Evaluation of Aquaponics Technology in Alberta, Canada

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Aquaponics is considered as a potentially important industry for Alberta with two profit centers: fish and plants, each locally grown high value products, which can be produced and marketed year round. A grant of $100,000 in 2002 by provincial government of Alberta gave a start to the first research aquaponic facility in Prairies.

The team used the funds to construct an aquaponic module at CDC South in Brooks with an assistance of a team of American experts led by Dr. James Rakocy from University of Virgin Islands. The evaluation of this model under Alberta conditions in greenhouse system with supplemental heating for both the fish and the crop was the major objective of the project in Brooks.

Preliminary results in 2002/2003 year showed that fish waste could be an adequate source of nutrients for intensive crop production. The yields under the conditions of standard greenhouse technology and plant density were about 40 kg of tomatoes meter^{-2} year^{-1}, 100 cucumbers meter^{-2} year^{-1} in . These yields far exceeded the average yields of greenhouse vegetables produced by organic soil-based technologies in Canada. However, the limited time did not allow evaluation of the system when operating in full mode production, as not all tanks were occupied by fish. Further research was required to measure the yield of the fish and crops. Therefore, the project continued in 2003/2004 for evaluation of crop yield, fish yield and the market potential for high value niche products in Alberta. Objectives of the project included evaluation of the stand-alone, warm water fish model at CDC South under Alberta conditions; achieving a sustainable balance between fish and plant parts of the aquaponic system and optimizing plant crop yields for greenhouse vegetables including tomato, mini cucumbers, basil and other crops in a computer controlled environment and marketing study.

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Recirculation System in Brooks

The stand-alone aquaponic system at the CDC South, Brooks was based on the J. Rakocy model (Rakocy 2002; Rakocy, Shultz, Bailey, and Thoman 2004) adapted to greenhouse conditions (Fig. 1). 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.

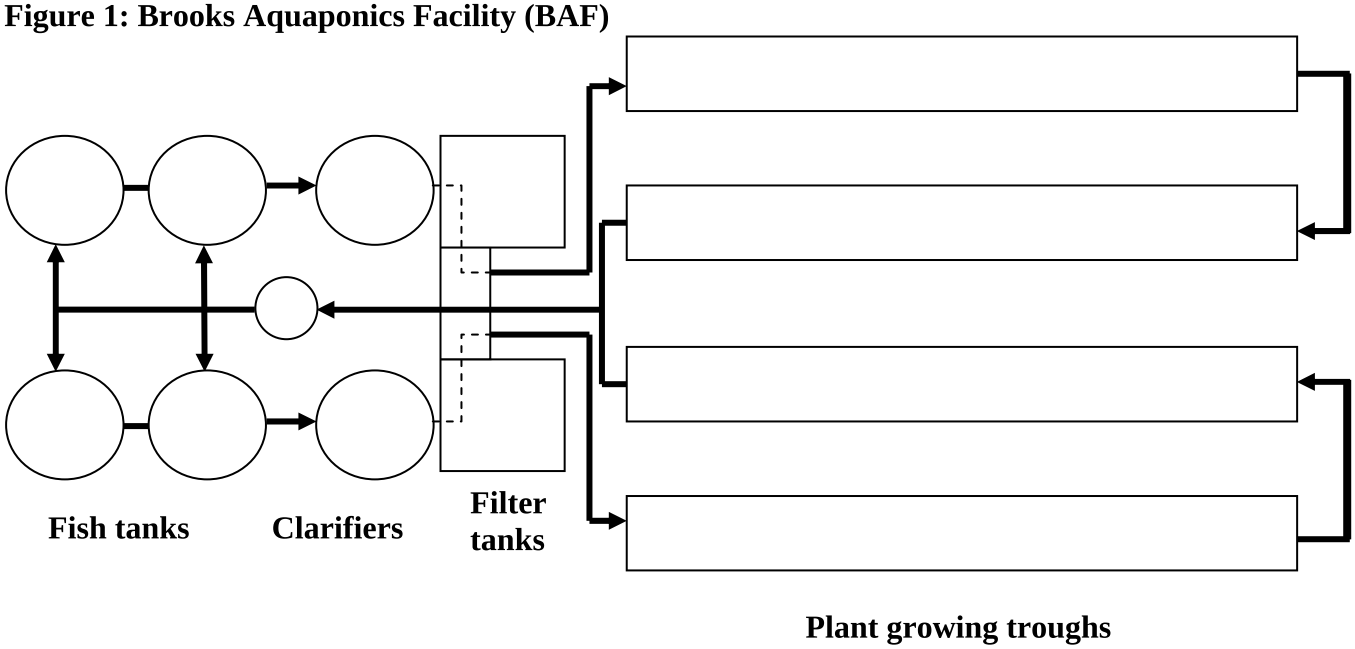
Cucumbers grown in the BAF aquaponic system

