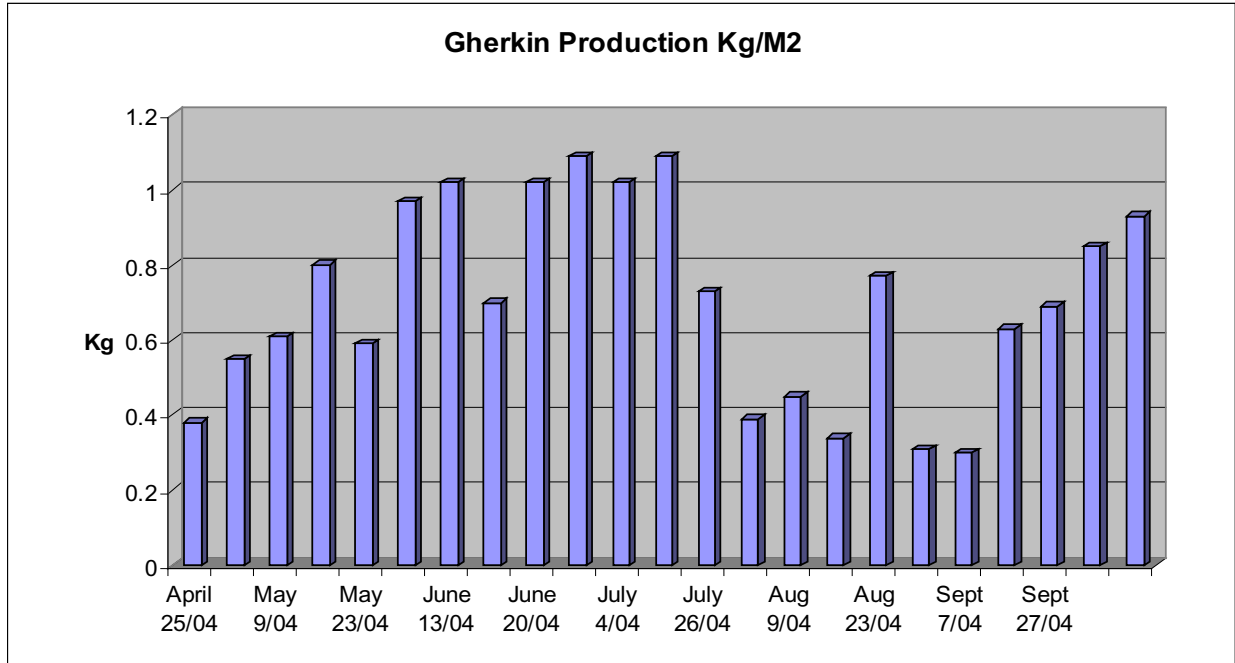
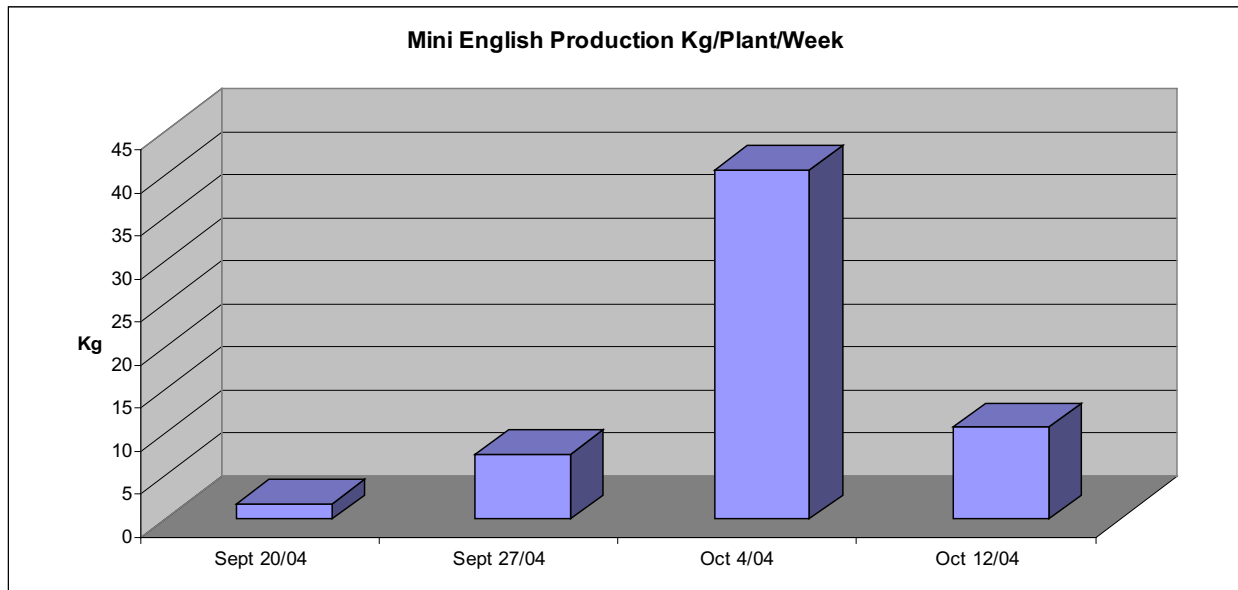


Figure 26. Weekly mini English cucumber production for the first planting in 2004 as a function of plant production (kg/plant).



•Gherkin Tray 20 and 21 were terminated July 21 – July 23/04 and tray 19 was the only tray harvested at that time.

