EFFECTS OF WATER HYACINTH-BASED *(EICHHORNIA CRASSIPES)* VERMICOMPOST TEA (AQUEOUS EXTRACT) SUPPLEMENT ON GROWTH PERFORMANCE OF LETTUCE UNDER NON-CIRCULATING HYDROPONICS AND AQUAPONICS SYSTEM

MASTERS OF SCIENCE IN AQUATIC ECOSYSTEMS MANAGEMENT

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A thesis submitted to the African Centre of Excellence for Water Management (ACEWM) in partial fulfilment of the requirement for Master's Degree in Water Management (Aquatic Ecosystems Management) of Addis Ababa University

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Supervisor: Dr Akewake Geremew (PhD)

November, 2020

DECLARATION

I, declare that this thesis is a result of my own original effort, and my best knowledge, the findings of this work have never been previously presented to the Addis Ababa University or elsewhere for the award of any academic qualification. Where assistance was sought, it has been accordingly acknowledged by way of references.

Name: Upile Ruth Pulaizi

Signature: ....

Date: 07/12/2020

CERTIFICATE OF APPROVAL

The undersigned, certify that this thesis is a result of the authors work, and that to the best of my knowledge, it has not been submitted for any other academic qualification within the Addis Ababa University or elsewhere. The thesis is acceptable in form and content, and that satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate through an oral examination held on 27th November, 2020.

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Examiner: Prof. Abebe Getahum

Signature:………………………………………Date: 08/12/2020

Chairperson: Dr Beteley Tekola

Signature:………………………………………Date: 08/12/2020

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DEDICATION

I dedicate this thesis to my parents and siblings for their spiritual and emotional support.

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Abstract

The study was conducted to determine the effects of water hyacinth-based (*Eichhornia crassipes*) vermicompost tea (aqueous extract) supplement on growth performance of lettuce under the non-circulating hydroponics system. Water hyacinth is nutrient-rich and can undergo vermicomposting and be used in hydroponics or aquaponics production systems. The purpose of this study was to investigate the potential use of water hyacinth-based vermicompost tea material in a hydroponics system for an improved product of lettuce and management of water hyacinth through utilization. The study used a systematic random sampling design to obtain the sample size of a total of 33 plants per unit. To compare the effect of various dilutions of water hyacinth based vermicompost tea and the growth performance of lettuce in non-circulating hydroponic and aquaponic systems leaf area, shoot length, root-shoot ratio, growth rate, moisture content analysis, were used. Ash and digesting methods were used to determine the effect of various dilutions of hyacinth-based vermicompost tea on the concentration of selected nutrients and heavy metals in lettuce. Lettuce dosed with hydroponics nutrient solution were significantly different at ($P<0.05$) from lettuce supplied with water hyacinth-based vermicompost extract dosed at 30%, 40% and 60%, the plants had a higher growth rate, shoot length and moisture content, large leaf area and a small root-shoot ratio. Lettuce dosed with vermicompost tea was resistant to aphid and fungi attack, while the ones dosed with synthetic solutions were attacked. Yield from hydroponics and aquaponics system was not significant. Lettuce dosed with WHBVCT were short in nutrient content in their solutions while the ones with synthetic solutions had enough nutrient supply. Lettuce dosed with WHBVCT had nutrient and heavy metal concentrations within the permissible limit, except for treatment dosed at 30% and 40% which showed a higher Pd and Zn values. WHBVCT is rich in chitinase, phenols and alcohol which digest the chitin of insects and phenol and inhibit the growth of fungus and spread of insects which made lettuce with WHBVCT more resistant than the others. Therefore, WHBCVT can be used to control aphids and fungus, but it cannot be used for lettuce production non-circulating hydroponics and trials have to be made on fruiting vegetables to observe its performance.

Keywords: WHBVCT, lettuce, hydroponics system, aquaponics system

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Abbreviations and acronyms

CT	Compost Tea
DO	Dissolved Oxygen
FAO	Food and Agriculture Organization
NFT	Nutrient Film Technique
TH	Treated Hydroponics system
UA	Untreated Aquaponics system
UH	Untreated Hydroponics system
UN	United Nations
VCT	Vermicompost tea
WHBVCT	Water Hyacinth Based Vermicompost Tea

Chapter One: Introduction

Agriculture is the backbone of food security in Africa. Food security can be expressed as "when all people have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary and food preferences for a healthy life" (Fawole *et al.*, 2015). Unfortunately, nearly one billion people in the world are undernourished and are living below their daily calorie requirements (PAI, 2015). Food security is still an issue in Africa because food deficit and insecurity are multidimensional problems. It is driven by several factors which include climate change, conflict, economic shock, limiting resources, political instability, population growth and others (FAO, 2017; IFPRI, 2017; UN, 2018). Most African countries are facing these challenges which are affecting food production and supply. In Africa for attaining food security, acceptable quality and quantity water and soil are required. This is a challenge because of water and land scarcity due to irregular rainfall distribution, to increase yield there is an excessive application of fertilizers and pesticides which impacts food production but also water and soil quality (Smith *et al.* 2016; Vilakazi *et al*., 2019). Nutrient load in water bodies can cause the development of invasive aquatic weed, which may affect the aquatic ecosystem (Knight *et al*., 2014).

Different organizations are trying to put in place measures to eradicate food insecurity, by engaging new forms of agriculture production. To produce more food to meet the growing population demands with less water and other resource input there is a need to apply productive, innovative, and sustainable production systems while making sure that production is pursued from a holistic and integrated perspective (UN, 2018; Vilakazi *et al*., 2019).

Aquatic weeds were first present in Africa since the end of the nineteenth century infesting the freshwater bodies very fast including lakes, ponds, rivers, canals, and agriculture fields (Mitchell *et al*., 1990). This infestation is damaging the environment, economy, fisheries, electricity production, transportation and among others. Among the aquatic weeds water hyacinth, water lettuce and water ferns cause the most serious problems (FAO, 2002).

Water hyacinth is a principal weed that grows and spreads very fast and it can invade water bodies due to its vegetative production and it moves with currents, wind or accidents for example fishing.

Water bodies such as Lake Victoria-Uganda, Lake Naivasha-Kenya, Shire river-Malawi, Shagashe river-Zimbabwe, Koka reservoir and Lake Tana-Ethiopia have been infested by this weed (Chapungu *et al*., 2018; Worku Melees and Samuel Sahile, 2018). The weed has an impact on the environment and economy, having disrupted agriculture, fisheries, electricity production, transportation and social structure (Chapungu *et al*., 2018). Water hyacinth interferes with water flows in rivers, canals and drains and it slows water flow from flood lands.

Water hyacinth infestation is not easy to control, but it can be managed/limited by chemical; biological and mechanical removing methods (Abdel-sabour, 2014; Mujere, 2015). However, these measures are insufficient to permanently control the weed. As such other applications are being developed to help control the spread and solve the problems associated with water hyacinth weed. Water hyacinth is a protein-rich plant capable of taking up nutrients and heavy metals from water systems, making it rich with nutrients (Abdel-sabour, 2014; Ogutu, 2019). Hence, it can be harvested and be used as animal feed, biogas production, fibre, and organic fertilizers. Production of quality composts through vermicomposting of this weed and its subsequent application in vegetable farming solves the problem of uncontrolled growth of water hyacinth in water bodies and reduce the use of chemical fertilizers.

Vermicomposting involves the biodegradation of organic wastes into a microbially active and humus-rich substance; under conditions of optimum temperature, moisture, and aeration with the assistance of earthworms. The material is passed through the worm's digestive system and it is used for food production. It is environmentally friendly, requires little energy, capital, or equipment, and does not involve intensive management (Hénault-Ethier *et al.,* 2016). Vermicomposting of waste material increases the nutrient availability of some nutrients like nitrogen, phosphorous, and potassium as a result of reduced volume of the vermicompost material. Shortage of freshwater, land and fertile soil for agriculture and effluents from other production systems has led to the development of a soilless system like hydroponics and aquaponics systems in across the regions (Alyssa *et al.,* 2019). Hydroponics is the growing of plants in a circulating liquid nutrient solution with or without the use of artificial media such as gravel, rock wool, peat moss, sawdust, wood fibre, coconut fibre for support (Dunn, 2015; Sharma *et al*., 2018). Aquaponics is a combination of aquaculture and hydroponics, which is the cultivation of fish and plants in a constructed recirculating system (Thorarinsdottir, 2015). The aquaponics system involves three main groups of organisms; fish, plants and bacteria and sometimes worms to facilitate circulation nutrients in the system. Although the hydroponic and aquaponic system's nutrient must be supplied to mimic the natural environment, these nutrients can either be organic or inorganic. Different approaches to using vermicompost in soilless culture have so far been investigated in various types of vegetables. However, water hyacinth-based vermicompost tea has not been investigated on the production of lettuce in a non-circulating hydroponic system.

1.1 Problem statement and justification

Regardless of the impacts, it has on the environment, water hyacinth can filter pollutants, nutrients, heavy metals and toxic organic matter from the water and it is rich in N, P, K and proteins (Abdel-sabour, 2014; Ogutu, 2019). Nutrients diffuse from the aquatic systems to the water nourishing it with nutrients such as N, P, Ca, Mg and K and other nutrients in many folds. The nutrient quality of water hyacinth is dependent on the water quality from which water hyacinth is harvested from (Abdel-sabour, 2010). The leaves are reported to contain 15, 9, 13.9, 8.8 and 8.5 mg of Ca, K, Mg, P and N per gram of dry weight, respectively (Abdel-sabour, 2010). Water hyacinth can be harvested and processed into vermicompost manure or tea, and be supplied to production systems such as the hydroponics and aquaponics, agriculture and horticulture to improve production.

