OPTIMISING AQUAPONICS PRODUCTION IN SOUTH AFRICA THROUGH THE DEVELOPMENT OF A MODEL USING LOCAL SPECIES AND ENVIRONMENTAL CONDITIONS

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ABSTRACT

Aquaponics (aquaponics systems) are the production of fish and vegetable at the same time by linking aquacultural fish waste to hydroponically growing plants. This waste serves as a natural nutrient source material to support plant life cycle in a water circulating system. In return, plants clean and purify water in the fish tanks thereby making it conducive for fish breeding and well-being. Despite its relevance to farming industry, aquaponics are still a new and emerging practice in developing countries like the Republic of South Africa (RSA) such that it has not been fully explored as a field of study. As a result, this study suggests that there is insufficient empirical information and tools, if any, to help local farmers in making decisions in order to have better opportunity to optimize their production system. Aquaponics has been shown to be a productive and innovative production system for sustainable nutrient cycling to supplement food production at all times. Aquaponics related benefits include the use of less water than conventional agriculture and, in particular, it provides an option for nutrient recycling and reuse. This is suitable and important for RSA to address water scarcity and food insecurity problems, which the country is currently facing. The primary aim of this study is to develop a decision-making tool (model) that can predict production of various aquaponics setups in RSA using local species and environmental conditions. The model is envisage to assist farmers as a decision tool in order to enable farmers to have better opportunity to maximise production for their aquaponics. To fulfil the aim of this study, the specific objectives were, (a) to determine the use of aquaponics and typologies currently in use in RSA, (b) to develop an aquaponics model specific to RSA species and conditions and to calibrate and validate the model, as a management tool suitable for RSA, (c) to determine the applicability of the tool to various aquaponics scenarios in RSA and (d) to assess the overall sustainability (economic, environmental and social), of various aquaponics in use in RSA. The study will follow a mixed method approach, which combines the methods and procedures of quantitative and qualitative data in a single study, using different sources of data. In this context, the study will collect data from people who already have an aquaponics in place using a self-administered web based questionnaire, observations, key informant face-to-face interviews and secondary literature relevant to the topic in discussion. This study purport that current aquaponics in RSA are quite small and few in extent. It is also assumed that the proposed decision-making tool/model will have the capacity to predict various aquaponics
setups production in RSA, giving local people better opportunity to maximised aquaponics production.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>i</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>v</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>vi</td>
</tr>
<tr>
<td>DECLARATION</td>
<td>vii</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>2 LITERATURE REVIEW</td>
<td>6</td>
</tr>
<tr>
<td>2.1 Overview of Soilless Systems</td>
<td>6</td>
</tr>
<tr>
<td>2.2 Hydroponics</td>
<td>6</td>
</tr>
<tr>
<td>2.3 Aquaculture</td>
<td>8</td>
</tr>
<tr>
<td>2.4 Aquaponics</td>
<td>9</td>
</tr>
<tr>
<td>2.5 Feed Conversion Ratios (FCR) and Species Combination for Aquaponics</td>
<td>11</td>
</tr>
<tr>
<td>2.6 Tilapia (<em>Oreochromis niloticus</em>) Production in RSA</td>
<td>13</td>
</tr>
<tr>
<td>2.7 Approaches to Optimising Aquaponics Nutrient Flow</td>
<td>13</td>
</tr>
<tr>
<td>2.8 Nutrient Flow in Aquaponics</td>
<td>14</td>
</tr>
<tr>
<td>2.8.1 Nitrification</td>
<td>15</td>
</tr>
<tr>
<td>2.8.2 Denitrification</td>
<td>15</td>
</tr>
<tr>
<td>2.9 Principles of Modeling and Model Development</td>
<td>16</td>
</tr>
<tr>
<td>2.10 Sustainability of Aquaponics</td>
<td>19</td>
</tr>
<tr>
<td>2.10.1 Environmental sustainability</td>
<td>20</td>
</tr>
<tr>
<td>2.10.2 Economic sustainability</td>
<td>21</td>
</tr>
<tr>
<td>2.10.3 Social sustainability</td>
<td>23</td>
</tr>
<tr>
<td>2.11 Role of Aquaponics to Food Security</td>
<td>24</td>
</tr>
<tr>
<td>2.12 General Discussion and Conclusions</td>
<td>25</td>
</tr>
<tr>
<td>3. PROPOSAL</td>
<td>27</td>
</tr>
<tr>
<td>3.1 Rationale</td>
<td>27</td>
</tr>
<tr>
<td>3.2 Research Aim</td>
<td>28</td>
</tr>
<tr>
<td>3.3 Research Questions</td>
<td>28</td>
</tr>
<tr>
<td>3.4 The specific objective of the study were</td>
<td>29</td>
</tr>
<tr>
<td>3.5 Originality of the Study</td>
<td>29</td>
</tr>
<tr>
<td>3.6 Study Area</td>
<td>29</td>
</tr>
<tr>
<td>3.7 Survey</td>
<td>30</td>
</tr>
</tbody>
</table>
3.8. Data Collection and Analysis................................................................................................. 30
3.9. The Model and its Development.......................................................................................... 31
  3.9.1. Model calibration.............................................................................................................. 34
  3.9.2. Biofilter area .................................................................................................................. 34
  3.9.3. Water flowrate .............................................................................................................. 35
  3.9.4. Recommended method of plant production................................................................. 35
  3.9.5. Validation and verification............................................................................................. 35
  3.9.6. Analysis........................................................................................................................ 36
3.10. Running Specific Aquaponics Scenarios ............................................................................ 36
3.11. Aquaponics Sustainability Analysis.................................................................................... 37
  3.11.1. Data analysis ............................................................................................................... 38
3.13. Equipment and Resources............................................................................................... 40
3.14. Expected Outcomes ......................................................................................................... 40
4. REFERENCES .......................................................................................................................... 41
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>NFT system</td>
<td>7</td>
</tr>
<tr>
<td>2.2</td>
<td>Floating raft system</td>
<td>7</td>
</tr>
<tr>
<td>2.3</td>
<td>Growth medium bed system</td>
<td>8</td>
</tr>
<tr>
<td>2.4</td>
<td>Recirculating aquaculture system</td>
<td>9</td>
</tr>
<tr>
<td>2.5</td>
<td>Aquaponics nutrient flow</td>
<td>11</td>
</tr>
<tr>
<td>2.6</td>
<td>Aquaponics showing the main components</td>
<td>11</td>
</tr>
<tr>
<td>2.7</td>
<td>Represents the beginning of a process or workflow in an activity diagram</td>
<td>18</td>
</tr>
<tr>
<td>2.8</td>
<td>Represents a decision process and always has at least two paths branching</td>
<td>18</td>
</tr>
<tr>
<td>2.9</td>
<td>Shows the directional flow, or control flow, of the activity</td>
<td>18</td>
</tr>
<tr>
<td>2.10</td>
<td>Indicates the activities that make up a model process</td>
<td>18</td>
</tr>
<tr>
<td>2.11</td>
<td>Marks the end state all flows of a process</td>
<td>18</td>
</tr>
<tr>
<td>2.12</td>
<td>UML as it relates to model flow chart</td>
<td>19</td>
</tr>
<tr>
<td>2.13</td>
<td>Sustainable aquaculture system</td>
<td>20</td>
</tr>
<tr>
<td>3.1</td>
<td>Aquaponics model design flow chart</td>
<td>33</td>
</tr>
</tbody>
</table>
LIST OF TABLES

Table 2.1 Feed rate ratio and planting density ................................................................. 12
Table 3.2 Derived aquaponics production ratios ............................................................... 34
DECLARATION

INTOBEO MCHUNU declare that

i. The research reported in this thesis, except where otherwise indicated, is my original work.

ii. This thesis has not been submitted for any degree or examination at any other university.

iii. This thesis does not contain other persons’ data, pictures, graphs or other information unless specifically acknowledged as being sourced from other persons.

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Signed:
Supervisor:
Co-supervisor:
1. INTRODUCTION

The increase in population and urbanization has resulted in increased need for food and water in RSA (Rana et al., 2011; Food and Agriculture Organisation (FAO, 2014)). In general, the Republic of South Africa (RSA) is a water and nutrient scarce country and there is a need to conserve this resource pool (Molobela and Sinha, 2011; Sinefu, 2011). RSA is among other 30 driest countries in the world, having an annual average rainfall of ±500 mm (Sinefu, 2011). This is a comparatively lower rainfall amount than worldwide annual averages of 860 mm (Mabhaudhi, 2012). This then, suggest that, RSA water resources are scarce and limited in extent (Mabhaudhi et al., 2013). Hence, the International Water Management Institute (IWMI) has categorised RSA as a water stressed country (Mabhaudhi et al., 2013).