•Mini English production was reduced on October 12th due to decreased water and air temperatures. Mini English were transplanted August 27th, therefore only 4 weeks of production until seasonal closure.

Figure 27. Weekly Clarence tomato production in 2004 as function of plant production (kg/m²).

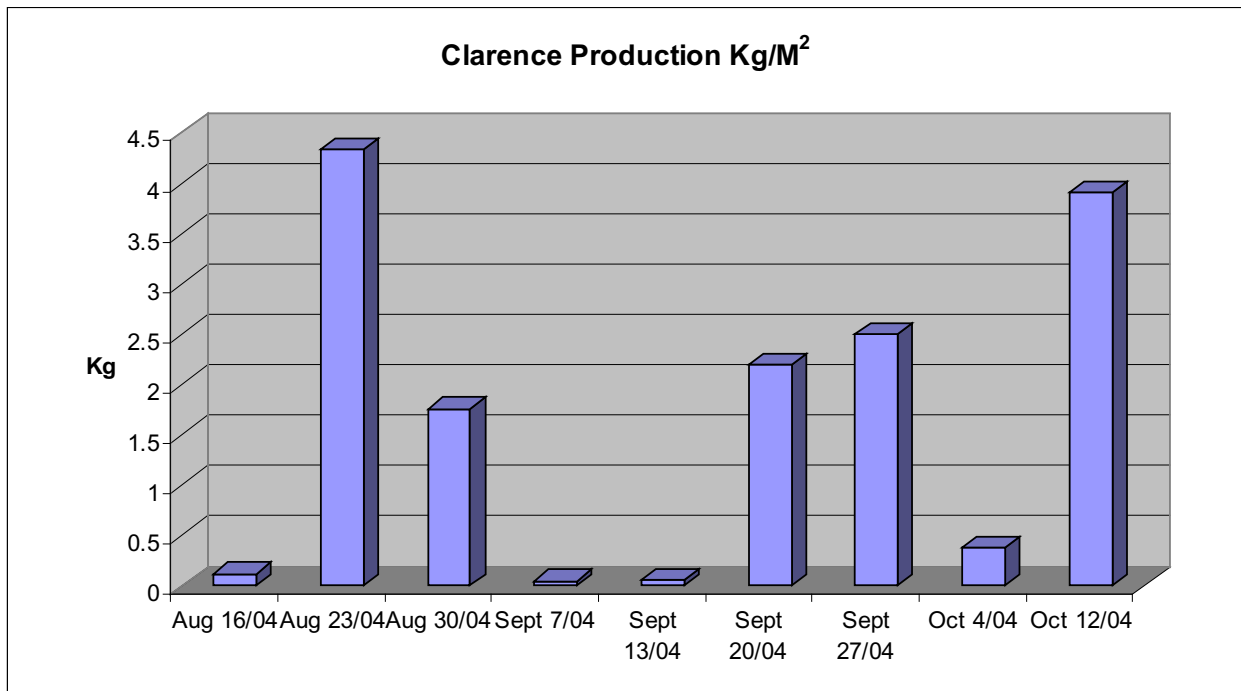


Figure 29. Weekly Chloe tomato production in 2004 as function of plant production (kg/m²).