Vermicomposting will also help control the weeds but also water quality degradation (Mohammad *et al.*, 2007; Diffen, 2019). Vermicompost manure from different materials including water hyacinth is being used as a nutrient supplement for most field crops production; such as vegetables, ornamentals, cereals and fruiting plants (Kaur *et al.*, 2015; Mashavira *et al*., 2015). It is reported to enhance germination rate, growth, flowering, yield quality and quantity (Mashavira *et al.*, 2015).

In hydroponics and aquaponics production, plants are not in the soil to take up nutrients, lack of nutrient affects yield, growth and development (ripening, shape, leaves pigment) for nutrient demanding plants (Goel *et al*., 1989: Herrero, *et al*., 2001; Haifa-group, 2019). As such nutrient must be supplied with organic and inorganic fertilizers to boost plant production. Inorganic fertilizers are expensive and cannot be easily accessed by small scale farmers (Ogutu, 2019). An increase in the use of inorganic fertilizer is also associated with excessive accumulation of toxic chemicals in vegetables and pose a risk to consumers. For example, nitrate is a beneficial nutrient for plant growth, yet prolonged use of chemical fertilizers results in the accumulation of nitrate in the system and in leafy plants like lettuce that easily take up nutrients (Anjana and Iqbal, 2007).

This is also linked to poor plant growth and health hazards to humans, for example, high levels of nitrate cause methemoglobinemia in babies. Therefore, harmful nutrient accumulation in soilless culture systems that grow leafy vegetables such as lettuce can be mitigated using organic fertilizers. Different forms of compost and vermicompost manure and tea are being used to supplement the systems with nutrients to improve yield and at the same time avoid nutrient accumulation (Pant *et al*., 2011). Other forms of vermicompost teas and manure are well established in leafy vegetable production in hydroponic and aquaponic systems (Fox *et al.*, 2012; Arancon *et al.*, 2018b). Vermicompost teas are preferred among many organic growers since they are easier to transport and apply than solid vermicomposts (Edwards *et al*., 2006). Water hyacinth based vermicompost has been reported to have large amount of nutrients, high electrical conductivity due to the nutrient rich nature of the raw material used, hence its use can be a problem for growing sensitive crops (Bernal *et al*., 2016). Therefore, there is a need to analyze the vermicompost tea supplementation effect at different dilution levels to avoid damage due to the excess level of nutrients. This study aimed to determine the effect of liquid supplementation of water hyacinth-based vermicompost tea in lettuce production under non-circulating hydroponics system for its sustainability. It also aimed to identify the best dilution level that prevents undesirable nutrient accumulation (including heavy metals) and avoids plant growth depression, and compare hydroponic and aquaponic lettuce production.

1.2. Objective

1.2.1. General objective

- To investigate the potential use of water hyacinth-based vermicompost tea material in a hydroponic system for improved production of lettuce and management of water hyacinth through utilization.

1.2.2 Specific objectives

- To investigate the effect of various dilution levels of water hyacinth-based vermicompost tea on growth and yield of lettuce.
- To compare the growth performance of lettuce in hydroponic and aquaponic systems.
- To determine the effect of various dilutions of hyacinth-based vermicompost tea on the concentration of selected nutrients and heavy metals in lettuce.

1.3 Research hypothesis

H_0: There is no significant effect of various dilutions of water hyacinth based vermicompost tea on growth and yield of lettuce in hydroponic and aquaponic systems**.**

Chapter Two: Literature review

Across the world, water and land scarcity are the main factors affecting food production and sustainability (FAO, 2016). Freshwater is becoming a scarce resource across the world due to water pollution, climate change, and increase in demand as a result of population growth and lack of economic resources to access the available water sources (Kummu *et al*., 2016). The land resource is also diminishing as a result of urbanization and population growth, reducing the available land which could be used for food production (Satterthwaite *et al*., 2010). Due to these challenges better systems which are soilless, less water and nutrient demanding such as hydroponics and aquaponics are being developed and used for food production to meet demands of the increasing population without damaging the environment (Newell, 2016).

2.1. Hydroponics system

Hydroponics is a subset of hydro-culture method that does not use soil for plant production, but rather mineral nutritional solutions are used in this system. The plants may be grown with their roots in the nutrient solution or a medium such as a perlite or gravels (Rakocy & Hargreaves, 1993 and Sayara *et al.,* 2016). This system can be arranged in several ways depending on the type of plants to be produced and available space. Some of the systems are open such as drip irrigation, while others are closed such as Ebb and flow, wick hydroponic system, deep water culture and Nutrient film technique

Ebb and flow system (Figure 1) is commonly used for potted plants and plug production. In this system, the growing bed is flooded with nutrient solution and then allowed to drain with the help of gravity and the flooding of nutrients is controlled by a timer. The nutrient water solution is pumped through tubes from the solution reservoir tank up into the grow bed where the plants are planted. The nutrient solution continues to flood the system until it reaches its maximum point where the plants' roots are soaked, then the overflow tubes drain the solution back to the reservoir tank (Chidiac, 2017). The overflow tube is set at about 2 inches below the top of the growing media. The duration and frequency of flooding and draining are dependent on the media used, plants water requirement and size of the container (Wortman, 2015). Most of the greenhouse lettuce industry commonly employs the Nutrient Film Technique (NFT) and Deep Flow Technique (DFT) for the hydroponic production of lettuce (Chidiac, 2014a). But the ebb and flow technique is equally productive as the other systems. Lettuce plants produced from an ebb and flow technique did not show any difference in terms of shoot fresh weight, dry weight, chlorophyll, or diameter from DFT, or NFT treatments (Chidiac, 2017).

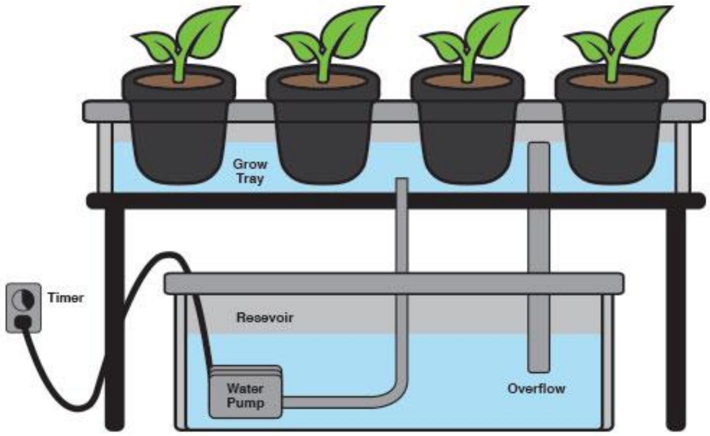

Figure 1: Ebb and flow hydroponic system, adopted from Sharma *et al.*, (2018)

Wick hydroponic system is another type of system considered simple and traditional because it does not require electricity or a pump for operation (Sharma *et al.*, 2018). This system has a nutrient solution reservoir, with a plant bucket or tray just above it. Nutrients move from the tank to the plants with the help of the wink (like hoe the blood capillary pushes the blood). A recommended wick hydroponic system is the one which has good-sized wicker (Figure 2).*;*

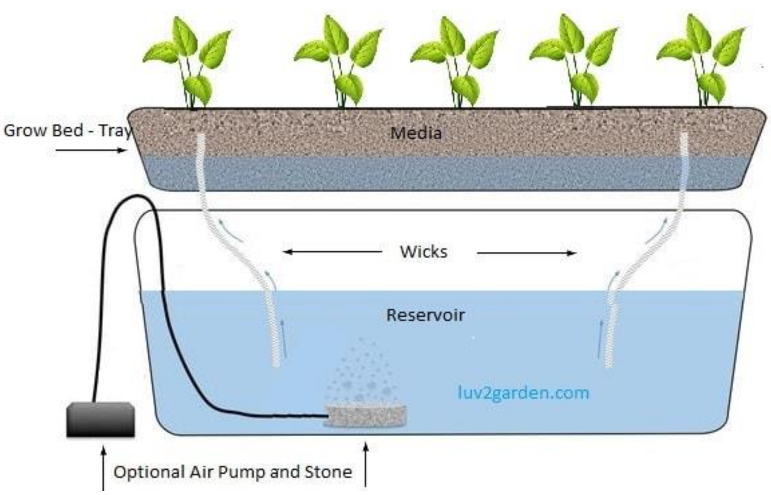

Figure 2: Wick hydroponic system, Adopted from Sharma *et al*. (2018).

Studies have been done to compare the productivity of lettuce between wick which had coconut coir and pine bark as substrates and NFT hydroponic system. Lettuce plants performed better than the ones from the NFT system, with high yield, roots volume, leaf area and root-shoot mass and ratio observed from the wicks systems. As such wick hydroponic system is better than NFT, comparing the results from Da Silva *et al*., (2005) with those from Ferrarezi and Testezlaf, (2016).

Deepwater Culture (figure 3) is also another hydroponic system that has plants suspended in an oxygenated nutrient-enriched solution. This system has a board or Styrofoam which is laid on top of the nutrient solution tank with a hole in it. Growing pots are inserted into the holes and the plants are grown with its roots developing in the solution. The board is lifted some times to expose the roots to air and prevent root rot.

