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Development Smart Water Aquaponics Model

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Abstract

The present paper contributes to the modeling aquaculture. The paper main objectives are to identify an analysis smart water aquaponics. The purpose is to add more value to end aquaponics products. Aquaculture production depends on physical, chemical and biological qualities of pond water to a greater extent. The successful pond management requires an understanding of water quality. Intensification of pond makes the water quality undesirable with a number of water quality parameters. The objective of this model is to test and predicts plant and fish growth and net ammonium and nitrate concentrations in water in an aquaponic system. This is done by comparing the model outputs with measurements under controlled conditions in order to assess the accuracy of the tool to simulate nutrient concentrations in water and fish and plant biomass production of the system.

Keywords: *aquaculture, aquaponics, integrated systems, business model, rural development.*

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1. Introduction

Agricultural and livestock activities are considered the biggest consumers of fresh water. Estimations reveal that 85% of the global fresh water consumption is for agriculture and nearly one-third of the total water footprint of agriculture in the world is used for livestock products [7], [11].

In the last 30 years, the increase in the income of the population in developing countries, led to an increase in fish consumption from 25.0 to 104.3 million ton fish per year. Due to the depletion of marine resources the FAO predicts that in the future the supply of fish for the population will be entirely dependent on fish production in aquaculture systems.

2. Problem Statement

The increased demand for fish, water and fertilizer for crop production and the concerns about environment and health are motivations to test innovative farming systems such as "aquaponics" as viable systems for sustainable fish and crop production.

Aquaponics has ancient roots. Aztec cultivated agricultural islands known as chinampas in a system considered by some to be the first form of aquaponics for agricultural use [3], [4], [15] where plants were raised on stationary islands in lake shallows and waste materials dredged from the chinampa canals and surrounding cities were used to manually irrigate the plants [3], [15]. Also, South China, Thailand, and Indonesia who cultivated and farmed rice in paddy fields in combination with fish are cited as examples of early aquaponics systems. These aquaponic farming systems existed in many far eastern countries, in USA, and Canada.

3. Aims of the research

Recent advances by researchers and growers alike have turned aquaponics into a working model of sustainable food production. The integration of fish and plants results in a polyculture that increases diversity and yields multiple products.

Aquaculture development as a whole in the country in combination with production technology, favorable socioeconomic condition and culture environment has already proven successful in terms of increasing productivity, improving profitability and maintaining sustainability [18].

Aquaponics is, farming technique in which water from aquaculture is used to grow crops and extra water returns back to the fish tank. When this water circulated near root zone, nitrogen fixing bacteria (manly nitrosomonas and nitrobactor) convert ammonia (NH_4) into nitrite (NO_2) and then to nitrate (NO_3) form. By these, plants get nutrients as fertilizer and nitrates been less toxic to fish; fish grows better than normal aqua farming. By this integration of fish farming and agriculture, one can get maximum output.

Fishes produces nitrogenous compound mainly ammonia which is hazardous to fish, even in small quantities and toxicity increases in relation to pH and temperature in the water column. On the other hand, Nitrosomonas bacteria break down ammonia to NO_2 and Nitrobacter convert the nitrite into nitrate which is food for the plants. By contrast, NO_3 is less harmful to fish. Decaying organic matters can help to fertilize ponds, at the same time provides good environment for growing plants which are less prone to disease unlike soil. Raft aquaponics is one of the ways to use aquaculture site for vegetable production and can help to overcome nutritional demand for the growing population.

Green leafy vegetables with low to medium nutrient requirements are well adapted to aquaponic systems, including lettuce, basil, spinach, chinese cabbage, chives, herbs, and watercress (www.backyardaquaponics.com).

The selection of plant species in aquaponics system is important. Lettuce, herbs, okra and especially leafy greens have low to medium nutritional requirements and are well suitable to aquaponics system. Plants yielding fruits like tomato, bell pepper and cucumber have higher nutritional requirement and perform better in a heavily stocked and well established aquaponics system [1].

Research conducted at University of Florida showed that cucumber crop can be successfully adopted with aquaponics system. This is estimated that 45.300 Kg of fish will produce sufficient nitrogen for 4050 lettuce or 540 tomato plants when they are fed with 3 % of their body weight.

