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14th September 2016

Re: Aquaponics Expedition: Assessment of worldwide state-of the-art techniques & technologies for consolidation and adaptation of findings for the UK and Sahara Africa scenario.

Dear Mike,

Thank you for considering me for the Nuffield scholarship and invitation to interview, the proposed set of expeditions is centered around the role technology will have in bringing a prompt end to world hunger. As requested I have attached the following documents:

- Five "Key Question"
- Brief Research Summary

My current role as a Control Systems Engineer at Aquaponics Lab involves a great deal of independent research, requiring initiative, self-motivation and the development of a wide range of relevant skills. Achievements in the aquaponics and electronics sectors in general has led to multiple industrial partnerships and strong personal ties with academic institutes conducting research in a similar area:

- Farnell
- Aquaponics Lab
- Equilibrium Co-op
- AVF [Association Vertical Farming]
- Lancaster University
- Sheffield University
- Liverpool University
- Benin University

I am confident that I can employ these skills and contacts over the period of the Nuffield scholarship to maximise the usage of the available funds and assist the Nuffield Foundation in building upon its reputation for exceptional research. The Area of food security is a high priority for the United Nations, It is a key part of their 2030 Sustainable Development Goals. The global push for food security gives me confidence that that need for research into technology and agriculture will continue along with resources for implementation following the scholarship expedition.

Thank you for your time and consideration

Kind Regards,

Michael Ratcliffe

Motivation

The Nuffield scholarship and network of scholars offers prestige to my work and provides a great opportunity to work with like minded people. This travel experience will further my personal development and to bring new know-how to the UK farming community. I wish to use the Nuffield scholarship to further my aim to see accessible, sustainable and low-cost automation systems and knowledge in the hands of small farmers who currently have little access to technology.

Gaining a global perspective of the use of technology in agriculture will prove useful in the development of technological solutions aimed at increasing productivity of farming systems.

Travel Outline

[See next section for country justification]

Note: To efficiently use the Nuffield scholarship I would like to propose splitting my study time into four one month sections, this will allow me to perform my role at the aquaponics lab while giving time to reflect on the previous trip before departing for the next.

In order to get a good perspective of the Aquaponics industry and get the most from my Nuffield experience it is important that I visit places with well established Aquaponics industries, countries where it is beginning to develop and countries that are promising for the industry but have seen little to no adoption. Below are the proposed countries,:

Part-1 March 2017: Assessment of recent aquaponics projects in developing world by visiting new aquaponics systems, identifying bottlenecks and lack of knowledge. [Brazil]

Part-2 August 2017: Assessment of worldwide state-of the-art techniques & technologies by visiting countries with well established aquaponics industries [Australia, Japan, America,China].

Part-3 October 2017: Assessment of viability in developing world by travelling to key locations, testing environmental conditions and farmer knowledge summarising their suitability to large scale aquaponics [Morocco].

Part-4 January 2018: Offering free consulting and sharing the knowledge gained in previous expeditions [Country to be confirmed].

Five Key Questions

Being an engineer, I much prefer quantitative data over qualitative data, much of the data I need can be derived from experimentation and measurement of key system variables on site, a short example of critical variables relating to management:

- pH Stabilization
- Nutrient Balance
- Water temperature
- Air Humidity
- Air Temperature
- Ventilation rate
- Food Conversion Ratio
- Ammonia Concentration
- Solid Waste Removal
- Dissolved Oxygen Concentration
- Fish Eating Habits
- Fish Health/Activity
- Crop Pests
- Mortality rate

That being said, the chance to interact with site managers and staff is a valuable opportunity. Over the length of the visits I will get to know their routine well and will adapt questions adhoc to suite their situation on top of some generic questions:

1- How important Is technology to your operation [1-10]
2- How many times a week are system variables measured
3- What expertise do you need to subcontract in for operation
4- What advice would you give to a aspiring farmer in this field
5- If you could change one thing about your industry, what would it be.

Research summary

-Quantifying the Problem [The need for Increased Food Production]
-A Promising Solution [Aquaponics]
-Country Justification
-Appendix A- Aquaponics Outline
-Works Cited

The Need for Increased Food Production

Learning how to farm from your father as he did with your grandfather is no longer going to cut it as the world is changing, the problem of food security is a growing concern. Yet, the methods are staying firmly the same. It is estimated that there are 750 million people suffering from chronic hunger and undernourishment around the globe (1).A further 2 billion people are struggling every day to put food on the table (2). There is some controversy surrounding the accuracy of these numbers, brought on by the methodology used to generate these figures (3), although the debate concerns the exact figures rather than the magnitude of the problem.

Fortunately, the problem is being addressed by the UN [United Nations] as objective two of its Global Goals, charting sustainable development for people and planet by 2030. Rightly dubbed the “Zero Hunger Challenge”, and in order to succeed in such a massive task, they are pushing on Countries, Civil Society, Farmers, UN Agencies, Private Sector and Academia to work on solving this problem (4).