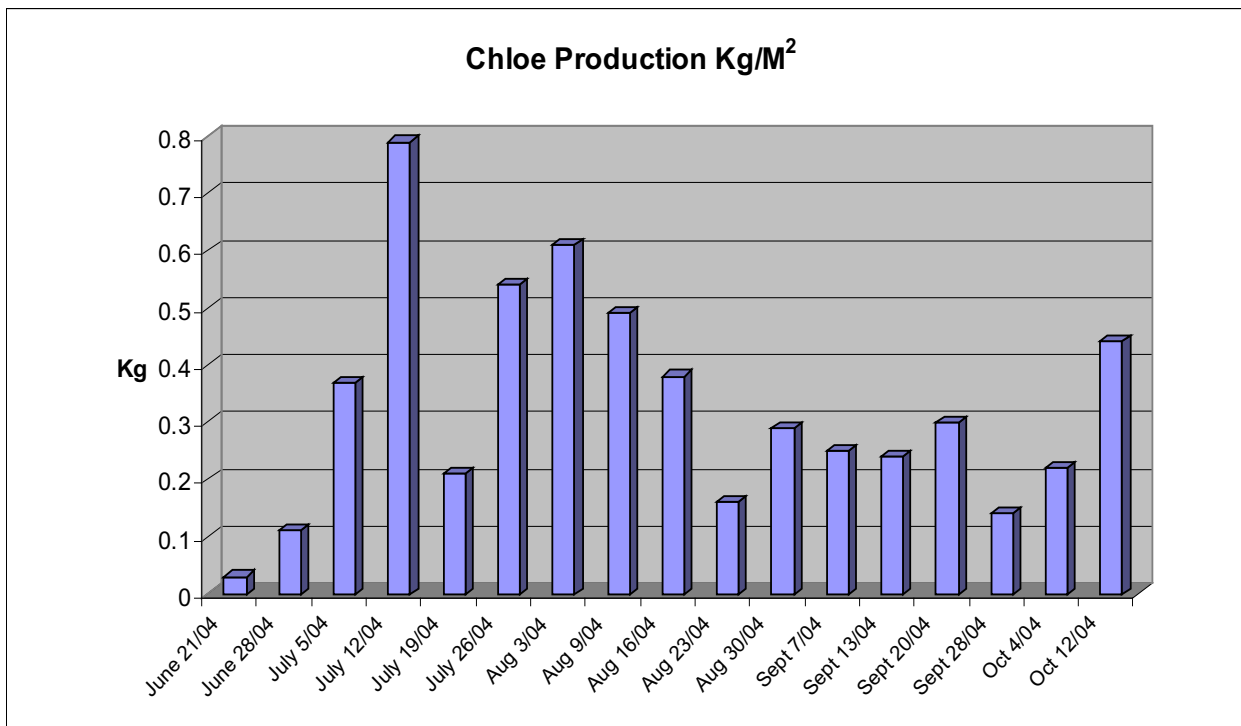
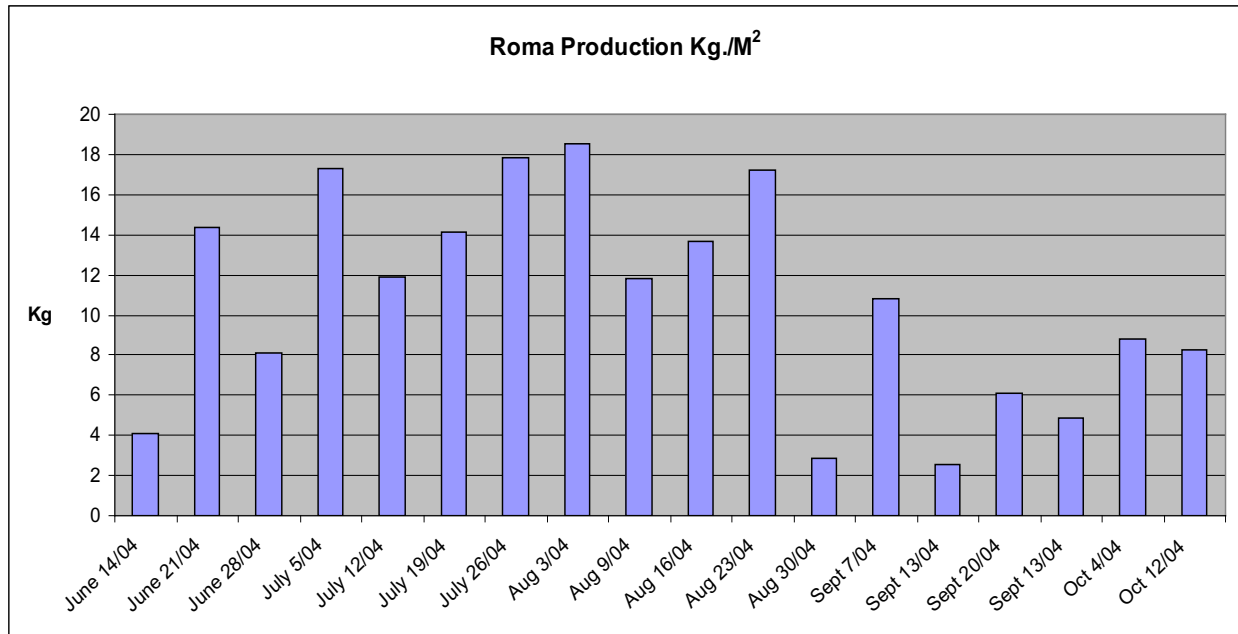
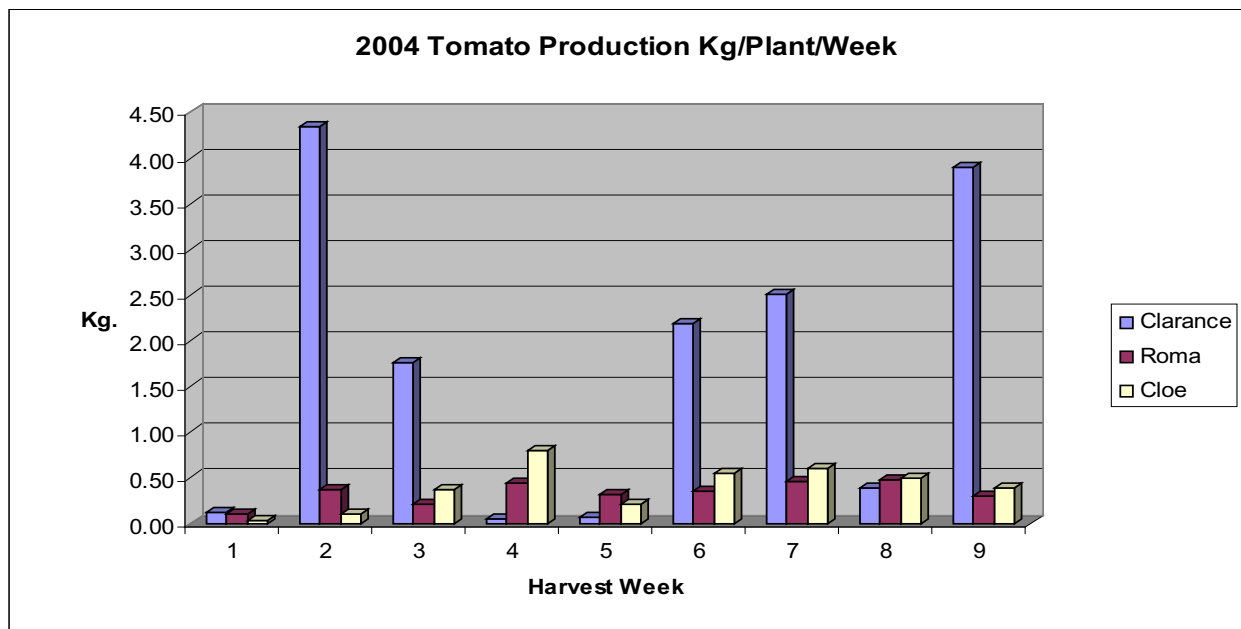


Figure 29. Weekly Roma tomato production in 2004 as function of plant production (kg/m²).