Moreover, it has been proven that the continuous use of synthetic fertilisers over time depletes soil diversity which is needed for crop production (Murugan and Swarnam, 2013; FAO, 2014) and challenges such as soil-borne diseases, weeds, and soil infertility, associated with soil plant production has made the soil culture risky and at times undesirable (Andersson, 2015). As a result of the need to produce more and good quality food, without further damage to the natural environment, there has been an exploration of soilless agricultural systems (Kratky, 2009).

Nitrogen (N) and phosphorous (P) are the main essential nutrients that are utilized in high quantities by aquatic organisms, particularly fish, to grow (Lam et al., 2015), and by plants to produce food (Mchunu et al., 2018). However, these nutrients are becoming more and more limiting in agriculture as it is expected that in the near future phosphate rock will run out (Roosta and Hamidpour, 2011). Similarly, the production of nitrogen fertilizers from atmospheric N is also expensive (Nyamangara et al., 2009). While biological N fixation has great potential, its use also requires other nutrients to grow the legumes (Nyamangara et al., 2009; Murugan and Swarnam 2013). Alternative sources of these nutrients need to be sought if sustainability of agriculture is to be achieved in RSA (Mchunu et al., 2018).

Amongst the list of soilless systems, there are three mostly adopted soilless production systems in agriculture, these are; aquaculture and hydroponic and recently aquaponics (aquaponics systems). Each system has a related benefit of saving water and sustainable food production (Goddek et al., 2015). In general, aquaculture and hydroponic production are common and
Hydroponics is a method of growing plants using mineral nutrient solutions, in water, without soil (Sikawa and Yakupitiyage, 2010). In hydroponic terrestrial plants are grown with their roots in the mineral solution only (in Nutrient Film Technique and in Floating raft system), or in an inert medium, such as perlite or gravel (Monnet et al., 2002).

Aquaculture is the farming and husbandry of aquatic organisms under controlled or semi-controlled conditions (Allison, 2011; United State Agency for Internation Dedevlopment (USAID, 2013)). According to FAO and USAID, aquaculture plays a critical role in food and nutrition security and in providing for the livelihoods of millions of people across the world including Africa (USAID, 2013; FAO, 2015). However, even though aquaculture plays a significant role in providing a livelihood for most households, like other systems, aquaculture is also faced with challenges of maintaining water quality to avert negative environmental impact.

It has been speculated and shown in literature (of more than 25 year research by Rakocy, 1989; Lennard, 2004 and 2012; FAO, 2014 and USAID, 2013), that the net nitrogen (N) and phosphorous (P) concentration in the aquacultural effluent equals to the nutrient requirement of most vegetables, flowers and herbs, hence, qualify as a potential nutrient source for plants (Birkett and de Lange, 2001). However, this may pose a pollution problem if disposed of in the environment (Mnkeni and Austin, 2009). As a result, aquacultural waste and effluent runoff can contribute to negative environmental impacts associated with eutrophication thereby affecting fish well-being (FAO, 2014). Eutrophication is the significant richness of nutrients in lakes and in other water bodies, predominantly due to water run-offs from crop lands, which trigger a growth of plant life (Schouw and Tjell, 2003).

Aquaponics combines aquaculture and hydroponic production systems into one system (Rakocy, 2007), and has been described as superior since it combines these two systems together (FAO, 2014). Aquaponics are common and well known overseas being most popular in Australia (Goddek et al., 2015). However, aquaponics are still a new and emerging technology in most African countries, including RSA. This opens a new niche for sustainable food production, which is necessary and important for RSA to optimize its food availability at all times. To make good use of aquacultural effluent and wastes, aquaponics have been designed with dual potential effect such as, (a) to reduce aquacultural fish waste product that
may otherwise cause water pollution problem in other environment bodies, and (b) to use nutrient-rich aquacultural effluent to produce healthy food suitable for active healthy life (Khater et al., 2015; Lam et al., 2015).

Aquaponics are the production of fish and vegetable at the same time through linking aquacultural fish waste to hydroponically growing plants as natural nutrient source material to support plant life cycle (Sace and Fitzsimmons, 2013; Roosta, 2014). Aquaponics related benefits include the use of less water than conventional agriculture and in particular, it creates a platform for nutrient recycling and reuse (Munguia-Fragozo et al., 2015). This, in particular, is suitable and important for RSA to address water scarcity and food insecurity problems.

RSA is one of the nutrition insecure countries amongst others in Africa. Fish meat provides nutritious foods that contribute significantly to human well-being for an active healthy life with related economic production (Allison, 2011; USAID, 2013 and FAO 2014). However, in most rural areas of RSA, freshwater fish and fish meals are not regarded as food or as a meal by the majority, rather it is discredited with related traditional beliefs (Faber et al., 2011). This is of a great concern because the majority of food and nutrition insecure people resides in rural areas, where the consumption and need for fish and fish meals ideally needs to be high to combat food and nutrition insecurity (USAID, 2013). Hence, nutrition insecurity in RSA could be the result of limited fish inclusion in meals of most households. As such, systems like aquaponics could be in the center to address these challenges.

Since it has been shown that aquaponics is still a small and emerging practice in RSA. This study suggests that there is insufficient empirical information and tools, if any, to help farmers with decision making in order for farmers to have better opportunities to maximize their system production. At the same time, aquaponics has been shown to be a productive and innovative production system for sustainable nutrient cycling to supplement food production at all times (USAID, 2013). The idea of aquaponics may be useful to a country like RSA that has limited agricultural production resources including water and fertile croplands, high urbanisation rate and increasing urban poverty. Aquaponics can provide quality food diversity such as protein and greens, for both rural and urban areas (Lennard, 2004; Rakocy, 2007; Diver and Rinehart, 2010; Hu et al., 2015; Liang and Chien, 2013). In addition to food production, aquaponics plays a critical role in safeguarding our environment. Aquaponics being a closed system, aquaponics avoids fertiliser runoff, which contaminates the environment (Munguia-Fragozo et
This implies that aquaponics has the potential to contribute significantly to sustainable organic food production. Furthermore, aquaponics has been shown as complex to manage such that balancing fish feed in aquaculture fish tank for maximum hydroponic plant production is often challenging (Goddek et al., 2015). The common problem in aquaponics are associated with environmental conditions and the type of species raised, which often make it difficult for fish to establish an independent viable economic population for production (Diver and Rinehart, 2010; FAO, 2014; Sikawa and Yakupitiyage, 2010). As such, this suggest that in order to kick start aquaponics in RSA could require an understanding of local environment conditions which could be associated with optimum production of different fish and plant species. This is because fish metabolic processes are very strict, sensitive and specific to temperature and climatic conditions (Rakocy, 1989). As such, decision tools such as one which was developed by Lennard (2004) could assist local farmers to have better chance to maximise production output by taking in to consideration model recommendations. At the same time, it is also important to note that aquaponics models and models in general are not and cannot be a substitute for real production on the field (Mazzotti and Vinci, 2007). However, when calibrated and validated with data from field experiments, they can help lower the overall costs of field experiments with regards to time and space (Trucano et al., 2006).

The main objective of this study is to develop an aquaponics model in RSA by conducting online survey. This documents contains all important topics related to the development and finalization of the study. These include literature review, project proposal and expected outcomes.
2 LITERATURE REVIEW

This is the literature review chapter containing all relevant information and topics of the area of study.

2.1 Overview of Soilless Systems

In soilless production, plants are raised without using soil as a growth medium, in most cases it is because of related soil infertility (low potential areas), erosion, adverse weather conditions and soil borne diseases problems associated with risk of field production (Andersson, 2015). The method of not using soil as a crop stand saves significant water because in soil systems water can leach to ground water (Diver and Rinehart, 2010). There are various common and available soilless productions systems which, include hydroponic, geoponics, aquaponics, vertical gardens and tunnel or greenhouse aquaculture culture (FAO, 2014). Soilless production plays a critical and unique role in providing out of season food (meat and crop plants), herbs and flowers (Roosta, 2014). As a result, soilless systems have been a viable option to food and nutrition security in many developing countries including Nigeria, RSA (Ibironke, 2013). However, there is little known or documented information about these systems in Africa, particularly in RSA. It is now well documented that the systems that make up an aquaponics are hydroponic and tank aquaculture, and these systems are well documented across most school of thoughts. Aquaponics lags behind. This also suggest that aquaponics are still an emerging practise worldwide and needs attention (Love et al., 2015). This is because aquaponics has proven to be superior in the long run over hydroponic and aquaculture because it combines these two systems as one system producing fish and plants at the same in a sustainable way.