Aquaponics

[See Appendix A for a more detailed review]

To achieve the goals set by the UN and realize food security and nutrition goals, it is likely that agriculture will be moving to modern farming techniques (5). Many of these techniques however are too complicated for the vast amount of farmers to comprehend, despite showing great promise with sustainability and productivity. One such modern farming technique that is showing much promise is Aquaponics. The approach of coupling aquatic systems with hydroponics is extremely resource efficient (6).Compared to conventional agriculture, aquaponics uses less than 10% of water, depending on the climatic conditions (7).The cycling of nutrients also leads to a greater degree of nutrient usage than is possible with conventional farming. As an example, only a 1.5–1.9% of nitrogen input is emitted to atmosphere as gas (8).

Some key benefits of aquaponics compared to traditional farming (9):

- Organic Production of Fish [Protein] and Greens
- Low Pollution Factor [No nutrient leech into natural water course]
- Reduced water usage
- Soil Pathogens Eliminated
- High production density

Country Justification

With aquaponics being a rapidly growing industry, demographic statistics can be hard to find and lack secondary studies for result verification. As the industry grows this problem will be solved, but for now that leaves me to select counties based on contacts within the industry and gut feeling based on how much activity I see in the sector from different parts of the world.

Morocco

Visiting morocco was a big influence on my decision to pursue aquaponics as a career, I was there for a two month off-roading trip with a friend and was amazed at the great expanse of desert. After a while it became apparent that most of this desert had a hard rocky surface, such a change from the rich soil of England that I was accustomed to.

Another big surprise was the abundance of water in the area, shallow wells [5-10m in depth] scattered around the desert, the strong sunlight was no surprise. Because of this abundance of water, sunlight and land connected by good quality ports and road transport networks I believe that Saharah Africa has great potential to help feed the worlds growing population.

I would like to again visit morocco, this time with my tools in hand to verify environmental conditions for their suitability to aquaponics at a large scale:

- Water quality
- Rock Types [effects pH]
- Water table depth
- Local Knowledge
- Current Aquaponic Practitioners

Brazil

With the 2017 Nuffield Contemporary Conference being held in Brazil, I will have the opportunity to add Brazil to my list of countries at very little extra travel expense. Brazil is also a country where the Aquaponics industry has big potential and is already semi developed.

The Aquaponics lab have contacts in Brazil who we use for testing our automation systems in a very hot environment with operators who have English as a second language. They are happy to host me free of charge as a guest and interact with any surveying exercises.

Australia/Japan/ America/China

As mentioned previously I would also like to visit places with well established Aquaponics industries, for assessment of worldwide state-of the-art techniques & technologies that can be employed in the UK and other countries with less experience in the sector.

The country of choice will depend on further research into demographics, it will most likely be one of the above countries.

Appendix A

Aquaponics Basics

A small extract from some previous work of mine that outlines Aquaponics:

-How it works

- Advantages of Aquaponics

-Challenges

-Management

-Role of Technology

Aquaponics Basics

Aquaponics brings fish and vegetables together in a symbiotic growing process (10) [see figure-1] Fish are fed on their normal Diet of fish pellets and they process this food, using some of it to grow and passing any extra out as waste, solid waste and liquid urine.The Urine [Ammonia] is high in Nitrogen. The gravel that the plants use to grow stable roots in contains beneficial bacteria that breaks this ammonia down into plant soluble Nitrogen. The solid waste is high in macro nutrients [P and K] and other micro nutrients that plants need to grow.

In summary, the fish dirty the water and the plants clean the water, both growing at an increased rate than if the systems were separate.The result is high-density food production that can be done at scales from the kitchen table to industrial warehouses (10).