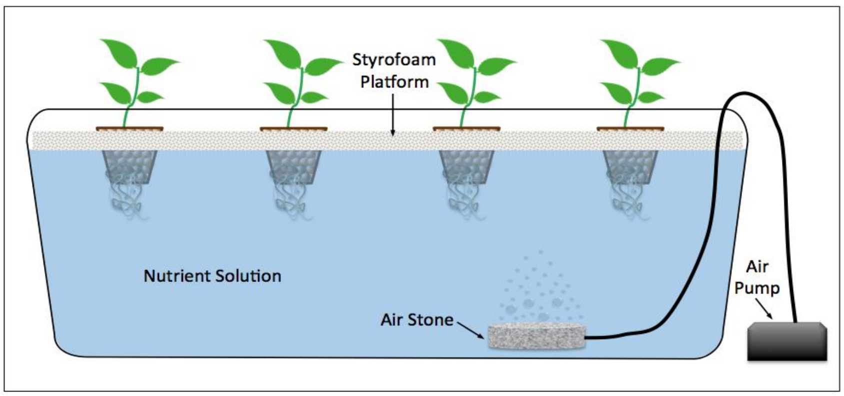

Figure 3: Deep Water Culture hydroponic system, Adopted from Sharma *et al*., (2018)

Nutrient film technique (NFT) (figure 4*)*, is one of the widely practised systems as compared to the above systems. The is preferred than the other systems because it has a substrate which can support both leafy and fruiting plants, there is a continuous flow of nutrient solution and oxygen supply to the plant roots (Domingues *et al.,* 2012; Aires, 2018). The nutrient solution is pumped from the reservoir and flow over or through the roots of the plant, then drained back into the reservoir. This results in a thin film of nutrient solution around the roots allowing them to aerate and take up nutrients. In an open system, the fresh nutrient solution is introduced for each irrigation cycle supplied to the plants through a drip system.

According to Sharma *et al*. (2018), many plants can be grown in this system, but lettuce is the commonly grown vegetable and can perform better if planted at 50 plants m^{-2}. In the hydroponic systems, lettuce can be harvested between 35 to 40 days as compared to traditional agriculture, which makes hydroponics better than conventional agriculture.

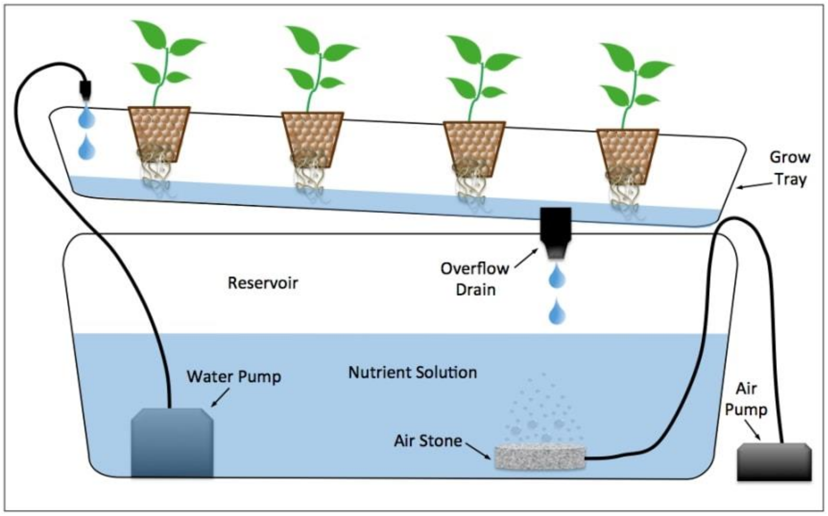

Figure 4: NFT adopted from Sharma *et al*. (2018)

2.1.1 Types of crops grown in a hydroponic system

Different crops can be grown in the hydroponics systems, the type of hydroponics system to be used is dependent on the crop type. Crops such as rice and maize, strawberry, tomato, chilli, brinjal, green bean, beet, winged bean, bell pepper, cucumbers, melons, green onion, lettuce, spinach, celery, swiss chard, parsley, mint and sweet basil can be planted in a hydroponics system depending on the type of system used (Sardare *et al.*, 2016; Dholwani *et al.*, 2018). Although there are other plant species, such as radish and lettuce, which are faster-growing, the larger plant size of the green bean and corn plants can be used in the hydroponics (Benton, 2014).

2.1.2. Strength and weakness of the hydroponic system

A Hydroponic system can produce crops that are free from soil-borne disease, insect, or pest infection to the crops thereby reducing the use of pesticides and their toxicity to humans. Plants require less growing time as compared to crop grown in the field and the growth of the plant is faster as there is no mechanical hindrance to the roots and the entire nutrient is readily available for plants. Hydroponics is used where the environmental conditions are a problem since the systems cannot be influenced by climate change and can be used for production all year-round

(Polycarpou *et al*., 2005; Manzocco *et al.,* 2011). Hydroponic systems practised at a large scale are automatically operated and anticipated to reduce labour and several traditional agricultural practices such as; weeding, spraying, watering, and tilling (Jovicich *et al.,* 2003). Hydroponics is considered sustainable because it uses less amount of water for irrigating the plants and waterlogging never occurs unless the pipes are clogged with roots. Weed is practically non-existent in hydroponics, if plants have been attacked with pest and disease it can be controlled easily. Higher yields can be obtained since the number of plants per unit is higher compared to conventional agriculture.

Although soil-less cultivation is an advantageous technique it is prone to significant limitations. Technical knowledge and higher initial cost are fundamental requirements for establishing a hydroponic unit (Resh, 2013). Plant in a hydroponic system share the same nutrient, and water-borne diseases can easily spread from one plant to another (Ikeda *et al.,* 2002). In the case of increasing temperature, hot weather and limited oxygenation may limit production and can result in loss of crops. It is a problem to maintain some water quality parameters such as pH, EC and proper concentration of the nutrient solution in the system as such they have to be checked often.

2.1 Aquaponics system

Aquaponics can be defined as the combination of aquaculture (raising fish) and hydroponics (the soil-less growing of plants) that grows fish and plants together in one integrated system with the support of microbes (nitrifying bacteria) (figure 5)(Somerville *et al*., 2014; Lennard and Goddek, 2019). These bacteria help in nitrifying ammonia from fish waste into nitrate. Nitrates are the form of nitrogen that plants can uptake and use it for their growth. The solid fish waste is turned into vermicomposting that also acts as a source of organic nutrients for plants, and the plants naturally filter the water for the fish (Lennard and Goddek, 2019).

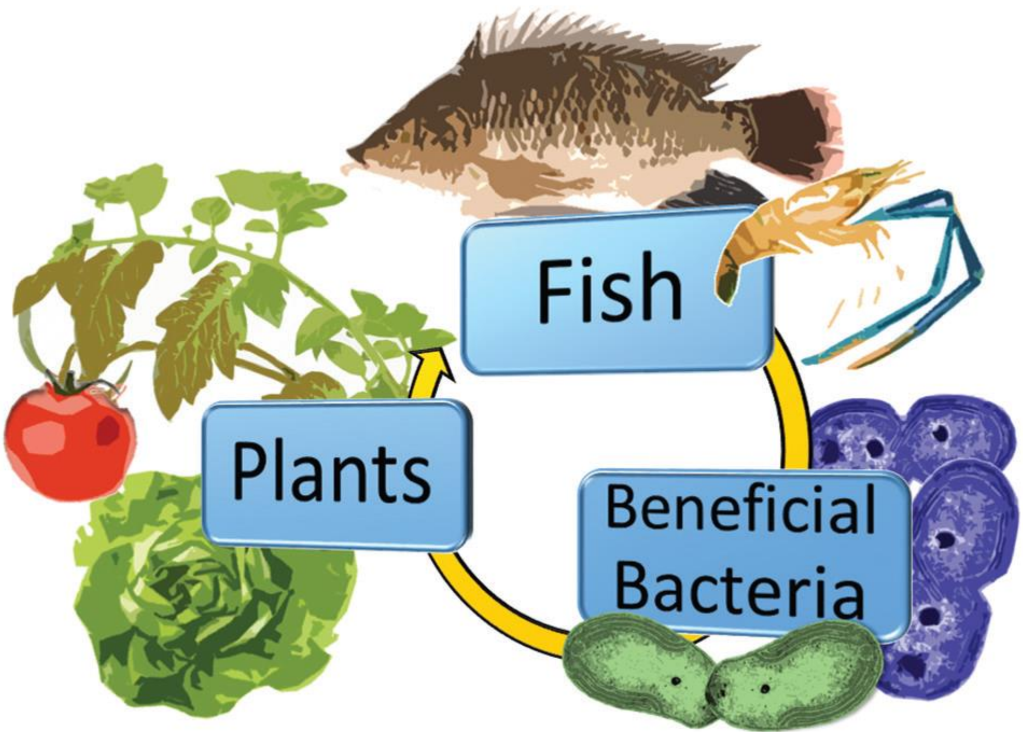

Figure 5: Aquaponics cycle (Pattillo, 2017)

There are mainly three types of aquaponics: Deepwater culture, Media-based culture and Nutrient Film Technique (NFT)

a) Deepwater Culture (DWC) or raft based

Deepwater Culture (DWC) or raft-based (figure 6) growing uses a foam raft that floats in a channel or tank filled with fish effluent water that has been filtered to remove solid wastes (The Aquaponics Source, 2019). Holes can be cut through the raft; in them is where plants are placed into net pots. The roots hang free in the water where nutrient uptake occurs. A major difference between the raft system and the NFT and media-based system is the amount of water used (Somerville *et al*., 2014). The water level beneath the rafts can be anywhere from 10 to 20 inches deep and as a result, the volume of water is approximately four times greater than other systems. This higher volume of water results in lower nutrient concentrations and as a result, the higher nutrient rate is used (The Aquaponics Source, 2019; Rinehart, 2019). Also, the plant roots are exposed to some harmful organisms that reside in the water, which can affect plant growth. This method is most appropriate for growing salad greens and other fast-growing, relatively low-nutrient demanding plants *(Roy et al*., 2006). It is also mostly used in larger commercial-scale systems.