2.2 Hydroponics

Hydroponics or hydroponic culture it where by plants are produced in a soilless growth medium where all mineral nutrients delivered to plants are dissolved in water before nutrients are available to plants (Ibironke, 2013). In summary, Roosta (2014) in agreement with Kratky (2009) and Monnet et al. (2002), described hydroponic as growing plants with nutrients and water without soil. There are two types of hydroponic systems that are usually in use, these are liquid and growth medium production systems (Kratky, 2009). The liquid hydroponic culture
usually adopts nutrient film technique (NFT) (Figure 2.1), and Deep Water Culture (DWC)/floating rafts system (Figure 2.2) (Lennard, 2004). For growth medium, hydroponic systems adopt various inert material such as, pea gravel, perlite, peat moss, peat, sawdust, rock wool, coconut fiber, grow stones, oasis cubes, vermiculite, coarse sand and expanded clay pellets (Figure 2.3) (Bugbee, 2004).

**Figure 2.1 NFT system (Shretha and Dunn., 2010).**

**Figure 2.2 Floating raft system (Shretha and Dunn., 2010).**
Aquaculture is the farming and husbandry of aquatic creatures under regulated or semi-regulated environmental conditions (Figure 2.4). These organisms may be fish, plants, shellfish, crabs, crawfish, shrimp, mussels and clams (USAID, 2013; FAO, 2015). However, Allison (2011) looked at aquaculture from the point of a farmer and argued that aquaculture can be viewed as agriculture, where the farmer farms the water instead of the land. On the contrary, there has been an environmental concern associated with aquacultural effluent and wastes, in that, it might contain significant nutrients enough to cause eutrophication in waters bodies if disposed of in the environment. This could affect environmental sustainability and fish well-being (Rana et al., 2011). To address this, various filtering methods have been developed and tried in aquaculture to avert negative impact of aquacultural effluent wastes. This included, the making and creation of wetlands using aquaculture waste (FAO, 2015), and the second fast growing method is aquaponics, which involves circulating aquacultural waste as a nutrient source to growing plants in hydroponic culture (Graber et al., 2014).
2.4. **Aquaponics**

Most literature agrees that aquaponics are the production of fish and vegetable (fish and greens) at the same time. This literature includes Love *et al.* (2015) who defined aquaponics as a bio-integrated system that links recirculating aquaculture with hydroponic vegetable, flower, herb production (Figure 2.5 and 2.6), which, in the process saves a significant quantity of water suitable for agricultural innovation. This is also in line with Lam *et al.* (2015) who had a similar view of definition of aquaponics but emphasized aquaponics as a most sustainable and healthy production system compared to field production. The aquaponics recirculating systems are designed to raise large quantities of fish in relatively small volumes of water (20 kg of fish per 1000 m³ volume of water). This makes aquaponics the most innovative and ideal food producing method suitable to today (Wilson, 2005). In addition, it plays a critical role in agricultural evolution and advancement. In aquaponics, effluent that is generated from the fish tanks is pumped and used to fertigate growth medium beds (GMB) in hydroponic culture (Rakoey, 2007). In return, this process is critical to the fish, because crop plants roots system together with rhizobacteria helps to extract available nutrients from water solution. The
nutrients materials produced from fish metabolic and excretion waste, manure, and decomposing uneaten fish feed are pollutants that could build up to lethal levels in fish tanks instead serve as liquid mineral fertilizer in hydroponic culture (Monnet et al., 2002). The hydroponic culture function as a biofilter (Graber and Junge, 2009) by removing off ammonia, nitrates, nitrites, and phosphorus and other trace elements. This enables the freshly cleansed water to be recirculated back into the fish tanks (Liang and Chien, 2013). The nitrifying bacteria living in the biofilter and growing medium in association with the plant roots play a crucial role in nutrient cycling (Palm et al., 2014). In the absence of these microorganisms, the whole system would not be viable (Munguia-Fragozo et al., 2015), this shows and suggest that aquaponics are dependent on other component for it to function.

Water is the natural backbone to all agricultural systems, but water in aquaponics are the most crucial input (Rafiee and Saad, 2005). This is because even though fish is a water creature, but fish health and quality could also be affected if water quality is poor and degenerated (FAO, 2014). In particular, a fish raised in recirculating tank culture, requires good water quality conditions as fresh water fish are very sensitive to environmental conditions, particularly in RSA because it is well document that RSA outside average environmental conditions does not support a viable economic production of fish population (Liang and Chien, 2013). Critical water quality parameters include dissolved oxygen (to be kept between the range of 4-8 mg/L), carbon dioxide, ammonia, nitrate, nitrite (to be kept between the range of 3-100 mg/L), pH, chlorine, and other characteristics (Endut et al., 2010; FAO, 2015). The stocking density of fish, the growth rate of fish, feeding rate and volume, and related environmental fluctuations can prompt rapid changes in water quality. As such, constant and vigilant water quality monitoring is required to keep the system running smoothly (Fox et al., 2010).
2.5. Feed Conversion Ratios (FCR) and Species Combination for Aquaponics

Feed Conversion Ratio (FCR) is defined as the amount of dry feed required to produce one kg of wet fish (Nunes et al., 2014). Rafiee and Saad (2005) reiterated that FCR is the amount of feed the fish is able to convert into body mass over time and it determines aquaponics nutrient release over time. On average, fish is generally kept at 1 kg per 100 m³ tank which is equivalent to 10 kg/1 000 m³. Ideally, this is a low stocking density, and it will convert to support
approximately 20 lettuce plants in the hydroponic culture (Sace and Fitzsimmons, 2013b). Diverse types of fish species could be cultivated in a controlled or regulated environment aquaponics conditions (Lennard, 2004). The cold and warm water fish species are both promptly and easily adapted to recirculating aquaculture systems (Allison, 2011). These fish species, include tilapia, trout, catfish, arctic char, perch and bass (FAO, 2015). However, the management and practices vary with the type of species raised, because different fish have different morphological and physiological environmental requirements (Wortman, 2015). The selection of plant species to adapt to the hydroponic culture in aquaponics greenhouses is determined by stocking density of fish tanks and subsequent nutrient concentration of aquacultural effluent (Pardossi et al., 2002). Vegetables such as herbs, lettuce, and specialty greens (chives, spinach, basil, and watercress) have low to medium nutritional requirements, and are well adapted to aquaponics (Goddek et al., 2015). The crop plant that yields fruit such as bell peppers, tomatoes and cucumbers have a higher nutritional demand and perform better in a heavily stocked and well established aquaponics (Buzby and Lin, 2014) as shown in Table 2.1.

Most commercial aquaponics are based on tilapia production (Rafiee and Saad, 2005). Tilapia are an ideal species because they mostly grow in temperatures that are similar to those required by the plants. They also grow fast and are tolerant to a wide range of environmental climatic conditions. This is what makes tilapia one of the most cultured fish across the world (Popma and Masser, 1999). It is also documented that, Barramundi and Murray cod fish species have been raised in recirculating aquaponics in Australia (Lennard, 2004). It is confirmed by various literature, including over 25 years of research by James Rakocy at the University of Virgin Island (UVI), in United States of America that tilapias are the most farmed fish species (Nunes et al., 2014a). Tilapia has been combined with most vegetables including lettuce, cucumber, tomatoes, herbs and most of the other leafy and fruity vegetables, and has been shown to be highly viable and productive in most cases or areas of the world (FAO, 2015).

Table 2.1 Feed rate ratio and planting density (FAO, 2015)

<table>
<thead>
<tr>
<th>Vegetable type</th>
<th>Feed Rate Ratio (g/m²/day)</th>
<th>Planting density (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leafy</td>
<td>40-50</td>
<td>20-25</td>
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<tr>
<td>Fruiting</td>
<td>50-100</td>
<td>4-8</td>
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2.6. Tilapia (*Oreochromis niloticus*) Production in RSA

Tilapia (*Oreochromis niloticus*) is the mostly farmed fish species in aquaponics in the world (Popma and Masser, 1999). Tilapia is a warm-water species that grows well in a recirculating tank culture with tolerance to fluctuating water conditions such as pH, temperature, oxygen, and dissolved solids. Tilapia can tolerate as much as (9-42.5 °C) water temperatures, dissolved oxygen as low as 0.1 mg/L, and anionized ammonia concentration of 2.4 mg/L, among others this could also explains why tilapias are the most farmed freshwater fish in the world (Nunes *et al*., 2014; Rakocy, 1989). Tilapia produces a white-fleshed meat rich in protein suitable for local and wholesale markets for easy availability and accessibility (USAID, 2013). However, in RSA Nile tilapia have not been able to establish a viable population in most areas of the country. Tilapia require an average temperature of 28 °C ranging between within 26 to 30 °C (Lam *et al*., 2015). These conditions need to be present for at least 7.5 months to establish a viable economic population. This is not achievable with RSA climatic conditions (Van der Waal, 2000). However, genetically improved tilapia that grows at an average rate of 2.75 g a day can be harvested within six months, still this is limited by winter colds of South Africa making the country nearly impossible for a viable independent economic pond fresh water aquaculture production (Rakocy, 1989). Nevertheless, the findings are exposing a research gap and the need for genetic engineering advancements in the field of aquaculture, particularly in RSA. To maximize fish growth within three to four months, in order for countries with low average temperatures to support independent economic establishment of fish population, to also have opportunity to achieve food and nutrition benefit associated with fish production.