After the end of August production and ripening started to slow. The space between harvests increased. Depending on the rate the fruit ripened, Clarence tomatoes were harvested 1 to 3 times a week.

Figure 30. Weekly harvest production for Clarence, Roma and Chloe tomatoes as function of kg/week per tomato species.



- The tomatoes were graphed according to their first 9 weeks of their growth.
- The Aquaponics fruit producer may determine from the eighth and production what varieties they may choose to grow may be based on the market and specific use of varieties and the price per kilogram of the different species.
- Sweet 100 cherry tomatoes were not included, as the consumer did not care for the taste of this variety.

Figure 31. Weekly micronutrient levels per week in 2003 (mg/L).

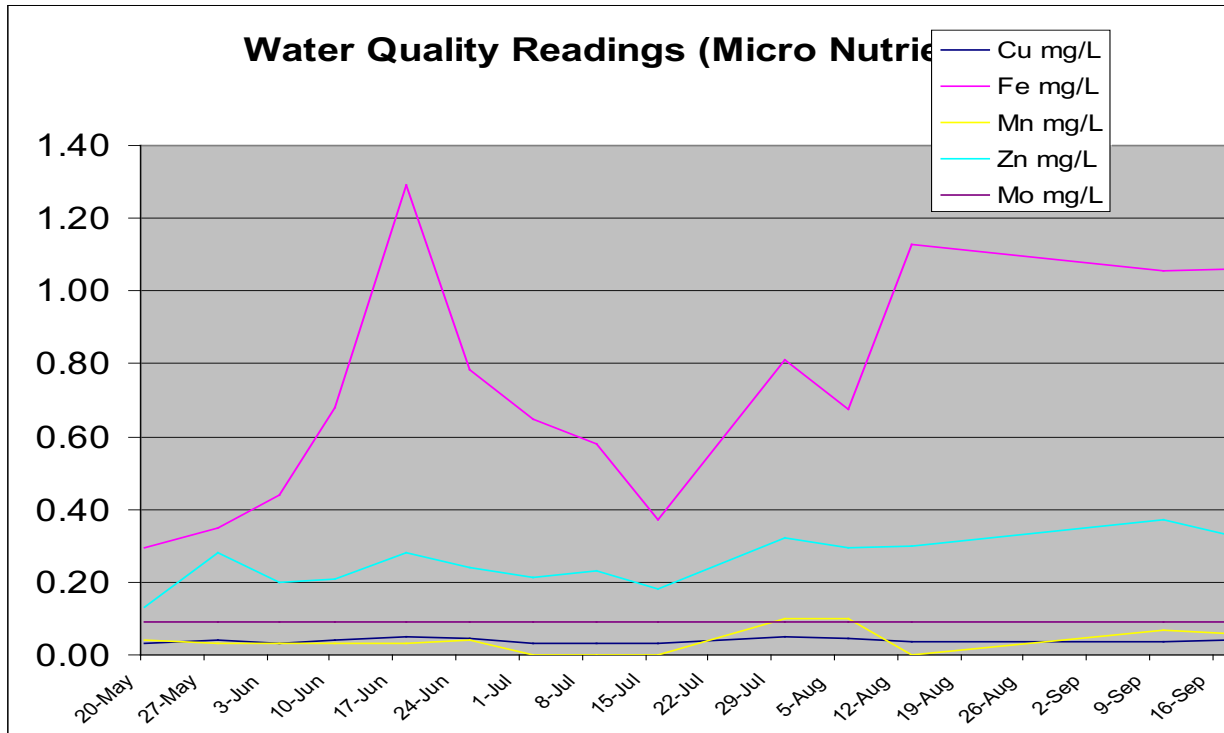


Figure 32. Weekly micronutrient levels in 2004 (mg/L).