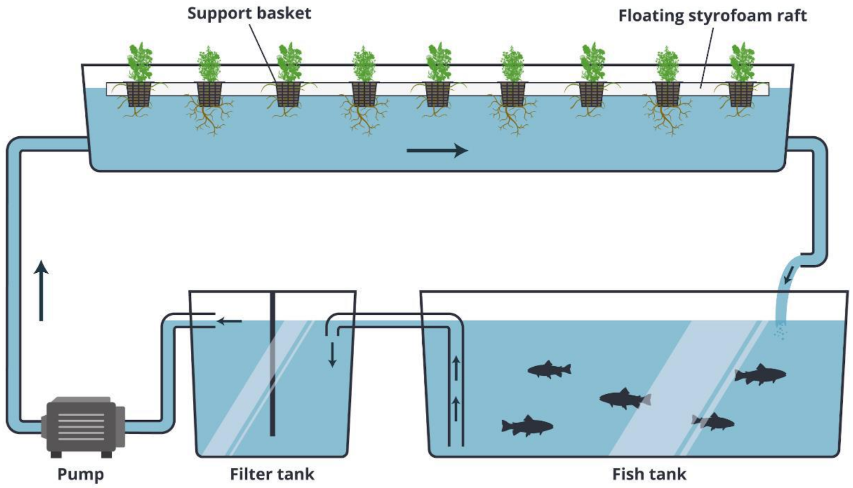

Figure 6: Deep Water Culture Aquaponics system (Verheyen L., 2019)

b) Flood and drain/ Media-based system

Media growing involves growing plants in inert planting media such as expanded clay pellets, gravel, or shale. The media supports bacteria growth which acts as a biological filtration and mechanical filtration (removal of solid wastes) in the same system. Media-based systems are great for home and hobby scale systems can be used to grow a wide variety of crops large fruiting plants in addition to leafy greens, herbs and other varieties (Aquaponics, 2008; Vallance1 *et al.*, 2011). Examples of media-based systems figure 7;

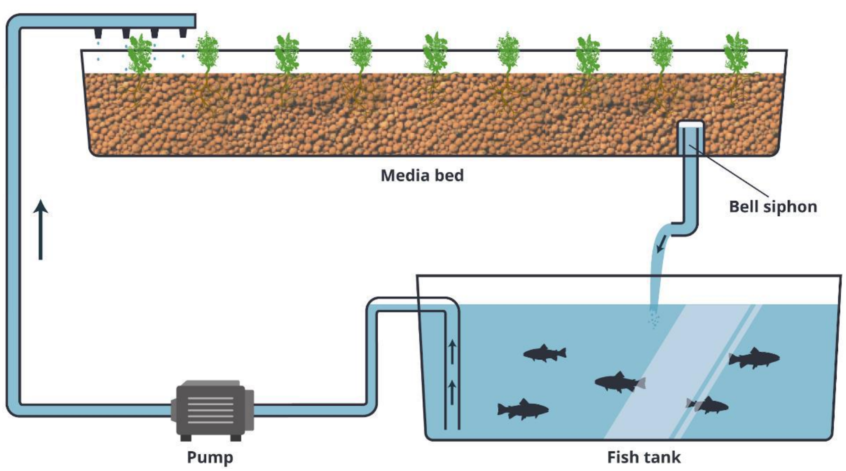

Figure 7: Media-based aquaponics system (Verheyen L., 2019)

c) Nutrient Film Technique (NFT)

NFT systems (figure 8) work by flowing nutrient-rich water through a narrow trough, such as a PVC pipe to the back to the pond. In NFT systems, nutrient-rich water is pumped down to small enclosed gutters, the water flowing down the gutter is only a very thin film. Plants sit in small plastic cups allowing their roots to access the water and absorb the nutrients (Getachew *et al.*, 2018). This is a system where the flexible plastic tube is supported by a tray. This method of growing works very well for plants that need little support, such as strawberries, lettuce and other herbs. NFT is also a great way to utilize unused space because they can be hung from ceilings above other growing areas or arranged vertically and utilize little space (Somerville *et al.*, 2014; Verheyen L., 2019).

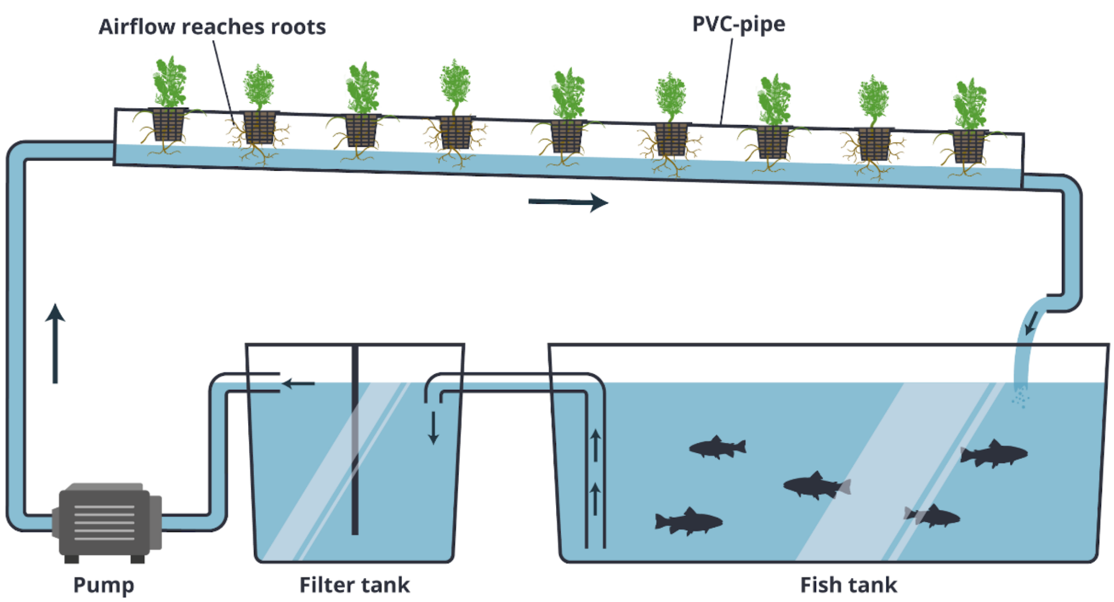

Figure 8: Nutrient Film Technique (NFT) (Verheyen L., 2019)

2.2 Bacteria

Aquaponics is a production system that is based on the dynamic balance between fish, plants, and microorganisms (Eck, *et al.*, 2019). Microorganisms such as bacteria play a big role in the transformation of effluents from both aquaponic and hydroponic systems into a usable form for both plants and fish (Graber & Junge, 2009; Moore, 2017). Bacteria are microorganisms that are found everywhere and can have different shapes such as rods, spheres, spirals and amorphous shapes (Moore, 2017). In aquaponics, there are mainly two genera of bacteria that help to keep the aquaponic system functioning and balanced and these are nitrifying bacteria like *Nitrosomonas* and *Nitrobacter* (Schmautz *et al*., 2017 and Moore, 2017).

According to Eck *et al*. (2019), the analysis with 16S rRNA gene deep sequencing *Proteobacteria* and *Bacteroidetes* are the predominant bacteria communities found in both aquaponics and aquaculture systems and the other bacteria. The nitrification process was studied during which ammonia is transformed via nitrite to nitrate, which is less toxic for the fish and preferred by plants (Graber & Junge, 2009; Timmons & Ebeling, 2013; Resh, 2013). The main bacteria involved in this transformation are the ammonia-oxidizing bacteria (AOB), such as *Nitrosococcus*, *Nitrosospira*, and *Nitrosomonas*, and the nitrite-oxidizing bacteria (NOB), such as *Nitrobacter*, *Nitrospira*, *Nitrococcus*, and *Nitrospina* (Itoi *et al*., 2007; Rurangwa & Verdegem, 2015). According to Daims *et al*. (2015) and Bartelme *et al*. (2017), some *Nitrospira* populations are also able to perform the complete ammonia to nitrate transformation and are known as complete ammonia oxidizers (COMAMMOX) by themselves. Archaea, such as the *Thaumarchaeota*, can also be involved in the ammonia-oxidizing process (Bartelme *et. al*, 2017). The anaerobic ammonium oxidation (ANAMMOX) group, members of the Planctomycetes responsible for the anaerobic transformation of ammonium and nitrite into nitrous oxide and N_2 may play a role as well where oxygen levels are low (Hu *et al*., 2011).

Apart from nitrification, microorganisms are involved in other important processes such as extracting the various macro-and micronutrients from the feed leftovers and solid faeces and make them available for plant uptake (Goddek *et al*., 2016). But this is dependent on the aquaculture compartment, design, fish species, and feed type, most of the fish used in aquaponic systems utilize 20-30% of the protein in their diets. The rest is excreted and is available for the bacteria to decompose (Timmons & Ebeling, 2013; Yogev *et al*., 2017; Schneider *et al*., 2005). Besides this, bacteria could also play a role in the solubilization of nutrients encompassed in solid compounds, such as phytates (Jorquera *et al*., 2008). Additionally, microorganisms in aquaponics are also involved in various plant growth promotion and protection pathways, such as biocontrol or the enhancement of root growth (Gravel *et al*., 2015, Sirakov, *et al*., 2016; Schmautz, *et al*., 2017).

A crucial function of the bacteria communities in aquaponics would be the solubilization of the fish indigestions and fish feed leftovers into macro-and micronutrients, which the plants can absorb. The members of the genera *Flavobacterium* and *Sphingobacterium* could participate in the decomposition of organic matter (Liu, *et al*., 2012). The *Saprospiraceae* family is typically found in the aquatic environment, such as wastewater treatment plants (Xia *et al*., 2008; Liu, *et al*., 2012; McIlroy & and Nielsen, 2014), and could be involved in the degradation of complex carbon molecules, such as proteins (Xia *et al*., 2008; McIlroy & Nielsen, 2014).