2.7. Approaches to Optimising Aquaponics Nutrient Flow

Feed Conversion Ratio (FCR) is very important in aquaponics management because it determines nutrient balance, release and flow in the system. There are currently two scientifically proven approaches to address feed conversion ratios in aquaponics. The first model was developed by Rakocy from the University of Virgin Island (UVI), and the model was named after him and his team- UVI/Rakocy (Rakocy *et al*., 2006). The nutrient flow approach was developed from more than 20 years of research in aquaponics by Rakocy (Rakocy, 1989). He proved that fish produces significant quantities of nutrients particularly nitrogen and phosphorous which are important for plant production. However, fish have different nutrient requirements to plants, as such, waste produced will not fully support
complete life cycle of growing plants. In turn, there will be a need to supplement other nutrients particularly trace elements. The significantly short mineral nutrients in the fish feed are Ca, K and Fe to which these nutrients are significantly important for crop plant production.

The UVI approach was recently challenged and adapted by Lennard when he was conducting a Ph.D. study that sought to optimise aquaponics production in Australia (Lennard, 2004). Out of a series of scientific experiments, one of Lennard’s Ph.D research outputs was the aquaponics model that predicted nutrient conversion of Murray cod for hydroponic production of vegetables (Lennard, 2004). Both the UVI and Lennard approaches agreed with each other, in that fish nutrient requirements are different from those of plants, and as such, when you try to balance one element others become short or in excess. Both approaches support the view that, to achieve sustainable nutrient flow, other elements will need to be supplemented.

There is a clear scientific evidence that aquaponics are a complicated system as it requires balancing nutrients and a sound simultaneous knowledge of two significantly different agricultural enterprises (fish and greens). As such, if aquaponics were to contribute in food and nutrition security in RSA, there will be a need for innovative tools to make aquaponics work. Among other options, it include developing an aquaponics model with user interface inputs and implement outputs model recommendations.

2.8. Nutrient Flow in Aquaponics

Fish waste produces significant quantities of ammonia-N and solids which have been shown to contain average plant nutrients sources that equal to the most vegetables nutrient requirements, hence, important for hydroponic plant production (Buzby and Lin, 2014). However, for fish waste to be made available to most plants, it has to go through mineralization process (Nyamangara et al., 2009). Mineralization is the process by which organic matter (solids) breaks down in the environment (aquaponics) (Hu et al., 2015). There are five main mechanisms that are responsible for mineralization, which in turn determines nutrient release pattern in an aquaponics, these mechanisms are, ammonification, nitrification, denitrification, immobilisation and volatilisation (Rafiee and Saad, 2005). Mineralization occurs quickly, less than a week (3-7 days) when conditions are perfect for bacteria to reproduce (Johnson et al., 2005). The conditions that favour optimum mineralization are high aeration, adequate moisture, appropriate pH, and balanced mineral nutrients (Roosta, 2014). The environmental
and growth media mineralogy factors affect the microflora players and their actions, which in turn determine the rate of mineralization in the system and the amount mineralized over time (Nyamangara et al., 2009). Microbial activity is limited at a temperature near freezing and at low pH less than 5.5 and increases with rising temperature and pH. Maximum nitrogen mineralization occurs when the temperatures in the system reach 30–36 °C. However, the decline in N mineralization indicates low microbial activity and a degradation of the biological properties of the grow medium (Lund, 2014). When temperature, moisture and pH is favourable for microorganisms to metabolize, it results in Mineralization whereas, the opposite of the process leads to immobilisation.

### 2.8.1. Nitrification

Nitrification is the transformation of NH$_4^+$- N (ammonium- N) into NO$_3^-$- N (nitrate- N) (Johnson et al., 2005). The requirements for optimum nitrification rate includes moisture (water), aeration (very critical in aquaponics), alkaline pH ranges and warm temperature conditions (Graber and Junge, 2009b). There are two types of bacteria or microorganisms that contribute to nitrate-N formation (nitrification). These are *Nitrosomonas europaea* which oxidizes ammonium-N into nitrite- N, nitrite-N is further oxidized by *Nitrobacter winogradskyi* into nitrate-N (Graber and Junge, 2009a). However, nitrification is inhibited at high temperature, whereas high temperatures result into the availability of N as ammonia-N. This contributes significantly to increased ammonium-N volatilization and reduced nitrification rate (Lam et al., 2015) which, is the important management factor in aquaponics. The optimum temperatures for nitrification vary between 25-30 °C. The pH for both processes is at 8.5 but steps differ with regards to their tolerance ranges. In acidic condition at pH less than 5.5 the nitrification is low and weak, which accounts for less nutrient availability (Khater et al., 2015). Nitrification requires sufficient oxygen supply, this a very important management factor in aquaponics given that water and suspended solids can suffocate the system (FAO, 2015). While restricted aeration delays nitrification, oxygen determines the speed of the process, and metabolisms are increased with increase in oxygen to the bacteria (Goddek et al., 2015).

### 2.8.2. Denitrification

Denitrification is the gaseous loss of nitrogen to the atmosphere via a microbial respiration process (Johnson et al., 2005). This process occurs under anaerobic conditions where microbes
obtain their O₂ from NO₂⁻ N and NO₃⁻ N with the associated release of N₂ and N₂O (Lund, 2014). The environmental concerns about emission of nitrous oxides are mainly related to the effect on global warming and the role of nitrous oxides in ozone destruction (Rafiee and Saad, 2005). The destruction of O₃ is catalyzed by NO, halogens, hydroxyl, and hydrogen (Brummett and Ponzoni, 2009). A possible source of NO is from N₂O, the product of denitrification, which can diffuse into the upper atmosphere and lead to atmospheric holes, hence causing problems for plants and animal life well-being from excessive exposure to ultraviolet radiation (Allison, 2011). To avoid these implications, aquaponics too, has to avoid denitrification as much as possible. It has been shown by (FAO, 2015), that the best common management strategy is to select a best growing method (NFT, GMB and DWC) that will allow suitable condition for microbial growth and production in order to avoid denitrification implications (Lennard, 2004; Rakocy et al., 2006).

2.9. Principles of Modeling and Model Development

Modelling is the simplified representation of a real system, in this case, aquaponics, and it requires a complete understanding of systems processes (Janse, 1997). In aquaponics, this include processes such as nitrogen mineralization, nutrient flow in the system (fish to plant), plant and fish ecosystem (Mazzotti and Vinci, 2007). Aquaponics can be very complex and sometimes near to impossible where there is lack of expertise. This is because aquaponics requires a sound simultaneous understanding of two agricultural enterprise (fish and crop plants) ecosystems. Models help to outline, organize and represent thoughts and understanding into a form of computer model or software (Daggupati et al., 2015). Models can act as a support tool for planning, decision making, output forecasting, and identifying research gaps (Mabhaudhi et al., 2013). As such, a model has the capacity to help solve or simplify aquaponics complexity for any ordinary person to use and foster related food security and economic production, However, it must also be noted that model application varies with systems dynamics and resources available (Schieritz and Milling, 2003).

The use of models involves standard protocols, including defining the purpose (why adopting the study? and for whom to benefit?), selecting the model (selection of model is based on the initial purpose, who are the end users?), collecting data, sensitivity analysis, calibration, and corroborarion (testing), uncertainty analysis, scenario analysis, results in interpretation and communication of uncertainty and post audit (Mazzotti and Vinci, 2007). Following the
modeling protocol serves a number of important benefits which otherwise could cause model failure if ignored, firstly it reduces potential modeler bias, providing a roadmap to be followed, allow others to assess decisions made in modelling, allow others to repeat the study, and lastly improves the acceptance of model results (Birkett and de Lange, 2001).