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.

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 CO_2 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

Figure 1: Brooks Aquaponics Facility (BAF)



plant troughs moved into a small sump tank (1000 L) where a submersible pump continuously circulated the water back to all 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 ºC for tilapia). When the float valve in the sump tank lowers with the water level it 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 received a flow of 200 L min^{-1}. This gave a turnover time of once per hour for the fish tanks and once every 45 minutes for the plant trays.

Top: tomatoes, Bottom: basil, both grown at BAF

The greenhouse and recirculation system is 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 are maintained at stable levels by the computer using heaters/coolers and humidifiers. Irradiation in the greenhouse is also being monitored. The recirculation system is aerated using air blowers and diffusers and had a liquid oxygen backup. Water temperature, oxygen levels, electric conductivity (EC) and pH are monitored continuously by the computer control system

Fish culture

Eric Hutchings, provincial aquaculture specialist, provided his expertise to conduct tilapia trials. 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 Fish Farmers Association.

Plant culture

The plants grown were selected according to their commercial importance and their conductivity factor (CF, 100 µS = 1 CF) which indicates their tolerance to different concentrations of minerals and their ability to extract minerals including nitrogen. Three groups were tested:
Group 1: high CF (20-45) tomato and egg plant
Group 2: medium CF (10-20) lettuce, basil, chives, spinach, parsley and cucumber
Group 3: low range of CF (2-10) water cress

Plants were also selected based on their ability to grow fast and resist disease. Plant seedlings were grown in rockwool and transferred to holes in Styrofoam sheets floating in the plant troughs. The plants were grown in the greenhouse at an air tem-

Figure 2: Iron deficiency in Faba vulgaris plants grown aquaponically

perature of 22-25°C, an irradiation level ^{3} 300 µmol photons m^{-2} sec^{-1} photosynthetically available radiation (PAR), and a 16:8 day:night photoperiod provided by natural and artificial lights.

Water pH was maintained near 6.5-7.0 by the addition of either Ca $(OH)_2$ (calcium hydroxide) or $KHCO_3$ (potassium carbonate) (alternate on weekly basis) to increase pH, or H_3PO_4 (phosphoric acid) 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 roughly 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 and basil every two weeks to ensure uniform consumption of the minerals during operation. The crops were routinely monitored for pests and diseases. Biological crop protection was carried out as required through integrated pest management (IPM). Predatory insects and hyperparasites were used for chemical-free protection. The plant growth trial protocol was standardized among the stand-alone and add-on facilities.

Plant Production

The facility in Brooks started in December after 600 fingerlings were placed in the tank #1. The first plants were transplanted in the middle of January. From April 1, 2003, till March 31, 2004, a number of crop species were tested in stand-alone aquaponics system. The total number of crops was sixty. Three major crops tested in the Brooks facility included tomato, cucumber and basil (see pictures on previous pages). Each crop occupied one trough. The forth trough was used to grow a variety of crops. The first two months of plant production was characterized by slow plant growth and number of deficiencies due to lack of nutrients mostly iron and magnesium (Fig. 2).