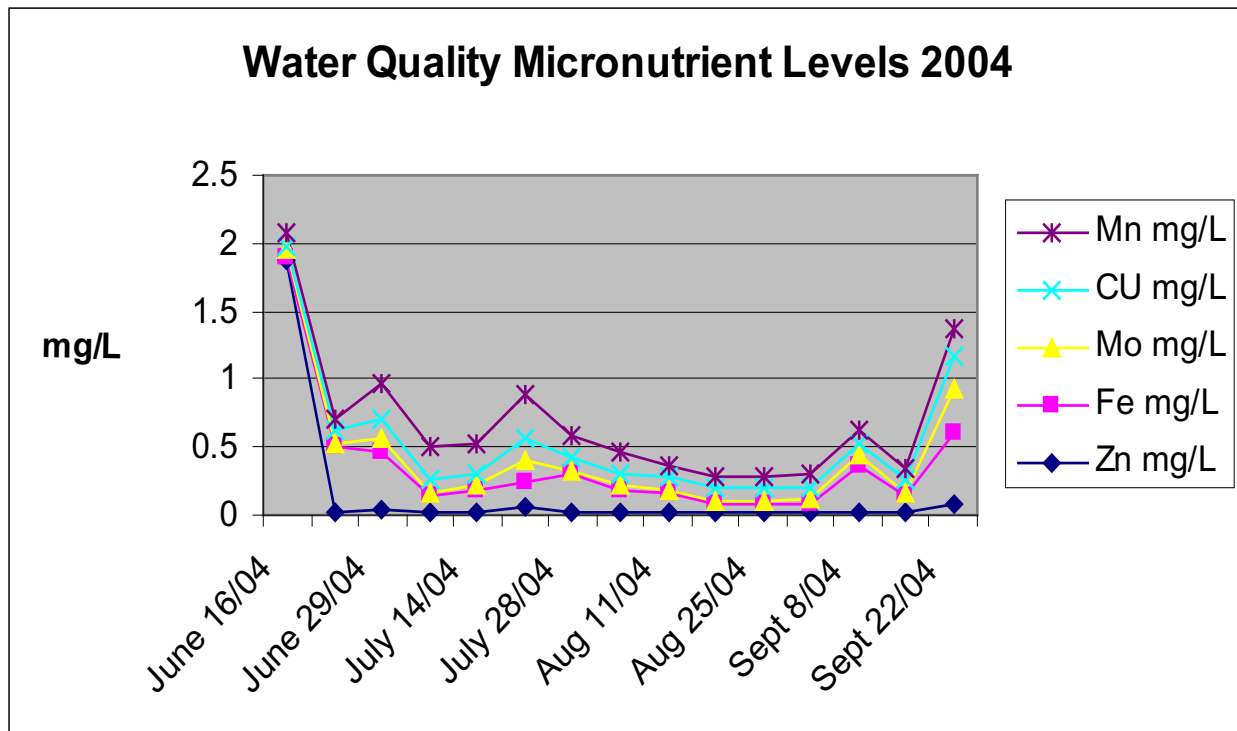


Figure 33. Weekly nutrient levels in 2003 (mg/L).

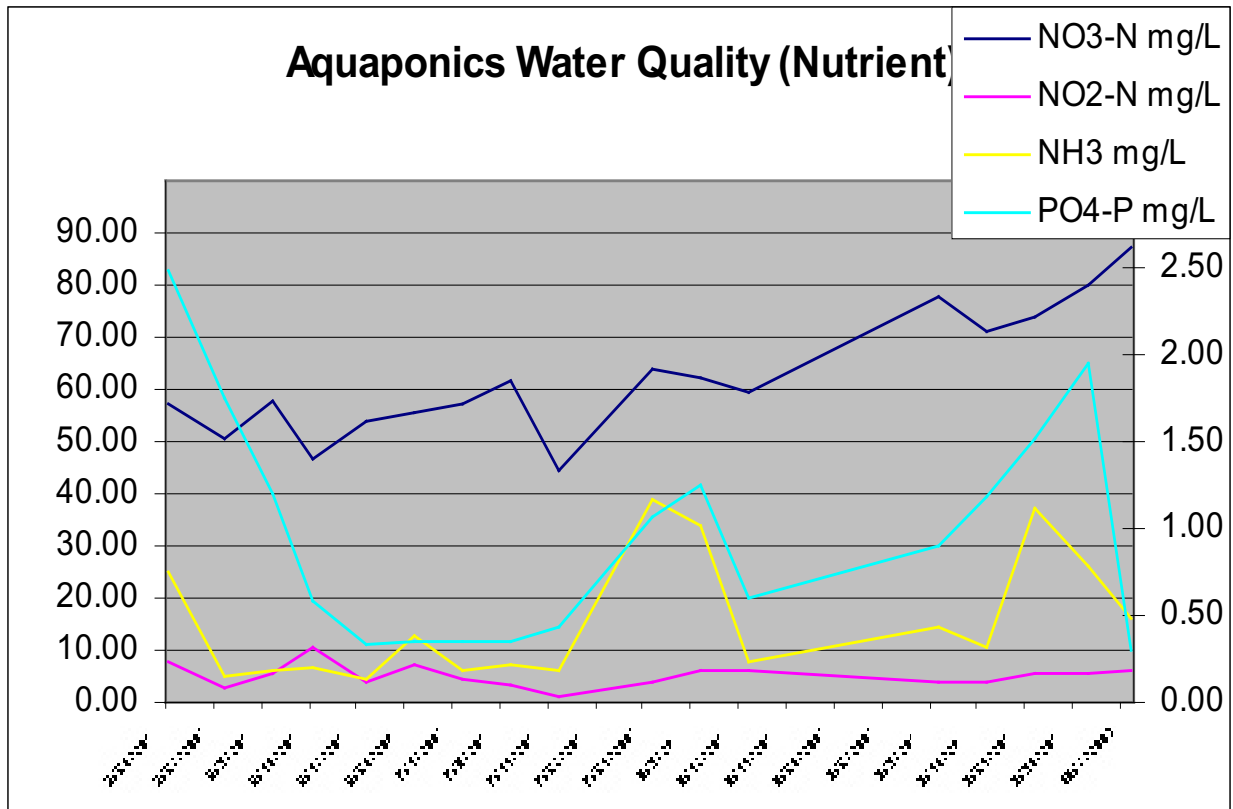
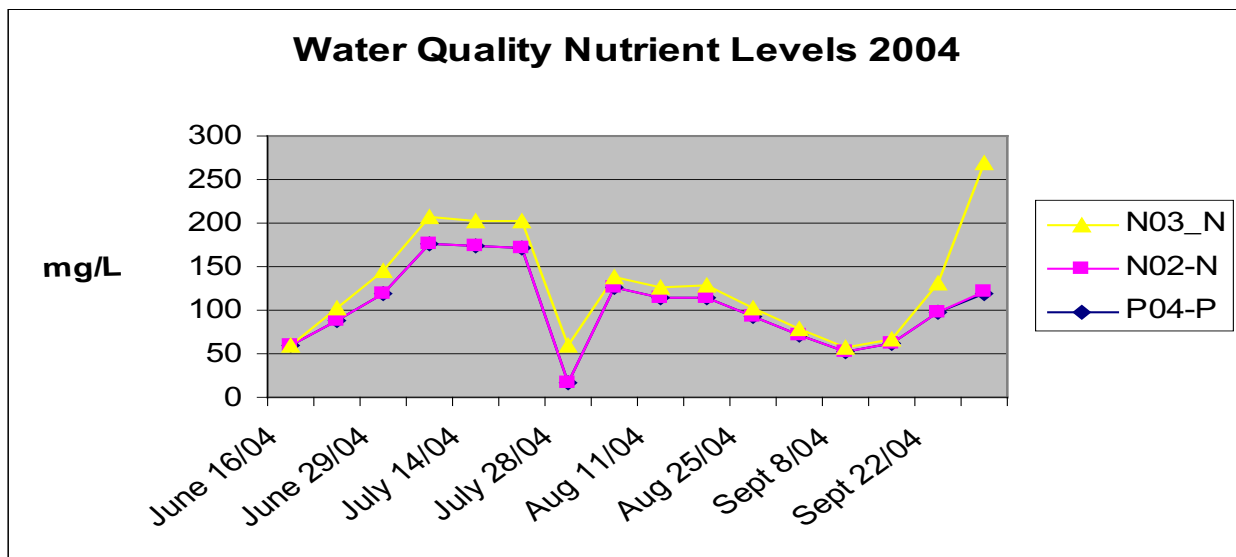