The genus *Nitrospira* detected in biofilter is commonly known as a NOB (Itoi *et al*., 2007; Rurangwa & Verdegem, 2015; Daims, *et al*., 2015; Gao *et al*., 2017). Daims *et al*. (2015), showed that certain strains of the *Nitrospira* genus could be complete nitrifiers, i.e., able to oxidize ammonia to nitrate without the help of AOB, a process now known under the name COMAMMOX. Denitrification has also been often observed in aquaculture and aquaponics (Monsees *et al*., 2017 and Wongkiew *et al*., 2017). Members of the genus Arcobacter are known to perform denitrification and have been particularly found in the denitrifying biofilter of the BQF system (Wang *et al*., 2017). The phylum Planctomycetes has already been observed in recirculating aquaculture and contains ANAMMOX bacteria (Van Kessel, *et al*., 2010; Liu, *et al*., 2012).

2.3 Plants

There are different types of plants that can be used in aquaponic systems. Some of the plants that can be grown in aquaponics are lettuce, herbs, tomatoes, kale, swiss chard, beans, cucumbers, broccoli, cauliflower, cabbage, sweet corn, beets and others (Nelson, 2010). According to Salam *et al*. (2014a), lettuce produced from aquaponics systems performs better than soil and hydroponics system. But according to the findings of Rana *et al*. (2018), soil system performs better than the aquaponics system. The soil had a higher plant weight, leaf average length and essential minerals as compared to the aquaponics. The aquaponics system had a high root weight value and high plant average length as compared to the soil system. According to Bethe *et al*. (2017), molasses vermicompost foliar spray in aquaponics and hydroponics systems had high yield vegetable growth after 180 days. This is because compost tea is a liquid that contains not only all the soluble nutrients extracted from the compost but also all the beneficial species of bacteria, fungi, protozoa and nematodes that help to protect the plants from harmful pathogens and diseases (Diver, 2011).

Plants grown from the aquaponics and hydroponics system are not exposed to residual toxic chemicals found in the soil or from other agricultural production systems which can be taken up by the plants. Lessor no pesticides can be used in the hydroponics system during vegetable production, but not in the aquaponics system because pesticides can be toxic to fish. Plants nutrient uptake in the systems can also help to maintain pH and reduce the micronutrient deficiency in the vegetables in the production which is associated with pH imbalance (Diver, 2011; Diffen, 2019). Furthermore, Mendoza-Castillo *et al*. (2019) suggested that hydroponics performs better than the aquaponics system for growing cucumber and lettuce. Both systems had no difference in the survival rates of the plant, but the yield of both plants was high in the hydroponics system than aquaponics. Since nutrients in the hydroponics system are supplied in the ideal amount and are available for plant uptake, resulting in a high yield in hydroponics than in the aquaponics system.

Schmault *et al*. (2014) compared nutrient distribution in tomato production using three main hydroponics systems; NFT, drip irrigation and floating raft culture. It was observed that the minerals such as N, Ca, P, K, Mg, Fe and Zn, fruit yield and quality were the same in all systems. However, drip irrigation performed better than the others in terms of internal fruit quality parameters, cumulative yield and number of fruits. This is because drip irrigation allows aeration which provides oxygen to the roots of the plant. Raft-based culture is not good for tomato production due to its unlimited water availability. This affects the fruit quality, most of the tomatoes may be cracked, deformed and spoiled (Schmault *et al*., 2014).

Vermicompost applied at 200gm/plant from organic waste can reduce aphid infestation in cabbage production and results in increased leaf length and weight, cabbage round head size, standing plant height, root length and the total number of leaves (Mulusew Getnet and Raja, 2013). The plant growth is associated with humus content excreted by earthworm which contains humic acid (Canellas *et al*., 2002).

According to Mashavira *et al*. (2015), different rates of water hyacinth-based compost application for tomato production can increase growth, yield and accumulation of heavy metals such as lead (Pb), copper (Cu), nickel (Ni) and zinc (Zn). This is an attribute of the presence of minerals and heavy metals from nutrient and mineral-rich landing rivers which the water hyacinth is based (Goel *et al*., 1989). Delayed maturity and ripening of tomato are observed in increased rates of compost application, this is due to increased levels of nitrogen which reduce the red tomato fruit colour and increase the green intensity in the tomato fruit, thus tomatoes at a high intensity of N delay on reaching the fruit colour index of pale red (Goel *et al*., 1989; Herrero *et al*., 2001).

According to Salam *et al*., (2014b), the type of media used and season has an impact on production outcomes in an aquaponics system. In this experiment tomato produced from gravel only had the best outcome as compared to gravel mixed with sawdust and brackets only. It had the highest mean plant height, leaf number, plant and fruit weight and the lowest root weight. This is because the gravel media maintains nutrients in the root zone and provides adequate space for gas exchange (Sikawa & Yakupitiyage, 2010). Licamele (2009) suggested that fish biomass and nutrient supplement can affect lettuce production and chlorophyll concentration index in an aquaponics system. It was discovered that 1kg of Nile tilapia would yield 6.4kg lettuce heads. According to Roosta & Hamidpour (2011), Foliar application of micro-and macronutrients in hydroponic and aquaponic tomato production showed that tomatoes under hydroponic system had higher biomass as compared to aquaponics (Roosta & Hamidpour, 2011). Furthermore, foliar application of K, Mg, Fe, Mn, and B increased vegetative growth of aquaponics plants and foliar application of Fe and B had positive effects on plant growth. The application of K, Mg and Zn increased fruit number and yield in hydroponics and aquaponics respectively, signifying that deficiency of some nutrient supply in aquaponics and hydroponics can affect plant growth and fruit production.

The aquaponics water with nutrient supplements can yield equal or greater biomass just as in the hydroponics system and can also affect the chlorophyll concentration index (Licamele, 2009). Nutrient composition (macronutrient and micronutrient) supplied in the growth solution can determine the nutrient content, growth and health of the plant. Furthermore, Licamele (2009), nutrients do not accumulate at the same rate, as such some supplements need to match the plants' demand or requirement. It has been supported that zinc, iron and manganese accumulate at different rates in an aquaponics system therefore they must be supplied (Seawright *et al.*, 1998). Nutrients can also be supplied from the system through fish solid waste or aquaponics sludge (Licamele, 2009). Plants such as lettuce require nitrogen for their growth in both systems, but too much of the nitrogen nutrient can affect the plants ripening period (Welch *et al.*, 1983; Herrero *et al.*, 2001)

2.4 Fish

The types of fish that can be used in aquaponics systems require that they should either have the same or close type of need in terms of pH and temperature to the plants used in the system and ensure that none of the organisms is deficient of some resources. For example, warm water fish like Tilapia does well with leafy vegetables like lettuce and herbs (Nelson, 2010). A system that has a high stocking density of fish would require fruiting vegetables like tomatoes, pepper, beans and others because the effluent is rich in nutrients (Nelson, 2010; The Aquaponics Source, 2019). Fish raised in aquaponics include tilapia, bluegill, sunfish, koi, crappie, various ornamental fish such as angelfish, guppies, tetras and others.

WorldFish (2015) reported that fish provides more than one billion poor people with most of their daily animal protein. Fish provides nutrients and micronutrients that are essential to the development of children and complete most of the important healthy diets (WorldFish, 2015). Fish play a role in the aquaponics system, by supplying nutrients to the plants through its uneaten food and waste from the fish tanks. The most raised aquatic animals in aquaponics by per cent were tilapia (69%), ornamental fish (43%), catfish (25%), other aquatic animals (18%), perch (16%), bluegill (15%), trout (10%), and bass (7%) (Love *et al*., 2015).

There are different species of fish that are being raised in aquaponics production such as; tilapia, rainbow trout, channel catfish, yellow perch, goldfish/koi and bluegill sunfish (Grove, 2016). These fish species are commonly raised in aquaponics due to its resistance to changes in pH, temperature and stocking density (Grove, 2016). Fish and feed waste provide most of the nutrients required by the plants in aquaponics if the optimum ratio between daily fish feed inputs and the plant growing area is sustained (Robaina *et al*., 2019). Most of the fish used in aquaponics systems utilizes 20-30% of the protein in their diets releasing about 70-80% of nitrogen supplied in their diets to the system supplying bacteria enough nitrogen to work on and make it available for plants use (Robaina *et al*., 2019).

According to Bethe *et al*., (2017), Nile tilapia raised in an aquaponics system dosed with molasses compost tea had a good growth performance in terms of length and weight. Furthermore, Alam *et al*. (2008) highlighted that mono sex (all males) Nile tilapia cultured in an aquaponics system resulted in high growth performance as compared to the mixed-sex stock of Nile tilapia. Licamele (2009) reported that Nile tilapia stocked at 5kg m^{-3} in an aquaponics system would produce a net yield of 1.58kg of fish at a feeding rate of 2% of its body weight. Using an NFT system to produce lettuce and cucumbers with 78±1.9g average weight of Nile tilapia, stocked at 90 organisms/m^3 would produce fish with a final weight of 242.9±8.9/fish, a survival rate of 97.2±2.4%, specific growth rate and FCR of 4.95 and 0.99 respectively after 49 days.