During model development there are three major procedural processes which are, calibration, verification and validation. Calibration is the process of modification of the model parameters and imposing within the margins of the uncertainties (in model parameters and / or model forcing) to obtain a model representation of the processes of interest that satisfies pre-agreed criteria (Mazzotti and Vinci, 2007; Trucano et al., 2006). Verification is the process of confirming that a computer code correctly implements the algorithms that were intended (Trucano et al., 2006). Furthermore, Mazzotti and Vinci (2007) explained model verification as the process of determining that a model implementation accurately represents the developer’s conceptual description of the model and the solution to the model. Validation is the process of confirming that the predictions of a code adequately represent measured physical phenomena (Daggupati et al., 2015). Daggupati et al. (2015) and Arnold et al., (2012) shared the same view that model validation is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model.

The main purpose of the model is to assist and help solve social, economic and environmental issues (Janse, 1997). However, the purpose of the model design depends on the targeted end users or beneficiaries of the model, and the tools to be adopted or employed to create the model. It is logical to argue that, in regions where significant population beneficiaries lack expertise like RSA and Africa at large (Statistics South Africa, 2014), it is advisable to adopt a relatively user friendly and easily accessible software’s such as Microsoft Excel which because it in cooperate functions like VBA, Solver, dropdown list, cell locks, and other relevant lookup functions which are important for model development implementation. In cases where the end user are highly educated such as scientist and engineers, programming languages/tools such as Java, Matlab, Python, C++ and many others, could be logically adopted.

When it is decided what model to develop, the next step now is to plan and present the models in a form of a flow chart or diagram, this practice has seen successful model development and implementation process (Booch et al., 1998). As a result of a need to guarantee successful
models, Unified Modeling Language (UML) was developed. Ever since then UML gained attention and popularity because scientist were now able to communicate their ideas with each other regardless of their location in the world. The main UML principle lies in diagrams different shapes as a form of a instructing and communicating (Figure 2.7, 2.8, 2.9, 2.10, 2.11 and 2.12).

Figure 2.7 Represents the beginning of a process or workflow in an activity diagram.

Figure 2.8 Represents a decision process and always has at least two paths branching.

Figure 2.9 Shows the directional flow, or control flow, of the activity.

Figure 2.10 Indicates the activities that make up a model process.

Figure 2.11 Marks the end state all flows of a process.
2.10. Sustainability of Aquaponics

Generally, sustainability is the ability to maintain any system at a constant rate or level (Buenfil and Olukunle, 2015). There are various definitions of sustainability across different schools of thought. From the school of environmental science perspective, sustainability is defined as the quality of not being harmful to the environment or depleting natural resources, thereby supporting long-term ecological balance (Christian et al., 2009). In economics, sustainability is defined as the use of various strategies for employing existing resources optimally so that a responsible and beneficial balance can be achieved over the longer term, including development activities which aim to ensure that countries produce operational profits by allowing them to continue to function (Palm et al., 2014). In sociology, sustainability is defined as the development activities that meet the needs of the present without compromising the
ability of future generations to meet their own needs. From this perspective a development activity aims to ensure that people experience good social well-being (Burns, 2012).

In all sustainability definitions, the common idea is that sustainability is the activities that will maintain a system at a constant level for a long run, be it a social, economic or environment system as seen in Figure 2.13 that all interventions or innovation must be socially relevant, environmental friendly and not economically constraining. The derived definition resonates with the first general definition of sustainability, therefore, this validates that sustainability is to maintain a system well-being constantly over a long period.

![Figure 2.13 Sustainable aquaculture system (USAID, 2013).](image)

### 2.10.1. Environmental sustainability

Since 1990 there has been a growing concern of agricultural systems pollution, particularly to the environment (Christian et al., 2009). The concern included water pollution by nitrates pesticides, erosion, greenhouse gas emission and biodiversity losses (Christian et al., 2009).
Over the years, this has called for the development of guidelines and principles to assess the environmental sustainability components to monitor and control sustainable development progress (Ochsenbein and Wachter, 2004).

The guideline included that:

(a) spaces of natural imperative and biodiversity needs to be preserved;
(b) the usage of renewable resources (such as raw materials such as water water) must be retained below the rate of natural replenishment or regeneration
(c) the usage of non-renewable assets such as raw materials and fossil fuels, must be retained below the rate of potential growth in renewable resources,
(d) at all impact of emissions and lethal materials on natural environment (soil, water, and climate) and human well-being must be reduced up to a safe level, lastly,
(e) the effect of environmental disasters must be reduced and environmental threats must only be recognized to the degree that, even in vilest case scenarios, no everlasting damage outliving one generation would be caused (Doualle et al., 2015).

It is important to uphold and conserve the environment (Molobela and Sinha, 2011). However, besides potential fertilizer runoff from agricultural land, there is a serious atmospheric concern with aquaponics. An aquaponics are a bio-integrated food production system that produces meat and greens at the same time (Rakocy et al., 2006). The success of aquaponics relies on microorganisms community to transform nutrients and solid wastes into plants (Nyamangara et al., 2009). In a typical aquaponics, denitrification usually occurs during mineralization and ammonium-N transformation process (Johnson et al., 2005). To avert this challenge of possible nitrogen toxicity and merely addressing denitrification, most aquaponics, take advantage of denitrification condition to remove excess nitrogen in the system, to an extent in that some aquaponics creates denitrification condition for similar reasons (Connolly and Trebic, 2010). The environmental concerns about denitrification are the emission of nitrous oxides which is mainly related to the effect on global warming and the role of nitrous oxides in ozone destruction (White et al., 2004). This implies that, aquaponics, when evaluated for environmental sustainability, should also be evaluated on that basis.

2.10.2. Economic sustainability
The aquaponics yields two enterprise products, which, are meat and vegetables. Most documented literature, shows that it is often difficult to manage and market these two distinctly different products (Doualle et al., 2015). In most cases, farmers or growers decide at the beginning which enterprise he or she wants to focus on (fish only, plants only or both). There is a risk associated with opportunity cost, that a farmer or a grower can make a wrong choice of enterprise hence, suffer from related opportunity cost or enterprise. In a typical farmers market, farm gate prices change depending on the quantity demanded and quantity supplied (available in the market) curve status, as such, this requires sound economic skills (Goddek et al., 2015), also see Figure 2.14. As such this suggest that if aquaponics economic sustainability is to be achieved, specific expertise is needed to make aquaponics profitable.

However, there are suggested guidelines to achieve a sound and acceptable economic sustainability. These are:

(a) ranks of income and employment must be increased and maintained as required, with outstanding consideration given to socially and geographically satisfactory distribution,
(b) it should be possible for productive capital, based on social and human capital, to be maintained and to show qualitative improvement,
(c) economic capacity and competitiveness for innovation must be improved,
(d) market instruments such as pricing must be the principal economic determinants, with outstanding considerations being given to scarceness factors and external cost lastly,
(e) the public sector must not be managed at the peril of future generations (such as failure to preserve assets) (Ochsenbein and Wachter, 2004).

Nevertheless, there is also the issue of generating the fish feed. This is because some fish species are carnivorous, while others are herbivorous and others are omnivores. Carnivores are meat eating fish only and they require 45% protein in their food intake, without which they become severely malnourished (Rakocy, 2007), herbivorous eats plants only, whereas omnivorous fish eat both plants and meat. Hence, the related challenge is to select the best fish type according to the sustainability of the economic resources and factors (protein source), market and price stability, politic stability, input cost, fixed cost) and to keep up with the standard guidelines of economic sustainability. While availability of fish feed in African
countries is limited, there is also a critical matter that concerns fish feed storage sustainability as fish feed is the main aquaponics input.

2.10.3. Social sustainability

A significant effort in science regarding sustainability has been based on an environmental approach into solving problems (Olukunle, 2014). There is inadequate documented information adopted by scientists in a social approach into solving scientific problems (integrational approach). This could be misleading in scientific research and research output that science produces every day (Doualle et al., 2015). There is a significant quantity of good scientific output (information) that could change the situations in the world. However, this information still remains in library shelves. This is because most of it cannot be implemented due to community dynamics that stands in the way. As a result, this causes project failures (Ochsenbein and Wachter, 2004). This could be attributed to the lack of social approach integration in the science field, particularly in engineering science. Thus, it is suggests that when conducting research, scientists need to understand the society they will be operating in and the nature of the people they will be interacting with.