Figure 34. Weekly water quality nutrient levels in 2004 (mg/L).



- The timing of fish sales in 2004 had a large impact on nutrient levels and amounts of supplement required.
- As nutrient levels in 2004 became low, production slowed down and leaves yellowed. Once supplement nutrients were added, the plants began to produce more rapidly.
- As in the gherkin production, the spikes in August show the addition of supplement nutrient and the adjustment in attempting to find the appropriate amounts.

4. Conclusions

4.1. Stand-alone aquaponics facility at CDC South, Brooks

- Aquaponics study in 2004/2005 fiscal year confirmed conclusions of the first year of aquaponics operation regarding the technical feasibility of the aquaponics technology in Alberta.
- The yields of greenhouse vegetables and fish production in aquaponics facility in 2004/2005 exceeded the same parameters in 2003/2004 indicating a considerable improvement of the technique.
- Greenhouse tomato and cucumber production in aquaponics system in 2004/2005 reached 20.7 kg plant⁻¹ year⁻¹ and 33.4 kg plant⁻¹ year⁻¹ respectively exceeding average yields of these crops in greenhouse sector in Alberta for the first time.
- The average yield of basil, cv. Genovese, increased in from 8.7 kg m⁻² of greenhouse area to 11.9 kg m⁻² in 2004/2005 compared to 2003/2005.
- Further growth in basil production has been observed in the first 6 months of 2005/2006 fiscal year reaching 15.3 kg m⁻².
- The overall gross income from basil production grew from \$133.8 m⁻² of greenhouse space in 2003/2004 to \$184.0 m⁻² of greenhouse space in 2004/2005 and to \$236.2 m⁻² of greenhouse space in 2005/2006. The gross income from basil production almost doubled for the period of two years without additional investments.
- Produced aquaponics basil was of highest quality according to the market standards as shown in marketing study in 2004/2005.
- Improved IPM in aquaponics facility allowed to successfully controlling population of whitefly, aphids, and thrips in 2004/2005.
- Water use efficiency in mixed basil/tilapia operation was 394.3 liters per \$100 of output, which is for 65.7% more efficient than in the best hydroponics systems (600 liters per \$100 of output).
- A stimulatory effect on plant growth observed in aquaponics culture was reported for the first time. It has been assumed that the observed phenomenon was due to unique conditions created in aquaponics culture, which combines both fish and plant production tied into one system.
- In model experiments the plants consumed nutrients and grow considerably faster in aquaponics water than in hydroponics with the same supply of nutrients.
- This result was documented with six greenhouse crops including tomatoes, long English cucumbers, lettuce (three varieties), basil, Echinacea and rosemary.
- The faster growth of greenhouse crops means reaching reproduction period for shorter period of time.

- These findings can be essential in removing biological restraints for earlier production season.
- Economic analysis is under way. However, a preliminary estimation indicates that aquaponic operations are economically feasible when growing high value crops like basil.