2.5 Strength and weakness of the aquaponics system

Each of the above systems has its strengths and weaknesses and the choice of a system to be used for production is dependent on how the strength of the system outweighs the weaknesses. There are many strengths of each aquaponics system which can affect the productivity and some of these include; produced food is free from field pathogens which might be hazardous to the human health, space and water utilization, water purification, maximization of fish and vegetable production, water loss control, environmentally friendly, cost-effective, large fish stocking density can be used and many other factors (Lobillo-Eguíbar *et al*., 2020). In some aquaponics system, medium based is used and are heavy, expensive because pumps, generators and aerators might be used to run the system, water loss and the system is prone to infections like fungus if it is not managed properly. Nutrient imbalance and to determine the recommended level of feeding fish to prevent water quality deterioration is another challenge in aquaponics system production (Nozzi *et al*., 2018). Therefore, the choice of the type of system to be used is dependent on the type of fish and plants to be produced, resources availability and outstanding system of production.

2.6 Vermicompost

Vermicompost is the product of microbial decomposition of organic waste through the digestive tracts of earthworms (Dioselina Álvarez *et al*., 2016). This compost is capable of improving soil health and nutrient status and can be used in food production (Adhikary, 2016). Vermicomposting (a biotechnological process of composting) involves several definite species of earthworms and microorganisms that can be used to improve the process of waste conversion and produce a better product. Species of worms such as *Perionyx excavates, Lumbricus rubellus, Eudrilus eugeniae, Eisenia fetida* and *Eisenia Andrei* (plate 1) can be used during the vermicomposting process (Zirbes *et al*., 2011). These organisms are active under moist conditions and they also require good temperatures of between 10°C to 32°C.

Plate 1: *Eisenia Andrei* (adopted from Dominguez, 2012)

Vermicomposting is one of the ways to improve production system fertility and food production, at the same time managing the waste and weed. The waste is converted to a useable form like manure or vermicompost tea which can be applied to crops or any production systems to improve productivity. Vermicomposting does not only serve as a waste management strategy and nutrient supplier but also the output of the composting contains more nutrients than the original materials used for composting (Adhikary, 2016). The vermicomposting end product contains about 5, 7 and 1.5 times more nitrogen, potash and calcium, respectively (Adhikary, 2016). Plants are nutrient demanding organisms; hence nutrients have to be supplied into their production systems to increase yield and also control pests and diseases. As such water hyacinth-based vermicompost tea would be one of the nutrient supplements to improve vegetable production.

Use of vermicompost tea is demanded from aquaponics and hydroponics producers to decrease or eliminate the use of synthetic fertilizers, and utilize renewable, locally available materials. During the study by Fox *et al*. (2012), aerated vermicompost tea was used to compare the growth of pakchoi and the buffering capacity of the vermicompost over synthetic fertilizer. The vermicompost was good in terms of both growth and buffering capacity as compared to synthetic fertilizer. Churilova and Midmore (2019) reported that the use of kitchen waste as material for vermicompost for pakchoi production was not a success. The study used NFT and pot hydroponics system and even though the results were not successful but comparing the pot and NFT system, pot hydroponics performed better because it was able to buffer the pH making some nutrients more available than in the NFT. According to Raja (2019), the use of hydroponics water to produce green herbal from seaweed, *Turbinaria conoides* liquid fertilizer gives high yield and growth.

2.7 Nutrient quality and heavy metal

Lettuce is one of the most widely consumed vegetables worldwide, which is low in calories, fat and sodium and it is a good source of fibre, iron, folate, and vitamin C (Kim *et al.*, 2016). Leafy vegetables accumulate trace elements more than fruiting vegetables, and lettuce is one of the leafy vegetables which is known to accumulate excessive nutrients (El-shinawy and Gawish, 2006; Gupta *et al.*, 2019). Because of this ability, different systems of production and nutrient sources are being developed to improve its productivity and at the same time reduce the risk of excessive nutrient accumulation which is associated with human health issues. Increased nitrogen treatment levels improved growth and biomass for lettuce plants grown in a hydroponics system, where the foliar nitrate content is high (Lastra *et al.*, 2009).

Some trace elements are important ingredients to animals, humans, and plants, but increased concentration can cause toxic effects and the toxicity of heavy metals is dependent on metal mobility in free form. Vermicomposting of waste materials of green weed *Salvinia natans* using *Eisenia fetida* showed an increase in heavy metal concentration when the volume and weight of the compost material decreased, but it later decreased with time towards the end of the vermicomposting process (Singh and Kalamdhad, 2016). This was so as the metals bioaccumulate in the worms tissue and forming organic-metallic complexes in their intestines, which reduces the solubility of heavy metals (Goswami *et al*., 2013). Solubility reduction is possible through cellular adaptation by binding of heavy metals to nuclear proteins forming nuclear inclusion bodies; and the cytoplasmic process which involves the synthesis of the specific metal-binding protein, metallothionein, within thenchloragogenous tissue (Hait and Tare, 2012).

Chapter Three: Materials and methods

3.1 Description of the experimental setup

The experiment was conducted at the aquaponics unit of the Zoological Sciences Department, Addis Ababa University. The experiment constituted of two Nutrient Film Technique (NFT) system, non-circulating hydroponic and circulating aquaponics systems. A Nutrient Film Technique (NFT) system (plate 2) was used in this experiment and each system had a plant growing trough made of PVC pipes with thirty-three planting holes.

The hydroponics system (plate 2) consisted of three PVC pipes which were used as the plant grow bed each with eleven plant pots. The plant pots were fitted with net cups made from plastic bottles which were filled with gravel and a sponge to support the plant and help hold moisture. The PVCs were connected and aligned in the direction of a nutrient solution (WHBVT and hydroponics solution) reservoir which was located at the lower part of the system. This reservoir was located at the lower part of the system connected with an air stone for oxygen, whereby the nutrient water was hand supplied to the plants through irrigation. Plants were irrigated four times a day (8 am, 11 am, 2 pm and 5 pm) at the beginning of the experiment to maintain moisture in the cups because at this time the plants had short roots hence cannot reach the bottom of the cup to take up nutrients. Then irrigation interval was reduced to twice a day (9 am and 5 pm) when the plants extended their roots outside the growing cup. The nutrient solution was irrigated to each plant pot, the sponge and gravel would help hold some of the nutrient water. Some of the nutrient water would remain in the pipe the rest would drain back to the nutrient reservoir tank.

The aquaponics system (plate 2) had a fish rearing tank of 350L of water with an air stone connected to maintain supply oxygen to the system. The fish tank was connected to a biofilter tank which comprised of gravel which acted as a bacteria media growth bed. Water from the fish tanks was drained to the reservoir tank, which was later pumped to the biofilter and clarifier and then drained to the plants (for nutrient take-up) with the help of gravity and back to the fish tank. Water used in this experiment was supplied from the reservoir tank located outside of the greenhouse.

 a)  b)

Plate 2: a) Aquaponics and b) hydroponics system.

3.2 Experimental design

The experiment was conducted in a Nutrient Film Technique system for 60 days (12^{th} May-8^{th} August), and it was laid out in a completely randomized design (CRD). Five treatments were employed in this experiment; untreated hydroponics (UH), untreated aquaponics (UA) and treated hydroponics (TH) with the liquid application of the water hyacinth-based vermicompost tea dosed at 30%, 40% and 60% dilutions for growing lettuce (Copetta et al., 2011). Untreated hydroponics and untreated aquaponics system in the experiment served as the control.

Untreated hydroponics was nourished with nutrient solutions made from different combination of elements such as potassium phosphate, boric acid, monoammonium phosphate, magnesium sulphate, calcium nitrate, copper sulphate and sodium molybdate. All treatments were done in duplicate and each experimental unit (n) had an equal chance of being a recipient to any of the treatment. Ten experimental units were used during this experiment and laid out as shown in table 1;

Table 1: Experimental design

Experimental unit(s)	1	2	3	4	5	6	7	8	9	10
Treatment(s)	UH	TH60%	TH30%	UH	TH60%	TH40%	TH30%	TH40%	UA	UA

(UH= Untreated hydroponics with standard prepared hydroponics solution, UA= Untreated aquaponics, TH30%= Hydroponics treated 30% dilutions of vermicompost tea, TH40%= Hydroponics treated 40% dilutions of vermicompost tea and TH60%= Hydroponics treated 60% dilutions of vermicompost tea representing treatments)

3.3 Source of vegetables and production

Lettuce seedlings used in this experiment were transplanted from the nursery bed which was constructed behind the greenhouse within the Addis Ababa University premises. These seedlings were transplanted to the hydroponics system 10 days after sprouting when the plants had developed a second set of leaves (Date et al., 2005). The plants were thoroughly washed to remove any soil from the roots, then transferred to a sponge for plant support. Then this sponge was placed in the plant growing plastic cup filled with gravel. After transplanting, the seedlings were subjected to the nutrient solution and water hyacinth-based vermicompost tea treatments.

3.4 Nutrients preparation

3.4.1 Hydroponics nutrient preparation

Lettuce plants grown in the untreated hydroponic systems were nourished with a nutrient solution that consisted of: 2.5mM $Ca(NO_3)_2.4H_2O$, 0.2mM KH_2PO_4, 0.2mM K_2SO_4, 0.3mM $MgSO_4.7H_2O$, 0.1mMNaCl, 20µM Fe-EDDHA, 7µM $MnSO_4$ H_2O, 0.7µM $ZnCl_2$, 0.8mM $CuSO_4$ $5H_2O$, 2µM H_3BO_3 and 0.8µM Na_2MoO_4. The solution was changed every 2 weeks. The nutrient solution for the hydroponic system was prepared using deionized water (Somerville *et al*., 2014; Rakocy *et al*., 2016).