An aquaponics are complex and expensive to establish at a fully operational subsistence scale (Rakocy, 2007). In the aquaponics, materials used to manage the system requires good skills and knowledge (Love et al., 2015). As a result, if the aquaponics are to make a difference in people's life in RSA, social sustainability is the crucial factor to consider. The following are some of the standard principles underpinning social sustainability to evaluate and guide any social intervention for sustainability:

(a) human safety and health must be promoted and protected comprehensively,
(b) education must be provided, warranting individual personal development,
(c) culture must be promoted, together with the protection and improvement of social standards and resources that constitute social capital,
(d) equivalent rights and legal safety must be certain to everyone, with specific attention to equivalent rights for men and women, equivalent rights and security for minorities, including respect for human dignity and rights and lastly,
(e) solidarity must be promoted between and within generations and also the global level (Ochsenbein and Wachter, 2004).
The aquaponics are outlined in the various literature to name but few (Palm et al., 2014; Rakocy, 2007) as the sustainable system that is representing a sustainable ecological model. Hence, for the aquaponics to be sustainable, it has to meet most condition set in each sustainability component (Environment, Economics, and Society see figure 2.13) when evaluated.

Globally, youth involvement in agriculture has been decreasing significantly, particularly in RSA (Faber et al., 2011). This is attributed to poor payments, direct contact with soil (soil dirty) and unpleasant social perceptions and stigma toward young farm workers. Inevitably, this has resulted in decline, failure and collapse of agricultural projects in RSA (Faber et al., 2011). Aquaponics present an potential opportunity for youth involvement into agriculture practice and development, which could be a kick start for sustainable economic freedom and development (USAID, 2013). There was a hypothesis notion that, if agriculture could be made innovative, sophisticated, adventurous and simple, youth involvement in agriculture could increase significantly (Burns, 2012), and foster a sustainable food security and economic production. It is possible to argue that aquaponics presents that possible opportunity in RSA society, given that aquaponics are less dirty due to its soilless nature. This is explained by majority of aquaponics across the world being categorized as hobby scale (Love et al., 2015). If all sustainability components could be achieved, it will present a perfect platform for sustainable aquaponics development programmes to be achieved, hence, prompts better opportunity for a food secure society.

2.11. Role of Aquaponics to Food Security

Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life (Ministry of Agriculture Food Security and Cooperatives, 2006). There are four food security pillars which define, defend and measure food security status locally, nationally and internationally. These are food availability, food accessibility, food utilization and food stability (Drangert, 1998). Food availability is achieved when nutritious food is available at all times for people to access. Food accessibility is achieved when people at all time, have economic ability to obtain nutritious food available according to their dietary preferences. Food utilization is achieved when all food consumed is absorbed and utilized by
Aquaponics provide an excellent opportunity for food and nutrition security because it produces fish and vegetables at the same time (USAID, 2013). In addition, aquaponics could address food sovereignty for food security if aquaponics are implemented as a programme for local people to own these systems. This could be a milestone in agriculture since people would control the means of production of the food they directly eat (Faber et al., 2011). In turn, it would boost food and nutrition status of society, because fish is a significant source of protein, essential amino acids, and vitamins, which are an import for food security (FAO, 2015). Even in small quantities, fish can improve dietary quality by contributing essential amino acids often missing or underrepresented in vegetable-based diets (FAO, 2014). In addition to proteins, fish and fish oils are a source of omega three fatty acids that are most crucial for normal brain development in unborn babies and infants (USAID, 2013). However, the USAID concern is that less nutritious fish are available to the poor as a result of lack of economic access related to lack of affordability and buying power (USAID, 2013). In this regard, if aquaponics could be implemented as a programme it presents a perfect opportunity for sustainable meat (fish) and greens (vegetables) production, which in particular is convenient to enhance, food, nutrition and water security, particularly in RSA (Faber et al., 2011).

However, the technology associated with soilless systems, aquaponics in particular, is complex (FAO, 2014). It requires the ability to simultaneously manage the production and marketing of two different agricultural products. Hence, a successful aquaponics enterprise requires special training, skills, or an easy to use computer control system (Lennard, 2004; Rakocy, 2007). This suggests the need for capacity development training or skilled development programmes before implementing aquaponics projects. Hence, it is possible to argue that if food security is to be achieved via aquaponics production, skills development must be implemented first. Nevertheless, aquaponics presents a perfect opportunity for sustainable food production for food security.

2.12. General Discussion and Conclusions

The need to increase food production is in response to the increases in population, which has resulted in greater use of water and synthetic fertilizer in agriculture. This has resulted in
instability within agricultural biodiversity, which is needed for sustainable agricultural production. The quest to address the challenge has resulted in the exploration of soilless production systems, particularly aquaponics. Aquaponics are a mutual benefiting system, where fish and vegetables are produced at the same time through linking aquacultural fish waste as a natural nutrient source to grow plants in hydroponic culture in a circulating system. In return, plants clean water by taking up most total nitrogen to maintain water quality for fish well-being. However, aquaponics are still an emerging practice in Africa including SA. This then suggest that, there is limited information, if any, to help aquaponics farmers to make the best decision for their system. Nevertheless, aquaponics are shown to have high potential to address water scarcity and food and nutrition insecurity. This is because aquaponics saves water more than conventional agriculture in addition provide platform for nutrient cycle and opportunity for organic food production. However, to manage two agricultural enterprises (fish and vegetables) poses a major challenge. As a result developing a model could help farmers to get started with aquaponics. However, this suggests that if a majority of SA people were to benefit from aquaponics, greater stakeholder intervention is needed. In this regard, tilapia is the mostly farmed fish species in most aquaponics around the world, because of its ability to withstand harsh and various pH and temperature ranges. Tilapia is also easy to breed and manage. Aquaponics foods are easily marketable because food produces from aquaponics are healthier than most production systems including field production. The research gaps were noticed in the field of genetic engineering. New research could be developed to manipulate fish growth period to fit well with hotter seasons of RSA. In order to avoid or escape winter colds which has been shown as significant factor in collapsing fresh water pond aquaculture. More studies also needs to be done to integrate indigenous knowledge with scientific knowledge in order to effect a successful aquaponics implementation. More research needs to be done to measure and quantify nitrogen losses in aquaponics and it related effect in the sustainability components.
3. PROPOSAL

This project proposal reports on rationale of the study providing a more clear view on why the study was chosen, it further goes down to outline the aim, objectives, research questions, originality of the study area, methods to carry out each objective, work plan, resources required and expected outcome of the study.

3.1. Rationale

Aquaponics are still an emerging practice worldwide compared to other food production methods like field production, hydroponics and aquaculture. Aquaponics are gaining attention due to its perception as a potential organic food producing system. This is because it uses significantly lower chemicals or inorganic inputs than conventional agriculture. There is high a opportunity that aquaponics will gain similar attention in RSA. As such, when that time arrives, RSA has to be prepared. Moreover, this further suggests that there is not enough information, data or method, if any, to help aquaponics farmers in RSA to have a better opportunity to achieve the desired yield for food security and economic production. At the same time there is a rapid growing urban poverty in RSA which aquaponics can help to solve. However, to achieve this goal, aquaponics has to be a sustainable production method, which needs evaluation for its sustainability. The critical question is, while aquaponics are shown as a sustainable ecological model, is it really sustainable? To answer this question, it is possible to argue that there is no documented study, if any, which has evaluated aquaponics for overall sustainability in RSA, particularly on the potential contribution to food security. There is no documented study, if any, which has specifically calibrated aquaponics for RSA. As such, there is a need to conduct this study toward shaping and placing RSA agriculture on another level of production through aquaponics.

A significant quantity of research work has been focused on hydroponics and aquaculture production systems. Fish waste is rich in nitrogen, and nitrogen is one of the most limiting macronutrients in agriculture (Wortman, 2015), as such fish waste can nitrify and fertilize crop plants via aquaponics. Simultaneously, fish waste also produces significant quantities of phosphorus and traces elements which are important for plant production (Graber and Junge, 2009a). Studies by Rakocy (1989) over a period of 25 years, have shown that aquaponics can be a competitive alternative to the field and hydroponic production with the advantage of fish
and greens being produced at the same time while input costs are reduced. Most aquaponics foods are considered healthy because they are produced by natural organic material (Sace and Fitzsimmons, 2013), which in particular is ideal and suitable for RSA, and Africa at large, to sustain an active healthy life (USAID, 2013 and FAO, 2014). However, there is limited data, if any, which relates to aquaponics with RSA species and environmental conditions, to provide options for sustainable food production. Nevertheless, aquaponics are gaining attention worldwide (Love et al., 2015), and soon will gain similar attention in RSA. Apart from saving water, aquaponics simultaneously produces fish and vegetables, as a result, it is potential to address the problems relating to water scarcity and food insecurity in RSA. This will be a positive development as it will address problems associated with human population growth, limited croplands, water scarcity and food insecurity (Palm et al., 2014), in RSA.