Freshwater fish are the most common aquatic animal raised using aquaponics, although freshwater crayfish and prawns are also sometimes used [4].

A few fish species are adapted to recirculating aquaculture which includes tilapia, trout, perch, arctic char and bass. Most commercial aquaponics system in North America is based on tilapia. Furthermore, tilapia is tolerant of fluctuating water conditions such as pH, temperature, oxygen and dissolved solids [14]. Tilapia is the fish species which is very hardy, can tolerate wide range of environmental parameters, can live with versatile of feed and are fast grow thing fish species [16].

4. Research Methods

The hydroponic greenhouse production system requires a high degree of environmental control including supplemental lighting and moveable shade to provide a target amount of light which, in turn, results in a predictable amount of daily growth. Computer technology is an integral part in the production of hydroponic. A computer control system should be used to control the abiotic environment. Different sensors are used to monitor greenhouse environment parameters. These parameters include temperature of greenhouse air and nutrient solution, relative humidity and carbon dioxide concentration of greenhouse air, light intensities from sunlight and supplemental lighting, pH, Dissolved Oxygen (DO) levels, and Electrical Conductivity (EC) of the nutrient solution. Sensors will communicate the environmental conditions to the control computer which will activate environmental control measures such as heating, ventilation, and lighting.

Atmospheric and water data model for aquaponic production system:

- Temperature
- Relative Humidity
- Carbon Dioxide or CO_2
- Lights
- Dissolved Oxygen
- pH
- Electrical Conductivity

For determine the growth parameters, length, weight and number of leaves and branches were taken into consideration. The percent gain of growth parameters of the aquaponic plan were measured using the following formula.

$$\%\text{gain} = \frac{\text{Final stage} - \text{Initial stage}}{\text{Initial stage}} \times 100$$

5. Findings

The recorded data were entered into the spreadsheet in MS Excel 2010 and then summarized properly before statistical analysis. After entering the data, the descriptive statistical analyses were done by MS Excel.

Temperature controls the rate of plant growth. Generally, as temperatures increase, chemical processes proceed at faster rates. Most chemical processes in plants are regulated by enzymes which, in turn, perform at their best within narrow temperature ranges. Above and below these temperature ranges, enzyme activity starts to deteriorate and as a result chemical processes slow down or are stopped. At this point, plants are stressed, growth is reduced, and, eventually, the plant may die. The temperature of the plant environment should be kept at optimum levels for fast and successful maturation. Both the air and the water temperature must be monitored and controlled.

The relative humidity (RH) of the greenhouse air influences the transpiration rate of plants. High RH of the greenhouse air causes less water to transpire from the plants, which causes less transport of nutrients from roots to leaves and less cooling of the leaf surfaces. High humidity can also cause disease problems in some cases. For example, high relative humidity encourages the growth of botrytis and mildew.

The CO_2 concentration of the greenhouse air directly influences the amount of photosynthesis (growth) of plants. Normal outdoor CO_2 concentration is around 390 parts per million (ppm). Plants in a closed greenhouse during a bright day can deplete the CO_2 concentration to 100 ppm, which severely reduces the rate of photosynthesis. In greenhouses, increasing CO_2 concentrations to 1000-1500 ppm speeds growth, CO_2 is supplied to the greenhouse by adding liquid CO_2. Heaters that provide carbon dioxide as a by-product exist but we do not recommend these because they often provide air contaminants that slow the growth.

Light measurements are taken with a quantum sensor, which measures Photosynthetically Active Radiation (PAR) in the units $\mu mol/m^2/s$. PAR is the light which is useful to plants for the process of photosynthesis. Measurements of PAR give an indication of the possible amount of photosynthesis and growth being performed by the plant. Foot-candle sensors and lux meters are inappropriate because they do not directly measure light used for photosynthesis.

Dissolved oxygen (DO) measurements indicate the amount of oxygen available in the pond nutrient solution for the roots to use in respiration. If no oxygen is added to the pond, DO levels will drop to nearly 0 ppm. The absence of oxygen in the nutrient solution will stop the process of respiration and seriously damage and kill the plant. Pure oxygen is added to the recirculation system in the ponds. Usually the level is maintained at 8 (7-10, no advantage to 20) ppm. For sufficiently small systems, it is possible to add air to the solution through an air pump and aquarium air stone but the dissolved oxygen level achieved will not be as high as can be achieved with pure oxygen.