3.4.2 Vermicompost tea preparation and application

The water hyacinth used for making the vermicompost was collected from Lake Ziway. Then it was transported to Batu Fisheries and Other Aquatic Life Research Centre for composting. Vermicomposting was done for two months following the procedure in Gezahegn Degefe *et al*., (2012). The vermicomposting process took place in a vermicomposting unit with a dimension of 12 m X 5 m (L X W) compartmentalized into six (LXW, 2.5m X 1.2m with 30cm depth) composting pits. *Eisenia fetida* species of earthworms collected from Adami Tulu Agricultural Research Center were used in the composting of the water hyacinth. The processing started by cutting the whole water hyacinth plant in segments of 2 to 3 cm and mixing it in 3:1 ratio with air-dried, powdered cattle manure (CM). This mixture was pre-treated for two weeks by forming a pile of 30 cm covered with a dark plastic sheet. The pile was watered and turned every other day to eliminate volatile gases potentially toxic to earthworms. Each pit was inoculated with 400 grams of worms (*E. fetida*) and then was covered with a shade net to prevent moisture loss and birds or rodents eating the worms. The process took 2 months to complete and homogenized samples were taken from the pits to use in the study at Addis Ababa University where it was processed into tea as a nutrient solution for the hydroponics system. Vermicompost tea brewing is done to increase the abundance and diversity of the microbial population already present in the compost.

Plate 3: The beginning of the vermicomposting process

Plate 4: The end of the vermicomposting process.

The manure was mixed with dechlorinated water in a bucket at a ratio of 1:4, the mixture was aerated by allowing it to stand for three days with temperature ranging from 18.3-24.1^{o}C (Weltzien, 1991; Fritz *et al*.,2012). The aerated WHB vermicompost tea was then sieved using a 600-µm sieve (Supertek standard test sieve), and the following dilutions were prepared from the brewed tea 120 ml, 160ml and 400 ml and each were diluted in 20L of water to achieve 30, 40 and

60% concertation of the tea. These dilutions were then supplied to the plants by irrigating the solution to the plants dosed at 300ml/plant per day according to Pant *et al*. (2011).

Plate 5: Vermicompost tea processing

3.5 Data Collection

3.5.1 Water quality parameters

Water quality parameters such as pH and temperature were monitored twice a day (9 am and 5 pm) every day using Adwa AD 111 pH/mV/^{o}C meter. Conductivity, salinity and total dissolved solids were measured twice every two weeks, before and after changing the nutrient solution and this was done using a conductivity meter (model 145A+). Ammonia (Phanate method), nitrate (Sodium salicylate method), soluble reactive phosphorous (Ascorbic acid method) and total phosphorous (persulfate digestion) concentrations were analyzed at 2 weeks interval using a spectrophotometer following the procedure by APHA (1999); Wood & Robertson (2015).

Plate 6: Taking temperature and pH readings and ammonia analysis

3.5.2 Plant growth and development

There are different features of a plant that can be observed and measured in an experimental period to determine the growth and development of a plant. Plant features such as whole plant head and dry weight, shoot wet and dry mass, leaf area, wet and dry mass of roots, root-shoot ratio, growth rate, shoot length and others can be used to determine growth.

The plant shoot length and leaf area (plate 7) were recorded every 3 days during the experiment for 60 days, the leaf area was determined by ImageJ (version1.53c) software. At the end of the experiment, representative plant samples were collected from each treatment to compare the growth of lettuce. Each collected plant sample was weighed to determine its head weight using a digital scale (YP Series Precision Balance). To determine plant growth rate the final shoot length was subtracted from the initial shoot length than multiplied by the number of days of the experimental period. To obtain dry weight the plants were dried overnight in an oven at 100^{o}F, then weight for each plant was recorded. After obtaining the whole plant dry weight, the roots and shoots were separated from the plant and weighed independently to obtain the Root-shoot ratio. All this was done following the procedure by Wood & Roper (2000); Li et al., 2018).

Plate 7: Leaf area determination a) original image and b) refined image when subjected to ImageJ

3.5.3 Heavy metal analysis

3.5.3.1. Heavy metal analysis in vermicompost tea

To determine the properties of WHB vermicompost tea, vermicompost tea extract was poured into a crucible and placed in an oven at 70 °C for an hour. The condensed material was ashed in a heavy-duty muffle furnace at 350 °C. The dried ash was then digested in HCl 2M and was determined using atomic absorption spectrometry (Zarei *et al.*, 2018).

3.5.3.2 Heavy metal analysis in lettuce samples

Lettuce was harvested and collected from the greenhouse 60 days after transplanting. The samples moisture content was recorded then packed in polythene bags and carried to the Fisheries laboratory in the same department for oven drying. The samples were oven-dried at 100^oF for 24 hours. Final dry weight was recorded, then the samples were transported to Hortcoop for sample digestion and heavy metal analysis was done at JIJE laboratory. The dried samples were grounded using a mortar and 2g of each powdered sample was weighed using the electronic balance then furnace dried at 400^oC for 3-4 hours. The sample was poured in a digesting flask and 30ml of concentrated Nitric Acid (65%) HNO_3 was used to digest the sample. The heavy metals in the plants were analyzed using the atomic absorption spectrophotometer (model AA6300) (Boamponsem and Kumi, 2012; Yang *et al*., 2017; Bahiru Daghe and Endate Teju, 2019).

3.6 Nutrient quality analysis of vermicompost tea and lettuce

To determine the nutrient quality of the vermicompost tea, fish and lettuce several methods were applied; total nitrogen was determined by the method of Micro-Kjeldahl (Bremner and Mulvaney 1982), total potassium by the use of flame photometer (Page *et al.*, 1985), magnesium by inductively coupled plasma atomic emission spectroscopy and total phosphorous by molybdate vanadate yellow method (Chapman and Pratt, 1961). Concentrations of Fe, Zn, Cu and Mn by the method of dry ashing and digesting in HCl 2M, and the elements were then determined using atomic absorption spectrometry (model AA-670G) method (Chapman and Pratt, 1961).

3.7 Data Analysis

Data were analyzed using SPSS (Statistical Package for Social Sciences) computer package version 20 for Windows and Microsoft Office Excel 2019. One-way analysis of variance (ANOVA) was used to determine significant differences in water quality and plant growth parameters among different treatments. A simple linear regression model was applied to determine the relationship between nutrient solution rate and growth of lettuce at an alpha level of 5%.

Chapter Four: Results and discussion

The treatments in this experiment did not have an impact on the water quality except for plants dosed with a nutrient solution that had higher ammonia than the treatments dosed with WHBVCT. High growth, leaf area and shoot length were recorded from plants dosed with the nutrient solutions than the treatments with WHBVCT. Lettuce produced from treatments dosed with WHBVCT were within the acceptable limits in terms of nutrient quality and metal concentration for human consumption, except for lead (for planted dosed at 30% and 40%) and iron which was above the permissible limit. Plants from the UH and UA were attacked with fungi and aphids, which was not observed from the treatment dosed with WHBVT.

4.1 Water quality

Water quality parameters such as temperature and pH were recorded during the experiment. Water temperature in the plant root zone both morning and afternoon varied from 13.10ºC to 25 ºC, both the minimum and maximum temperature ranges were observed in the morning. The higher temperature ranges were recorded from the beginning of the experiment due to sunlight. Temperature differences were not significantly different among the treatments ($P > 0.05$) (Table 2). pH ranged from 5.87 to 8.66 during the experimental period. UH was significant to the rest of the treatments ($P < 0.05$) in the morning observations. DO range between 4.69—6.98 mg/L in the treatment during the experimental period. The concentration of dissolved oxygen indicated UA was significantly different from the other treatments ($p > 0.05$).

The ideal water temperature range in hydroponics systems for lettuce production is between 15 ºC to 25ºC (degrees Celsius). Increased temperature is related to increased growth rate and lower temperature affects growth. This agrees with the results that lower temperature was recorded in the morning and increased during the day. Morning temperature observations are a representation of activities that happen at night. Optimal increased temperatures result in induced water and nutrient uptakes, speeding metabolic processes most of which are enzymatic and require optimum temperatures range (Brechner *et al*., 2016). Hence shoot growth, the nutrient solution, therefore, supplies the heat energy required for optimum plant growth and development (Gorbe *et al*., 2008; Brechner *et al*., 2016).

Increasing temperature also facilitates solubility of mineral nutrient uptake since the rate of dissolving of solutes increases with increase in temperature (Huang, 2006). Temperature tends to determine the concentration of nutrients absorbed by the plant since more nutrients are dissolved at higher temperatures (Nxawe *et al.*, 2011). But if the temperature below and above the optimal ranges, the metabolism starts to deteriorate and as result chemical processes slow down or are stopped, and plants are stressed, reduce growth, anthracnose, leaf top burn can develop and can even die (Brechner *et al.,* 2016). During the experiment, the conditions in the systems were favourable for the growth and development of lettuce (Silva *et al*., 2018).

The pH from both hydroponics and aquaponics systems had recommendable pH levels in which both lettuce and fish can survive and grow. The optimal pH range for lettuce in hydroponics and aquaponics system is between 5.5-7, too high or too low pH it affects nutrient mobility and uptake of nutrients. The pH kept fluctuating between 5.87-8.66, signifying the nutrients were being used by the plants in the systems. The treatments dosed with WHBVCT in the hydroponics systems did not have any impact on the pH quality of the nutrient solution in comparison to the control.

According to Pennisi and Thomas (2015), when the pH is too low, the micronutrients become more mobile and are absorbed more than what the plant needs, resulting in this potential for toxicities. It also promotes nutrient toxicity in water and growth is reduced. When the pH is too high, the micronutrients mobility is reduced and the plant cannot take up enough. This results in deficiencies which can affect some of the plants' properties such as leaf area, leaf number, shoot dry weight, leaf length and width, photosynthesis and chlorotic growing tip and young leaves (Pennisi and Thomas, 2015). High pH can reduce solubility and nutrient uptake for iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and phosphorus (P) to plants; low pH can reduce potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), and P availability to plants (Roosta and Rezaei, 2014). In a study on lettuce, the plants treated with low pH had a higher concentration of micronutrients in their shoots than those treated with higher pH (Roosta, 2011).