Model could help save time and production costs (Mabhaudhi et al., 2013), particularly in aquaponics. This is because models can act as support tools for planning, decision making, and yield forecasting, evaluating effects of climate change as well as for identifying research gaps (Birkett and de Lange, 2001). This is important and can be useful to RSA. However, there are also limited studies, if any, relating to the development of aquaponics models for RSA, as a result there is a need of a model development in RSA.

3.2. Research Aim

The primary aim of this study is to develop a decision-making tool that can accurately predict the production of various aquaponics setups in RSA using local species and environmental conditions, to assist growers and farmers to have better opportunity in making the best decision to maximise production of aquaponics.

3.3. Research Questions

Aquaponics are still an emerging practice in RSA. Hence, questions were asked in order to test if this study could be done. The questions were:

(a) Is aquaponics suitable and relevant to RSA?
(b) What is the nutrient flow pattern in the aquaponics in relation to RSA species?
(c) What are the appropriate fish and plant species suitable for RSA's aquaponics conditions?
(d) Is aquaponics relevant for rural small-scale farmers and commercial farmers?
(e) What are the economic benefits associated with different aquaponics and species combinations?
(f) Can aquaponics address challenges of water scarcity, food insecurity and, if so, to what extent?

3.4. The specific objective of the study were:

(a) To determine the uses of aquaponics and typologies currently in use in RSA.
(b) To develop, calibrate and validate an aquaponics model specific to local species and environmental conditions as a management tool.
(c) To apply the tool to assess the applicability to various aquaponics scenarios in RSA.
(d) To assess the overall sustainability (economic, environmental and social) of various aquaponics in use in RSA.

3.5. Originality of the Study

The study will contribute to new knowledge in science, in the field of soilless production systems, particularly in aquaponics in RSA. Since aquaponics are still an emerging practice in RSA, this study will develop a model/decision-making tool to help aquaponics practisers to have better opportunity for their system productivity. This would be the first tool, if any, ever produced that is specifically designed to complement aquaponics production in RSA. There is also limited authentic documented data, if any, to prove that aquaponics are indeed sustainable. As such, the study will further assess the sustainability of aquaponics to ensure sustainable development. This will contribute not only to RSA’s scientific body of knowledge but could also be a valuable outcome, in decision making to adopt aquaponics as food sovereignty policy approach worldwide.

3.6. Study Area

The study will be carried out in the Republic of South Africa (RSA), RSA is bordered by the Atlantic Ocean on the west and the warm Indian Ocean on the east giving the country its
spectacular and comfortable yearly average temperature along with variation range of fish and plants biodiversity which RSA is well known for making the country a possible destination for aquaponics (Van der Waal, 2000).

3.7. Survey

A national (all provinces of S.A) internet survey platform with pre-coded questionnaire categories will be designed and administered to relevant stakeholders, and will be allowed to collect data for a period of three months, from September to November 2016. A minimum of 45 aquaponics grower population will be targeted throughout RSA since aquaponics was hypothetically an emerging practice, as was noted in the Love et al. (2015) international survey study, where he recorded 257 responses worldwide and only one response from RSA. Hence the all-inclusive sampling method will be employed in this study. Sampling technique will include all aquaponics farmers, growers and owners in RSA who will be willing to participate in the study. There will be no specific requirement for an aquaponics to be used in the study. All systems will be included, from hobby, subsistence and commercial scale. The sampling technique will also include chain-sampling method, as was explained and adopted by Love et al., (2015).

3.8. Data Collection and Analysis

To capture and gain in depth information about aquaponics adoption, uses and distribution in RSA, various data collection sources and tools will be used. Using a mixed data collection approach, the web based survey, face-to-face structured and unstructured interview and secondary literature will be useful to generate appropriate information, which will address the research questions. However, the online survey platform will be the main data collection methods, hence, data collected by this method will account for most data collected and analyzed. After obtaining the ethical clearance from the University’s ethic committee and other concerned bodies of research, online survey will be implemented with pre-coded question categories to be completed by the participants. The questions will be both closed and open-ended. The question category in the survey questionnaire will include demographic information (age, gender and education level), aquaponics information (location of aquaponics by province and city, scale of operation, aquaponics environment, system level of automation, enterprise focus, aquaponics trouble shoot options and aquaponics management), fish production (fish
raised, fish tank size, fish stocking density, fish feed information, fish management and fish yield) and plant production (plants raised, method of plant production, plant production management information and plant yield). Furthermore, data collection will include popular social media communities (Facebook and WhatsApp social media), by posting and sharing the survey link.

The analysis tools will include the use of SPSS 24 edition (SPSS inc, 2016) and ArcGIS 10.2 edition (ArcGIS inc, 2016) to determine the findings of this study and to arrive at appropriate conclusions. In the SPSS, frequencies function will be used to determine dominant fish and plant species, scale of production, method of plant production, and type of fish feed, fish feed protein content, enterprise focus, level of aquaponics management (pH, nutrients, suspended solid and dissolved oxygen), location of aquaponics by provinces, type of aquaponics currently in use (tunnel, field and greenhouse) and dominant system automation level, and so on. Split variables will be used to compare relationships and variations between and within groups. The ArcGIS spatial tool will be used to determine the distribution of various aquaponics setups locality within RSA. The locality of aquaponics that will be provided by participants in the survey questionnaire will be transformed into coordinate, whereas province shape files for RSA will be downloaded from the internet and in cooperated with ArcMap function to generate distribution of aquaponics by map. Furthermore, content data recorded from workshops and aquaponics meetings, will also be used to determine dominant fish and plant species cultured, fish and crop combinations, factors driving adoption of aquaponics, dominant scale of production, factors that determine scale of production, factors that determine yield production and factors driving sound aquaponics management.

3.9. The Model and its Development

Model development will be conducted after analysing online survey results, hence will inform decision making, and model development principles will guide the model development process. Model development principle will guide this study, hence, due to the envisage end users of this research work, it is logical to suggest and conclude that, if optimization or kick start of aquaponics in RSA is to be achieved through this model, the model itself has to be user-friendly, available, easily accessible and applicable, among other platform excel platforms fits well with intended end users. To develop the model, data collected from online survey and data (ratios) from authentic sources of literature provided by 25 years of Dr James Rakocy,
USAID and FAO will be used to design, inform and calibrate model inputs. The Unified Modelling Language (UML) method and principles will be employed in this study. However, using MS PowerPoint to create flow chart showing different connections between various inputs and outputs of the model (Figure 3.1). The model will be designed with the user interface.
Figure 3.14 Aquaponics model design flow chart.

[Note]: G stands for Greenhouse, T stands for Tunnel and F stands for Field.
3.9.1. Model calibration

Plant list generated from the online survey will be categorised as leafy and fruity as per literature (FAO, 2014; Rakocy, 2002) and will be assigned to specific production ratios as per plant type (fruity or leafy vegetable) (Table 3.2). The aquaponics production ratios put forward by FAO (2014) and Rakocy (1989) will be used to develop an aquaponics model that predicts specifications for aquaponics production unit based on a yield desired by a grower from a dropdown list of different plant type categories. Hence, yield selector input will be the main input that will generate the outputs. In order to calibrate different plant types to match with aquaponics production ratios, it will be assumed that the average market size of any individual plant type is 500 g including those that work in bunch like spinach, basil, salad greens, etc. Hence, 25 heads of lettuce will translate to be 12.5 kg/m², in calculation: (25×0.5 kg or 25×500 g/1 000 g = 12.5 kg) also see Table 3.2 for clear ratios and calculations. Similar method will be applied to fruity vegetables giving 4 kg/m², in calculation: (8×0.5 kg or 8×500 g/1 000 g = 4 kg). The model will be designed to predict yield output for the cycle of weekly harvest thereby determine how much plant population will be needed to be in the system. To determine how much a farmer will be able to harvest per week, crop growth duration will be multiplied by desired yield option. For example, lettuce takes four weeks to grow and if a farmer wishes to harvest 25 heads of lettuce every week, 4×25 = 100 heads will be needed to be in the system in order to harvest weekly, the same will done for all vegetables. Fish tank volume size will be based on the FAO (2015) ratios that, suggesting that 10 kg/m³ fish stocking, and all province and regional temperature will be obtained from RSA Weather Service.