4.2. Add-on aquaponics facility at LCC, Lethbridge

- Best market species in terms of revenue were based on consumer preference for taste, size, use and storage value.
- Harvest methods ranging from twice a week to three times a week did not effect total production but did influence the consumer's use for the fruit.
- The timing of fish sales influenced production, air and water temperature changes, and controls of pests, insects and diseases.
- Timing of bio-control placement must be immediately upon identification of insect to be able to control it.
- Specific plants are heat tolerant and others not so. Those that are not need to be planted in spring or fall to prevent early bolting or tip burn.
- Production may be effected by the learning curve as some of the plants may be topped which decreased yield. A novice Aquaponics farmer can expect yield increase as skills improve.
- To maximize yield, better use of growing space must be utilized as well as air and temperature control installation.
- Fish sales were early in the season and nutrient levels dropped off severely. Supplemental nutrient was added but production appeared to be slowed down while attempting to find proper amounts required.
- Plants such as bok choy and lettuce showed signs of the effects of the heat. The bok choy bolted early in its growth and the romaine lettuce displayed tip burn. Other varieties of lettuce did not show heat effects.
- The taste of the cherry tomatoes did not appeal to many customers as a sweet flavor was not consistent. The flavor ranged from sweet to bitter and did not sell as well as other varieties of tomatoes this past season.

5. Presentation to Industry

Second year of aquaponics operation at CDC South was an important step for dissemination of the technology in the province. More greenhouse and aquaculture growers were involved in the workshops and seminars compared to the first year. The results of aquaponics study were presented during Alberta Aquaculture Association on November 19, 2004 and Alberta Horticultural Congress on November 17, 2005. The results were also reported during regular meetings of Alberta Greenhouse Growers Association and to Red Hat Co-op Board of Directors.

Industry-led initiative called Alberta Aquaponics Group-AAG, had a third meeting on January 18, 2005 (see the attached agenda). The group included representatives from greenhouse producers, aquaculture operators, organic crop growers along with representatives from the government and academic institutions. The members of the project team made thirteen presentations

on different aspects of aquaponics production and funding options during the workshop. The topics included Alberta's Aquaponics History in Alberta by Eric Hutchings; Update on Aquaponics Stand-alone System: Plants by Dr. Nick Savidov; Update on Aquaponics Stand-alone System: Fish by Eric Hutchings; Update on Aquaponics Add-on System by Dr. Bill MacKay; Warm Water Aquaponics with Tilapia by Curt McNaughton; Production of high value aquaponics crops by Dr. Manjula Bandara; Options for aquaponics vegetable and fruit production by Dr. Chris Neeser; Biocontrol for pest problems in aquaponics by Paul Le Blanc; Update on Biocontrol Network by Dr. Andrew Keddie; Comparing Aquaponics Plant Production to Hydroponics by Dr. Vipan Bansal; Federal IRAP program by Cal Koskovich; and Tax incentives for aquaponics research by Doug Clay.

The aquaponics facilities at CDC South in Brooks and Aquaculture Centre of Excellence at LCC in Lethbridge hosted numerous visitors representing greenhouse and aquaculture sectors of Alberta agriculture during 2004/2005.

Other presentations and publications

Savidov, N. 2003. Horticultural Congress November 12-14 2003, Edmonton, Alberta.

Savidov, N. 2004. Fourth regional meeting of the Biocontrol Network Canada November 17 2004, Edmonton, Alberta.

Savidov, N., and Hutchings, E.. 2004. Fish and Plant Production in a Recirculating Aquaponic System. *Aquaponics Journal*.

Savidov, N., Hutchings, E. and Rakocy, J.. 2005. International Conference on Soilless Culture. September 5-8 2005, Singapore, Singapore

Bansal, V., Savidov, N., Howard, R. and Kharbanda, K.. Aquaponics: A Novel Greenhouse Production System and its Challenges. Proceedings of Plant Canada 2005, June 15-18, Edmonton, AB.

V. Bansal, Rakocy, J. and Savidov, N. 2005. International Conference on Soilless Culture. September 5-8 2005, Singapore, Singapore.

Savidov, N., Hutchings, E., and Rakocy, J. 2006. Fish and Plant Production in a Recirculating Aquaponic System: A New Approach to Sustainable Agriculture in Canada. *Acta Horticulturae*. In press.

6. Industry Reaction

Continuous operation of aquaponics facility at CDC South for three years and success of aquaponics project during 2004/2005 in validating results of the previous year ensured enthusiastic support of the project by Alberta greenhouse and aquaculture growers. The industry provided significant in-kind and cash support including \$20,000 from Alberta Aquaculture Association, which secured federal funding of the project at CDC South by Department of Fisheries and Oceans. Other Alberta companies and individuals who contributed to the project from the industry side included Mark McNaughton and Kurt McNaughton, MDM Aqua Farms, Rumsey; Doug Millar, Circle M Trout Farm, St. Paul; Greenview Aqua Farms, Calgary; George Peter Harvey, Double-D Greenhouses, Okotoks; and Reg Proudfoot, Lyalta Gardens Greenhouses, Strathmore. Mark McNaughton, Kurt McNaughton, Doug Millar, and George Peter Harvey

actively participated in Alberta Aquaponics Group meetings and contributed to the dissemination of the technology in the province of Alberta.

Red Hat Co-op Ltd., the largest greenhouse producer in Prairies, decided to support a study of growth stimulator from aquaponics water, which can be used for boosting greenhouse crops production in commercial hydroponics. The proposal was sent and discussed during Red Hat Co-op Ltd. Board of Directors, who voted for providing in-kind and cash support of \$10,000 for the project.