The absence of nutrients in the beginning visibly affected biomass accumulation. That was anticipated due to lack of nutrients in the beginning of aquaponic production cycle. In the beginning, the symptoms included nitrogen, phosphorous, potassium, iron and

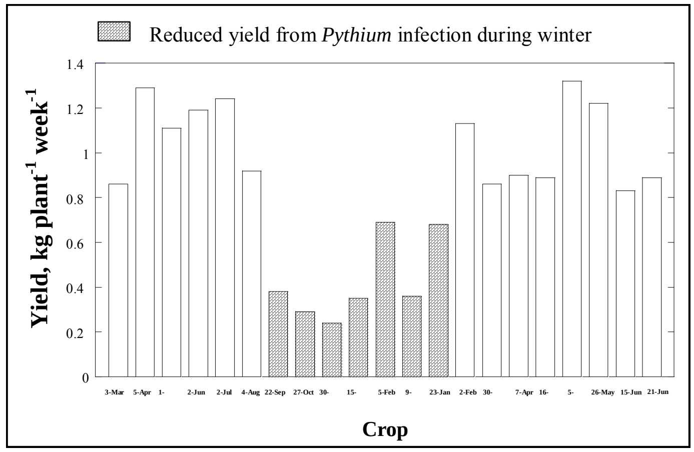


Figure 3: Mini Cucumber production, cv.Alamir, 2003/2004

other microelement deficiencies. However, there was a significant difference in severity of the observed symptoms among different species. Lettuce proved to be the most affected and portulaca showed minimum deficiency symptoms.

Aquatic plants such as water hyacinth, frog bit, crystal wort and azolla were not affected by the nutrient deficiency at all. Aquatic plants are known for their ability to extract nutrients from very diluted solutions. The situation with traditional greenhouse crops dramatically improved when aquaponics solution accumulated enough nutrients for crop production after 3-4 months of operation. Mini cucumber variety Alamir reached peak of production by April 2003 (1.29 kg $plant^{-1}$ $week^{-1}$, Fig. 3).

The high production period continued until September, then yield started decreasing. The problem was identified as a root rot caused by *Pythium aphanidermatum* by the Plant Pathology Program led by Dr. Ron Howard. After consultations with Dr. James Rakocy, the problem was contained by weekly cleanings of the sedimentations tanks, which served as a breeding ground for *P. aphanidermatum* zoospores. One of the possible reasons of increased susceptibility of cucumbers to *P. aphanidermatum* was decreased light period in the fall. The combined improved sanitation measures and increased length of day light in the end of February 2004 led to higher yields, which were restored to the levels in summer 2003.

The projected level of mini cucumbers in the stand-alone aquaponic facility per year during *P. aphanidermatum*-free period in 2003/2004 considerably surpassed the average level in the industry using conventional hydroponics. Cv. Alamir was compared with three other varieties of mini cucumbers including Harmony, Kian and Melita. There were no significant differences between four varieties except cv. Harmony showing slightly slower growth in August and September.

Tomato varieties performed well in aquaponics exceeding the average yield level in the industry by 10-15%. However, the low yield of Roma tomatoes in the winter 2004 indicated the need for higher light conditions for this cultivar. The adequate level of irradiation in May increased the yield more than four times. The basil crop was definitely one of the most successful crops in aquaponics.

The yield was steadily growing from 13 kg m^{-2} $year^{-1}$ to 42 kg m^{-2} $year^{-1}$ increasing more than 3 times. There were not any problems observed with pests and diseases for the reported fiscal year. We suggest that this growth in production reflected gradual accumulation of favorable factors for this crop in an aquaponic system. Among other vegetables, Japanese eggplant and bitter melon, were tested. Both crops produced good yields.

However, the yield of bitter melon was high 37.2 kg $plant^{-1}$ $year^{-1}$. This crop, produced for ethnic markets in Alberta, can potentially provide a steady cash flow for a greenhouse grower.