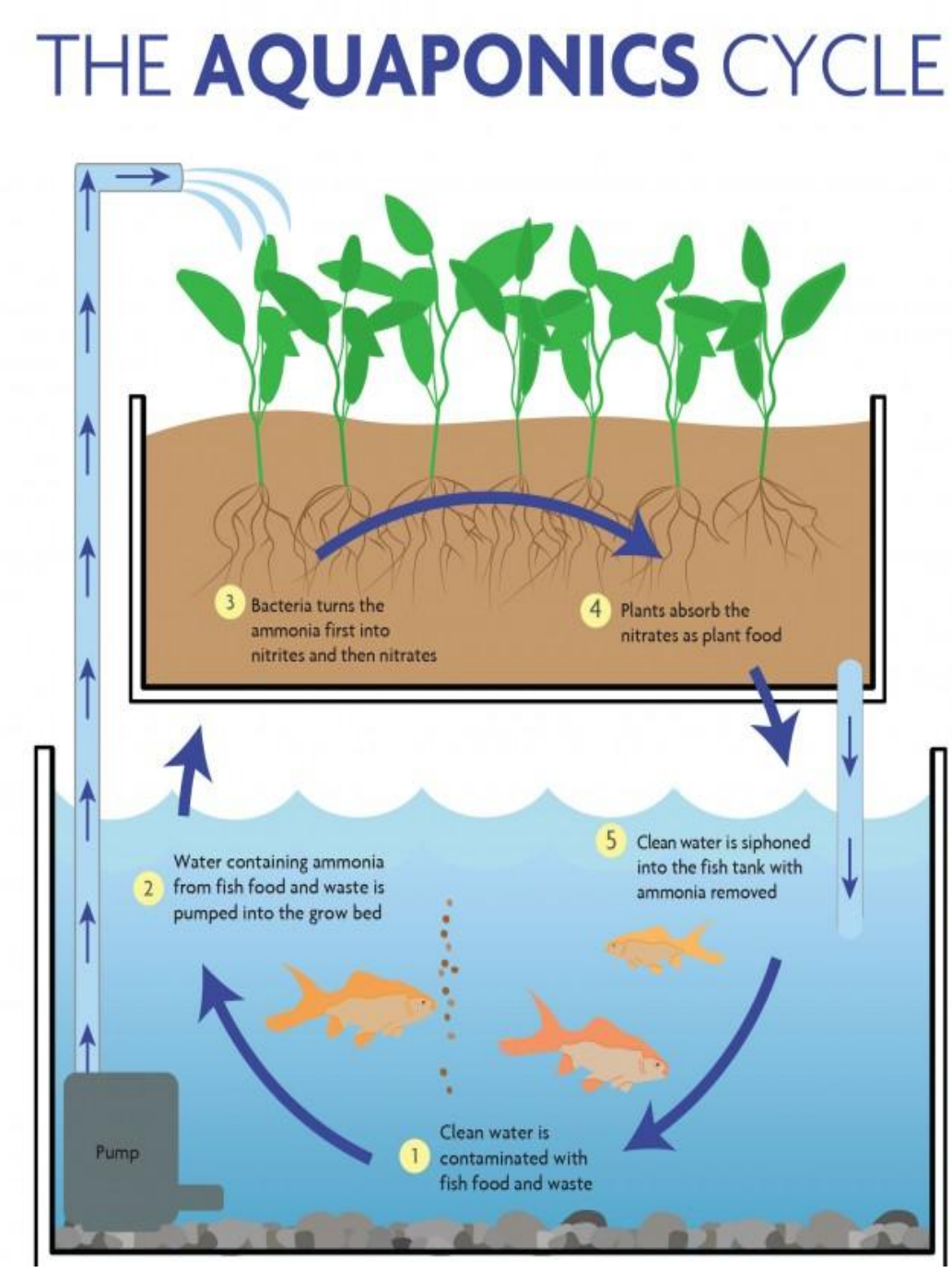

Figure 1: Aquaponics Basics

Advantages of Aquaponics

To achieve the goals set by the UN and realize food security and nutrition goals, it is likely that agriculture will be moving to modern farming techniques (5). Many of these techniques however are too complicated for the vast amount of farmers to comprehend, despite showing great promise with sustainability and productivity. One such modern farming technique that is showing much promise is Aquaponics. The approach of coupling aquatic systems with hydroponics is extremely resource efficient (6).Compared to conventional agriculture, aquaponics uses less than 10% of water, depending on the climatic conditions (7).The cycling of nutrients also leads to a greater degree of nutrient usage than is possible with conventional farming. As an example, only a 1.5–1.9% of nitrogen input is emitted to atmosphere as gas (8).

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Aquaponics Challenges

Aquaponics system design and application can be considered as a highly multidisciplinary approach drawing from environmental, mechanical and civil engineering design concepts as well as aquatic and plant related biology (11).

Managing even a small aquaponics system can become somewhat of a full time job, many variables need to be critically assessed and adjusted to realize the full potential of aquaponics systems production. The variables below are usually kept as close as possible to a static value or set point and these will traditionally be measured and adjusted hourly to daily (12):

- pH Stabilization
- Nutrient Balance
- Water temperature
- Air Humidity
- Air Temperature
- Ammonia Concentration
- Solid Waste Removal
- Dissolved Oxygen Concentration

Cost is also a large barrier to implementation of modern growing techniques. Aatif Hussain (13) summarises it well: “There has already been a great deal of buzz throughout the scientific community for the potential to use soilless culture in third world countries, where water supplies are limited. Though the upfront capital costs of setting up soilless culture is currently a barrier but in the long-run, as with all technology, costs will decline, making this option much more feasible”.

These variables are well suited to traditional control system implementation that is we know that the variable has to be at a set value for prime productivity. There are however other tasks in the aquaponics management system that are not suited to traditional sensing:

- Fish Eating Habits
- Fish Health/Activity
- Crop Pests

These tasks are largely based on visual inspection by a trained and educated operator.