First successful aquaponics operations emerged in Alberta, including MDM Aqua Farms, Rumsey, and Circle M Trout Farm, St. Paul, are a direct result of ongoing project in Brooks. The companies have been actively communicating with the project team in 2004/2005 in a process of technology transfer to the industry. As a result, the output of aquaponics commercial operations considerably grew this year compared to the previous years.

The project in Brooks attracted considerable interest among commercial growers in Canada and abroad. An “Aquaponics Short Course”, originally scheduled March 2003, showed considerable industry interest, with people registering from eastern and western Canada and the USA. The intended small, hands-on seminar had turned into large meeting group. The Federal government's AquaNet, an education arm had committed considerable funds to offset expenses. This course was canceled due to lack of information about aquaponics production technology in Alberta that time. The successful results of NIF aquaponics project in 2003/2004 and 2004/2005 fiscal years will pave the road for the first aquaponics course in Canada in fall 2006 held in Alberta.

7. Summary of Results/Conclusions for Overall NIF Program Report

Aquaponics study in 2004/2005 fiscal year confirmed conclusions of the first year of aquaponics operation at CDC South about the technical feasibility of the aquaponics technology in Alberta. Yields of tomatoes and mini-cucumbers reached 20.7 kg plant⁻¹ year⁻¹ and 33.4 kg plant⁻¹ year⁻¹ and exceeded average values of commercial greenhouses in Alberta that employ conventional hydroponics technology. The yield of Genovese basil increased from 13 kg m⁻² year⁻¹ to 42 kg m⁻² year⁻¹ for two years of aquaponics operation. The aquaponically produced basil was of highest quality according to the market standards as shown in marketing study in 2004/2005.

Improved IPM practices in aquaponics facility allowed to successfully control of whitefly, aphids and thrips populations in 2004/2005.

Water use efficiency in mixed basil/tilapia operation was 394.3 liters per \$100 of output, which is for 65.7% more efficient than in the best hydroponics systems (600 liters per \$100 of output).

A stimulatory effect on plant growth observed in aquaponics culture was reported for the first time. It has been assumed that the observed phenomenon was due to unique conditions created in aquaponics culture, which combines both fish and and plant production tied into one system. In model experiments the plants consumed nutrients and grow considerably faster in aquaponics water than in hydroponics with the same supply of nutrients. This result was documented with six greenhouse crops including tomatoes, long English cucumbers, lettuce (three varieties), basil, Echinacea and rosemary. The

faster growth of greenhouse crops means reaching reproduction period for shorter period of time. These findings can be essential in removing biological constraints for earlier production season.

The timing of fish sales in 2004 had a large impact on nutrient levels and amounts of supplement required in add-on aquaponics system. Air and water temperatures, timing of fish sales and nutrient levels influenced growth of greenhouse crops in add-on aquaponics facility. Economic analysis is under way. However, a preliminary estimation indicates that aquaponic operations are economically feasible when growing high value crops like basil.

Acknowledgments

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- Diversified Livestock Fund, AAFRD and
- New Initiative Fund IDS/AAFRD

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Edmonton team:

Nabi Chaudhary

Advisory Committee:

Christine Murray, Manjula Bandara, Ron Howard, Andrew Keddie, Chris Neeser, Mohyuddin Mirza, Thean Pheh, James Rakocy, Terry Schroeder and Dan Watson.

Industry partners:

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Appendix 1

Aquaponics Interest Group Meeting

Crop Diversification Centre South - Brooks, Alberta,
January 18, 2005

The following meeting is scheduled for those interested in current aquaponics research and development in Alberta. It is planned as part of a cooperative effort for stakeholders. You will be updated on results and are welcomed to ask questions, provide insight into future direction and tour the aquaponics facility.

Meeting begins 10:00 a.m. Lunch will be no host, costing \$10. If you plan to attend, please call Nick Savidov at CDC South, Brooks, (403) 362 1312 or Eric Hutchings at Lethbridge, (403) 381-5574. You can also email (preferable) them at nick.savidov@gov.ab.ca or eric.hutchings@gov.ab.ca .

Welcome from the Director of Crop Diversification Centre, South
Christine Murray

1. Alberta's Aquaponics History
Eric Hutchings
2. Update on Aquaponics Stand-alone System. Plants
Nick Savidov
3. Update on Aquaponics Stand-alone System. Fish
Eric Hutchings
4. Update on Aquaponics Add-on System.
 - a. Aquaculture Centre of Excellence.
Bill MacKay
 - b. Warm Water Aquaponics with Tilapia.
Curt McNaughton
5. Production of high value aquaponics crops.
Manjula Bandara
6. Options for aquaponics vegetable and fruit production.
Chris Neeser

Lunch - on site (After lunch)

7. Biocontrol for pest problems
Paul Le Blanc

8. Update on Biocontrol Network.
Andrew Keddie
9. Comparing Aquaponics Plant Production to Hydroponics
Vipan Bansal
10. Federal IRAP program
Cal Koskowich
11. Tax incentives for aquaponics research
Doug Clay
12. Aquaculture in Ukraine e
Anatolyi Korenev
13. Organizing upcoming National Aquaponics Course.
14. Aquaponics Future Plans. Round Table Discussion.
15. Questions or concerns ... tour facility.

Wrap up at 4:00 p.m. Any additions to the agenda welcomed at this time. Please acknowledge, if others in your group are planning to attend. Your confirmation is important for seating and luncheon arrangements.

Appendix 2

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