Up to 60 different crops were tested for the reporting period. Most of them were culinary herbs. Cilantro was the slowest growing crop producing only 4 kg m^{-2} $year^{-1}$. The highest yield was produced by Swiss Chard and water spinach (51.5 kg m^{-2} $year^{-1}$ and 58.3 kg m^{-2} $year^{-1}$ respectively).

Fish production.

The fish production was monitored through fish sampling every second week. The results showed that the biomass increased steadily in all fish tanks.

However, the mortality was high in the beginning of the reported fiscal year reaching 30%. The number of fish in tank #1 dropped from 600 to 420 in July 2003. It was suggested that the low quality of fingerlings was the major cause of the problem. The situation was considerably improved when the company providing fingerlings changed a supplier. A significant number of fish (up to 25%) was lost in September due to a power outage. The incident suggested that a backup power generator should be a compulsory requirement for running aquaponic operations. Despite the lower than expected production in 2003/2004, no major problem in aquaculture was associated with the water quality.

Water Quality, pH and the Nutrient Balance in the Fish Effluent

The nitrogen cycle is a central factor of bio-productivity in natural and artificial ecosystems. Ammonia is the main component in the excrements of freshwater teleosts. Ammonia is oxidized in two-step reaction by nitrifying bacteria with production of nitrate. The nitrification is a crucial process in aquaculture as it reduces the level of ammonium, which is a major cause of toxicity for farmed fish. The efficiency of nitrification is higher in alkaline solution, pH 7.5-8.0, which is the reason for relatively high pH in most aquaculture facilities. We used pH 6.5-7.0, which was a compromise between requirements for active nitrification and plant nutritional requirements. The $N\text{-}NO_3^-$ (nitrate) level gradually increased from 0 to 10 mM, which provided a sufficient source of nitrogen for plants. The iron and microelements were added to the solution to reverse the deficiency symptoms.

Since the concept of aquaponics implies use of fish feed as a major source of nutrient for the plant production, the nutrient balance in the fish feed is crucial for the plant production. The requirements for potassium are different for plants and for fish. Fishmeal, the major component of the fish feeding formulations is not always rich in potassium. The measured level of potassium in the fish effluent was 10 fold less than that of calcium and 5 fold less than sodium in the beginning of the experiment. The recommended Ca:K (calcium:potassium) ratio for hydroponic production of most crops is between 2:1 and 1:1. Ca (calcium) and Na (sodium) interfere with K (potassium) uptake. The increased level of these elements can cause severe K starvation. Thus, the preliminary observations in this aquaponics system revealed an intrinsic nutrient imbalance in the system based on fish feeding formulations as the only source of the plant nutrients.

The existing aquaponic systems use either calcium or potassium hydroxide supplements in order to control pH. In such systems, however, potassium level is not controlled by the plant demands, but rather by pH. We proposed to add potassium supplement, due to its deficiency in fish feed. The balance between the plant nutrients in the fish effluent was controlled by the addition of supplements limited to iron and potassium to provide the best nutrient regime for the maximum plant production. On the other hand, the fish effluent provided the major portion of the nutrients. After six months of operation, the macro- and micronutrient balance in this aquaponic facility closely mimicked a standard commercial mixture with minimum supplements with minerals. As a result, leaf analysis showed no deficiencies in both macro- and microelements in aquaponically grown cucumbers.

Potential for Organic Production

There are a number of retailers supplying organically certified minerals. Rock potassium sulfate containing up to 50% K_2O (potash) and soluble kelp powder can be used as organically certified potassium supplements. Developing aquaponics in North America offers a new opportunity for expansion of industry supplying soluble fertilizers for organic hydroponics. For example, these supplements may include soluble kelp powder containing biologically active components and microelements besides potassium. These components were shown to have a positive effect on crop production and development.

The other approach is a development of plant-based fish feed. This feed will have more potassium and is more balanced for growing plants. Commercially available fish feed is mostly based on fish meal and comprises up to 60% and higher of total production cost in aquaculture. Fish feed based on plants can be a key factor for the expansion of inland fish farming and aquaponic operations.

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