Table 3.1 Derived aquaponics production ratios

<table>
<thead>
<tr>
<th>Vegetable category</th>
<th>Fish Feed (g.day⁻¹)</th>
<th>Planting density (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leafy vegetables</td>
<td>50-60 (Rakocy, 2007) or 40-50 (FAO, 2014)</td>
<td>20-25 (Rakocy, 2007) or 40-50 (FAO, 2014)</td>
</tr>
<tr>
<td>Fruity vegetables</td>
<td>80-100 (Rakocy, 2007) or 40-50 (FAO, 2014)</td>
<td>4-8 (Rakocy, 2007) or 40-50 (FAO, 2014)</td>
</tr>
</tbody>
</table>

3.9.2. Biofilter area
Biofilter area is a very important part of an aquaponics because it determines microbial component well-being, which in turn determines the productivity of the aquaponics by facilitating a smooth nutrient flow process. Hence, biofilter area was determined using FAO (2014) ratios from Equations 3.1 and 3.2.

\[
(g/\text{feed}) \times 0.32 \times 0.16 \times 0.61 \times 1.2 = g/\text{ammonia} \tag{3.1}
\]

Where,
\[
\begin{align*}
0.32 & = 32\% \text{ protein in (g/\text{feed})}, \\
0.16 & = 16\% \text{ g of nitrogen contained in the protein}, \\
0.61 & = 61\% \text{ of wasted nitrogen, and} \\
1.2 & = \text{ each gram of wasted nitrogen, 1.2g of ammonia is produced.}
\end{align*}
\]

\[
1 \text{ m}^2 \over 0.57 \text{ g ammonia} \tag{3.2}
\]

Where,
\[
0.57 = \text{ ammonia removal rate by bacteria per day/m}^2
\]

3.9.3. Water flowrate

Water flowrate will be determined following a ratio that suggested that 30-40 % water circulation of total fish tank water needs to be channelled to plant growing area within an hour in order to maintain good water level and circulation (FAO, 2014).

3.9.4. Recommended method of plant production

The method of plant production will be based on FAO (2014 and 2015), Lennard (2004) and Rakoczy (2007). The Lennard recommendation comes from more than five years of aquaponics research and Rakoczy ratios comes from more than 25 years into aquaponics research.

3.9.5. Validation and verification

Validation process will be performed manually by matching and calculating all model inputs and outputs databases using aquaponics production ratios as was proposed by FAO (2014 and 2015), Lennard (2004) and Rakoczy (2007). In terms of verification aquaponics production data collected from local farmers, across the country will be used. The online survey data will be organised and summarised to create model main model input, which is yield selector. This will
be performed by taking all crop yield results from the online survey data and transforming it until it matches the yield selector of the model. The crop yield results from online data will be based on yearly average yield (kg), this will then be divided by 12 to get how many (kg) farmers produced every month and will be further divided by 4 to get how much each farmer produced a week as per the model requirement/design.

3.9.6. Analysis

Data analysis will be carried out using the General Linear Model, Repeated Measures using the Genstat 18th Statistical Package to compare variable means. Statistical significance will be determined at the 5% probability level. Furthermore, the analysis will be done using goodness of fit of simulated model outputs against observed field measurements by using the coefficient of determination ($R^2$).

3.10. Running Specific Aquaponics Scenarios

Scenario analysis is very important in situations where there is high degree of output variety and uncertainty. Scenario analysis can help to determine the most possible practical outcome of real life situation. To determine the applicability and relevancy of the tool to various aquaponics scenarios in South Africa, the data that will be retrieved from the model together with data that will be collected from online survey questionnaire, and also content data gathered from sites visit and veteran aquaponics farmers by means of observations, structured and unstructured interviews will be used, to determine the applicability of the model to RSA conditions. The scenarios will include applying the tool to determine relationships between within fish-crop species vs location, suitable regions for independent economic population production of fish and cost of different scale (hobby, subsistence and commercial) of aquaponics, system setup and cost of different scale of aquaponics. Hence, this study will adopt a mixed method approach, which will combined the methods and procedures of quantitative and qualitative data in a single study, using different sources of data.
3.11. Aquaponics Sustainability Analysis

This study will be conducted to determine the overall sustainability of aquaponics in RSA, particularly to determine whether it could be promoted as best alternative. To assess the overall economic, environmental, and social sustainability of aquaponics in RSA, a mixed research method will be employed. This will be the technical combination of quantitative and qualitative research methodologies. Hence, sustainability principles and guidelines will be reviewed in order to provide findings for this study. Both survey and participatory rural appraisal (PRA), (these will be unstructured face to face interviews, observation and seasonal diagram/calendar), techniques will also be used to collect all relevant data providing findings for this study, and all data will be evaluated against sustainability principles to determine the sustainability of aquaponics in RSA. The survey questionnaire will be designed with two question categories (growers and none-growers). The grower category will be answerable to those who have an operational aquaponics in place, whereas none grower category will be answered by people who do not have an aquaponics in place but is keen or may be not keen in aquaponics. The grower category question will include questions about aquaponics information, fish production and plant production. None growers will include one question category which will include all questions tracking interest in aquaponics. The questions in none grower category will be specifically designed to track interest by local people, particularly youth, toward aquaponics, to determine the overall sustainability (environmental, social and economic) future of aquaponics in RSA, to address food shortage attributed to lack of youth involvement in food production activities particularly agriculture. In growers category there will also be strategic questions to determine overall sustainability of aquaponics in RSA. This will include amongst others questions like, whether a farmer periodically add water on their system or not, if so, this question will answer environmental sustainability question that, why is aquaponics considered sustainable or flagged as a water saver while water is continuously added into a system attributed to water loss? And, the follow-up question in the same category will ask about how much quantity of water added, to which this will explain the extent of this effect to environmental sustainability principles. In the grower category there were also strategic questions about economic, these will include structural makeup of the famer’s aquaponics (field, tunnel or greenhouse), feed cost and related fish and plant harvest yield. In the social sustainability this will include questions about nature of an aquaponics design whether it promotes social sustainability or not. In none growers question category this will include question about whether or not respondents knew about aquaponics, if yes, a follow-up question
will ask the respondent the level of knowledge (low, moderate and skilled) about aquaponics, if not, a following question will ask about whether yes or no respondents are interested in aquaponics, if not, survey will be programmed to jump to an end and close the survey. If yes, respondents will be asked question about what aquaponics scale (hobby, subsistence and commercial) of production there are interest in. This question will be followed by multiple options question asking why respondents are interested in aquaponics. The hypothesis therefore is, will not be sustainable in RSA.

3.11.1. Data analysis

The data will be analyzed using SPSS 24 software to determine the findings of this study. In the SPSS, frequencies function will be used to determine variables percentage means, using frequencies function variables data will be split by groups to compare relationships and variation between within groups. The differences in means will be separated by Least Significant Different (LSD). Significant tests will be done within 5 % level of significance.
### 3.12. Work Plan and Time Schedule

<table>
<thead>
<tr>
<th>TASK NAME</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
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</thead>
<tbody>
<tr>
<td>Objective (a) Research development and online survey study</td>
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<tr>
<td>Literature review</td>
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<td>Submitting literature review paper to a journal</td>
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<tr>
<td>Submission of first draft seminar paper</td>
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<td>Submission of final seminar paper</td>
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<tr>
<td>Online survey development and set up</td>
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<tr>
<td>Online survey data collection</td>
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<tr>
<td>Data analysis and online paper write up</td>
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<tr>
<td>First draft paper for publication review</td>
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<tr>
<td>Submitting online survey paper</td>
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<td>Objective (b) Model development</td>
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<tr>
<td>Submitting model development paper to a journal</td>
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<tr>
<td>Defending study</td>
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<tr>
<td>Objective (c) and (d), Running specific scenarios and sustainability study</td>
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<tr>
<td>Thesis write up and organization</td>
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<tr>
<td>Final submission</td>
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</table>
3.13. Equipment and Resources

The study will adopt both quantitative and qualitative methodologies with most of data being collected from people who already have aquaponics in place using a self-administered web based questionnaire. This data will be used in model development study where one of the main inputs is the locality selector which will be linked with climatic condition according to provinces. Experimental data to verify and calibrate the tool will be obtained from survey data and farmers production records. Additional data will be collected through field visit, unstructured interview, workshops, conferences and observation. Data analysis will include GIS software, Excel software, Computer, Statistics software and others which will be determined as the research findings.

The project expenses are fully funded by NRF, University of KwaZulu-Natal College funding and JW Nelson scholarship.

3.14. Expected Outcomes

The following outcomes and deliverables are envisaged as a final product from this study:

(a) The study will determine the distribution and locality of aquaponics, which will aid in national statistics records in RSA
(b) A decision making tool/model for aquaponics in RSA
(c) The study will determine the overall sustainability of aquaponics in RSA which will set basis for green evolution
(d) One Doctor of Philosophy thesis document
(e) At least two published articles in accredited journal
4. REFERENCES


Sinefu, F., 2011. Fikile Sinefu Submitted in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE IN AGRICULTURE ( CROP SCIENCE ) Crop Science School of Agricultural Sciences and Agribusiness Faculty of Science and Agriculture University of KwaZulu-Na. University of KwaZulu-Natal.