Aquaponics Management

To correctly design a productive aquaponics system one must have expertise in chemistry, engineering and agriculture at a minimum. Recently there has been a rise in government bodies, hobbyists and groups releasing open source design plans for systems that have been well thought-out and verified to perform as expected (14).

The daily management of aquaponics systems however, is still very demanding in time and knowledge, putting it out of the reach of many farmers around the globe. By implementing control systems, it is possible to reduce the demand of time and in depth knowledge of the operator. It is also likely that these control systems could be optimised to not only match a dedicated, educated and patient operator but exceed what is humanly possible.

The variables below are an example of the core system variables that need constant attention:

- pH Stabilization
- Nutrient Balance
- Water temperature
- Air Humidity
- Air Temperature
- Ammonia Concentration

These variables are well suited to traditional control system implementation that is we know that the variable has to be at a set value for prime productivity. There are however other tasks in the aquaponics management system that are not suited to traditional sensing:

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An Example of Management and Productivity

Just as it is with any system, the level of management has a very direct result on the productivity of the system. Aquaponics is relatively demanding of time and knowledge for correct management and prime production (11) leading to educational barriers. Let us break it down into just aquaculture for now. Annually there is 156 Billion kilograms of fish reared [that is more than beef] (15). This has led to heavy academic research in the area of increased productivity that can reliably be called upon. The raising of fish is quite a complex matter consider Figure 2, these are only the elementary functions controlling the feeding of fish.

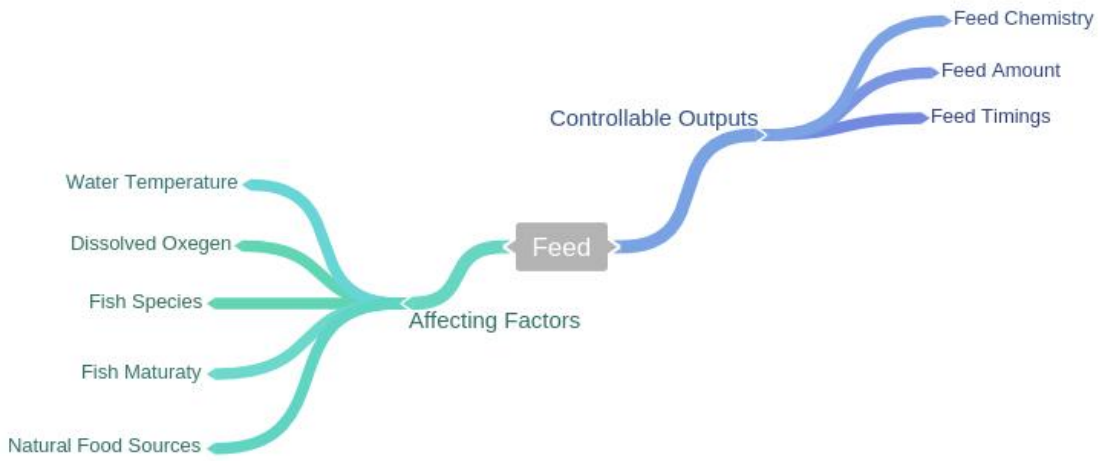

Figure 2: **Fish Feeding Variables (16)**

Research on optimum feeding regimes have shown increases in productivity of 40%, food efficiency by 20% compared to conventional once per day feeding (17). In simpler terms, good fish management leads directly greatly increased productivity and resource efficiency. The downside is these types of feed managements need a dedicated expert to achieve, not something that is very common in the nations suffering from a food crisis.

The Role of Technology

Control systems engineering and the engineering discipline that applies control theory to implement automation of systems to generate desired behaviors in the system. In a wider sense it is the engineering discipline of automating systems to achieve ideal operating conditions, the benefits of system automation can be summarised as (18):

- Can operate 24 hours a day with no breaks.
- Can work without holidays or sick days.
- Will work without any wages.
- Will accurately repeat actions over and over again.
- Can process data from sensors very quickly.
- Can take account of hundreds of inputs at the same time.
- Can make reliable and accurate decisions.
- Can be used in dangerous or awkward environments.

Control theory is a heavily researched area of engineering, with mathematical principles being investigated by Airy as early as 1826 (19). Over the years, it has seen the development of strategies to control a vast range of systems. The advent of the computer has largely increased the power of control systems engineering and now it silently and efficiently runs many modern systems that we take for granted.

Many of the tasks in aquaponics are repetitive, demanding in time and knowledge. However by breaking down the management processes of aquaponics into distinct operations, it become apparent that control strategies exist for similar tasks in different industries. Take the controlling of pH as an example, it is a common process variable to be controlled in many chemical processes (20).

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