The pH of a solution is a measure of the concentration of hydrogen ions. The pH of a solution can range between 0 and 14. A neutral solution has a pH of 7. That is, there are an equal number of hydrogen ions (H+) and hydroxide ions (OH-). Solutions ranging from pH 0-6.9 are considered acidic and have a greater concentration of H+. Solutions with pH 7.1-14 are basic or alkaline and have a greater concentration of OH-. The pH of a solution is important because it controls the availability of the fertilizer salts.

Electrical conductivity (EC) is a measure of the dissolved salts in a solution. As nutrients are taken up by a plant, the EC level is lowered since there are fewer salts in the solution. Alternately, the EC of the solution is increased when water is removed from the solution through the processes of evaporation and transpiration. If the EC of the solution increases, it can be lowered by adding pure water, e.g., reverse osmosis water). If the EC decreases, it can be increased by adding a small quantity of a concentrated nutrient stock solution.

Pond water quality is largely defined by temperature, transparency, turbidity, water color, carbon dioxide, pH, alkalinity, hardness, unionized ammonia, nitrite, nitrate, primary productivity, biological oxygen demand and plankton population [2].

The accepted level of ammonia should be under the range of 0.05 to 0.10 mg/l [17] and above range it is toxic to the cultured fish [5].

According to Mizanur et al., intensive aquaculture ponds sediments has various fertilizing components such as nitrogen, phosphorous, sulphur etc. which are very useful for growth and production of aquaponic plants [12]. Moreover, water spinach is an efficient plant having clustered roots that can absorb nutrients from the water very efficiently [8].

The length-weight relationship of water spinach depends on the fertility of media from where nutrients are supplied. The plant's length-weight relationship is attributed to a variety and concentration of nutrients, of which nitrogen is the dominating factor. Waste water of stinging catfish ponds supplied various nitrogenous components of which ammonia has considerable fertilizing supports to the plant under floating condition on the pond surface [8].

6. Conclusions

Water quality parameters such as NH_4/NH_3, NO_3, NO_2, PO_4, pH and dissolved oxygen were measured fortnightly using test kits. Number of flowers, fruits and fruits weight were recorded. All the sampling data were recorded in the Microsoft Excel 7 for analysis.

To understand the environmental condition of pond, the physico-chemical parameters of water were needed to be measured. The main parameters including temperature, pH, dissolved oxygen, nitrate and ammonia were measured before starting the experiment.

Aquaponics is an integrated and intensive fish-crop farming system under constant recirculation of water through interconnected devices. It is considered a promising technology, which is highly productive under correct set up and proper management [9]. First, fish feed is eaten by fish and converted into ammonia (NH_3). Some ammonia ionizes in water to ammonium $\left(NH_4^+\right)$. Then, bacteria (Nitrosoma) convert ammonia into nitrite $\left(NH_2^-\right)$ and consequently bacteria (Nitrobacter) oxidize nitrite into nitrate $\left(NH_3^-\right)$ [19]. Finally, the water delivers nutrients and oxygen to promote plant growth. Graber and Junge, found similar yields between hydroponic systems and aquaponics systems. Finally, it is important to establish systems under "smart water" use and to balance nutrient concentrations in water to ensure maximum fish and plant growth [6].

Aquaponics is considered a method where water and nutrients are efficiently used and maintained within the system [10]. In aquaponics it is possible to reduce daily water loss to 2% of the total water volume of the system. Due to the constant recirculation of water it is also possible to maintain evenly distributed high nutrient concentrations in the water (nitrate) as the small addition of water to compensate the daily loss will not dilute the nutrients [13]. The "water smart" approach makes aquaponics an alternative system to produce food under sustainable practices in areas where water is scarce.

Developing an accurate and practical tool to predict plant and fish growth and monitor nutrient concentrations in water, will improve the adoption and implementation small or commercial scale of aquaponic systems as urban farming or as a business model for household food security.

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