Fertilizer salts availability is important to plants and can be controlled by the pH of the solution. If a solution is rich in phosphates and the temperatures are above 20^{o}C, uptake of phosphate from the solution increases which may result in lower levels of pH which was not the case in this trial. The decrease in the pH can also be presumably associated with the oxidation process undertaken by bacteria and not temperature alone, indicating that there was no relationship between temperature and pH (Brechner *et al*., 2016).

Brechner *et al*., (2016), reported that dissolved oxygen (DO) measurements indicate the amount of oxygen available in the nutrient solution for the roots to use in respiration. Lettuce can grow performs better at a DO level of at least 5 mg/l. When oxygen is not supplied to the nutrient solution which is passed through the plant roots, DO levels drop to approximately 0 mg/l. Pure oxygen is added to the recirculation system in the reservoir tank with the assistance of air stones and at this level, the DO is maintained. Dissolved oxygen is an important parameter because it is required in the process of oxidation of ammonia and for fish and vegetable survival. To maintain fish and vegetable optimum growth, an optimum DO concentration should be maintained above 5 mg/L (Colt, 2006). DO concentration of less than 2 mg/L, is insufficient to oxidize ammonia to nitrite and nitrate by nitrifying bacteria (Hargreaves, 2006).

Results in Table 2 indicate that conductivity was significantly different ($P < 0.05$) between treatments. Electric conductivity ranged from 87 µS/cm to 1407 µS/cm, with the lowest volume observed before changing the nutrient solution (nutrient water used for 2 weeks) and the highest after changing it (after adding the nutrients). UH was different overall the treatments before and after changing the nutrient solution. Comparing the EC from TH30%, TH40% and TH60% before changing the water TH60% recorded the highest followed by TH40% and TH30%. After changing the nutrient water TH30% had the highest, TH60% and TH40% was the least. For Lettuce production under hydroponics and aquaponics systems, the EC should be between 0.8 and 3 mS/cm and less than 1mS/cm (Wortman, 2015; Bruce and Singh, 2016; Sublett *et al*., 2018). EC ranges outside the optimal levels affect leaf nitrate concentration and increase phenolic compounds and antioxidant enzymatic activity, which reduces plant fresh weight (FW) and dry weight (DW), leaf size, photosynthesis and transpiration, consequently lowering yield (Scuderi *et al.,* 2011; Zanin *et al*., 2009; Ding e*t al.*, 2018). This is in line with the results from TH30%, TH40% and TH60% of EC, leaf area, wet and dry weight and yield were significantly different from UH due to insufficient nutrient availability. Meaning that UH and UA had a higher amount of dissolved salts as compared to TH30%, TH40% and TH60%. But it does not agree with the results for UA where the EC was significant and yield, leaf area, dry weight was insignificant. This means that EC cannot be the only determinant of nutrient availability and plant growth, organic metabolites and alternative nutrient form or ratio can be some of the contributing factors to the plants growth (Wortman, 2015).

Comparing the WHBVCT treatments the TH60% dose had a higher concentration of salts followed by TH30% and TH40% was the least. EC initial was lower than the EC final during the experiment because EC final is subjected to pH changes and disassociation of ions affects the concentration of the final EC level. According to Abou-Hadid *et al*., (1996), increased EC in different lettuce variety reduced yield with no difference in nitrate levels. But the results showed an increase in the concentration of phosphorous, zinc, manganese, calcium and iron in leaf. Mineral nutrient concentration increases with an increase of EC, except for potassium, because it can reach a saturation point and decrease in plants exposed to high concentrations (Sublett *et al*., 2018).

Ammonia ranged between 0.04mg/l to 5.35 with a minimum level of ammonia observed from UA and the highest in UH. UH was significantly different from UA, TH30%, TH40% and TH60%. Comparing the concentration of ammonia from TH30%, TH40% and TH60%; TH60% had the highest concentration and TH30% had the lowest. Nitrate concentration ranged between 0.05gm/l to 2.30 mg/l, UH was significantly different from UA, TH30%, TH40% and TH60% and the minimum was observed from UA and the maximum from UH. Comparing TH30%, TH40% and TH60%, TH30% had the highest and TH60% the lowest, and UH was significant when the means were compared.

Optimal ammonia concentration for producing lettuce is less than 2mg/l (Savvas *et al*., 2006), of which all the treatments were within the acceptable ranges of concentration. But when ammonia levels are less the pH levels decline which affects the availability of bacteria fixing colonies because it is acidic, essential elements to plants and plant growth is affected (Jones, 2005). Nitrate availability is associated with the concentration of ammonia, nitrite and nitrifying bacteria colonies in the nutrient solution and biofilter, when the ammonia concentration is high then the water will also have an increased nitrate level. Less than 1mg/l is considered as the maximum concentration for nitrate (reference) if it is greater than it means the plants in the system are not enough hence other plants need to be added.

TDS ranged from 78mg/l to 610mg/l, with the lowest observed from UA, TH30% and TH40% before changing the water and UA after changing the water, while UH recorded the highest before and after changing the water. Before changing the water TH60% recorded the highest then TH40% and TH30% after the water was changed TH30% recorded the highest followed by TH60% and TH40%, but overall UH was significant when the means were compared. All the treatment was below the normal TDS range but UH was significant to UA, TH30%, TH40% AND TH60%, meaning that UH had more soluble substances than the rest of the treatments. It is important to maintain the aquaponics system under acceptable amount TDS to lower the risk of disease susceptibility (Kjelland *et al*., 2015). The total dissolved solids (TDS) is the measure of ions in water. These are a balance of both cation and anion. It is mainly derived from the uneaten feed and feed residue; dissolved salts from nutrient solutions in aquaponics and hydroponics systems.

Total phosphorous was from 0.05mg/l to 2.30mg/l, the concentrations were observed from UA and UH and UH was significant. When TH30%, TH40% and TH60% concentrations were compared TH30% had the highest and TH60% the least. Soluble phosphorous ranged from 0.1mg/l which was recorded in TH40% to 1.67mg/l recorded in UH, and UH was significantly different when the means were compared. On average TH30% had the highest concentration and TH40% had the least when TH30%, TH40% and TH60% were compared Table 2.

The phosphorous concentration range of between 0.025 and 0.1 mg/l stimulates plant growth, any concentrations above 0.1mg/l accelerate plant growth consequences and if the water is released into the environment can cause eutrophication in water bodies (Dodds & Smith, 2016). According to the results above all the systems were within the recommendable concentration of phosphorous.

Table 2: Water quality parameter in hydroponics and aquaponics systems with mean ± SE

Parameter	Treatment UH-nutrient solution	UA-nutrient solution	TH Vermicompost tea 30%	TH vermicompost tea 40%	TH Vermicompost tea60%	P-Value
Temp Morning	17.94±0.18^{a}	17.60±0.15^{a}	18.0±0.18^{a}	17.9±0.17^{a}	17.95±0.187^{a}	0.508
Temp Afternoon	20.27±0.14^{a}	20.08±0.15^{a}	20.29±0.14^{a}	20.29±0.14^{a}	20.30±0.14^{a}	0.289
pH Morning	7.17±0.04^{a}	7.60±0.02^{b}	7.66±0.14^{b}	7.65±0.02^{b}	7.56±0.03^{b}	0.000
pH evening	7.06±0.03^{a}	7.66±0.03^{b}	7.59±0.03^{b,c}	7.60±0.02^{b,c}	7.47±0.03^{c}	0.000
DO (mg/L)	4.89±0.01^{a}	6.98±0.02^{b}	4.78±0.01^{a}	4.89±0.01^{a}	4.8±0.01^{a}	0.00
EC (mS /cm)	1075.70±99.10^{a}	176.57±15.56^{b}	248±19.79^{b}	242±12.53^{b}	294.10±18.56^{b}	0.000
TDS (mg/l)	521.40±48.49^{a}	90.14±4.74^{b}	117.90±9.52^{b}	114.80±5.89^{b}	139.00±8.60^{b}	0.000
Ammonia (mg/L)	1.76±0.54^{a}	0.70±0.23^{b}	0.41±0.11^{b}	0.70±0.20^{b}	0.84±0.24^{b}	0.032
Nitrate (mg/L)	1.19±0.19^{a}	0.48±0.13^{b}	0.51±0.11^{b}	0.39±0.07^{b}	0.44±0.06^{b}	0.000
Total Phosphorous (mg/L)	1.19±0.19^{a}	0.49±0.13^{b}	0.51±0.11^{b}	0.39±0.07^{b}	0.44±0.06^{b}	0.000
SRP (mg/L)	0.50±0.16^{a}	0.13±0.03^{b}	0.17±0.06^{b}	0.12±0.03^{b}	0.10±0.02^{b}	0.005

Values in the same row with different superscripts are significantly different at ($P < 0.05$).

4.2 Plant growth and development

Shoot length did not show any significant difference in between the plants for different treatments initially. Between treatments, a significant difference in all the plant growth parameters was observed (P < 0.05). UH and UA performed better than the other treatments (Table 3). The final shoot length for UH and UA did not show any significant difference Classifying shoot length into weeks showed that there was no difference in from week 1 through week 5, but a significant difference was observed from week 6 to week 8 of the experiment (figure 9). Minimum average shoot length was recorded in TH40% and the maximum average length in UA.

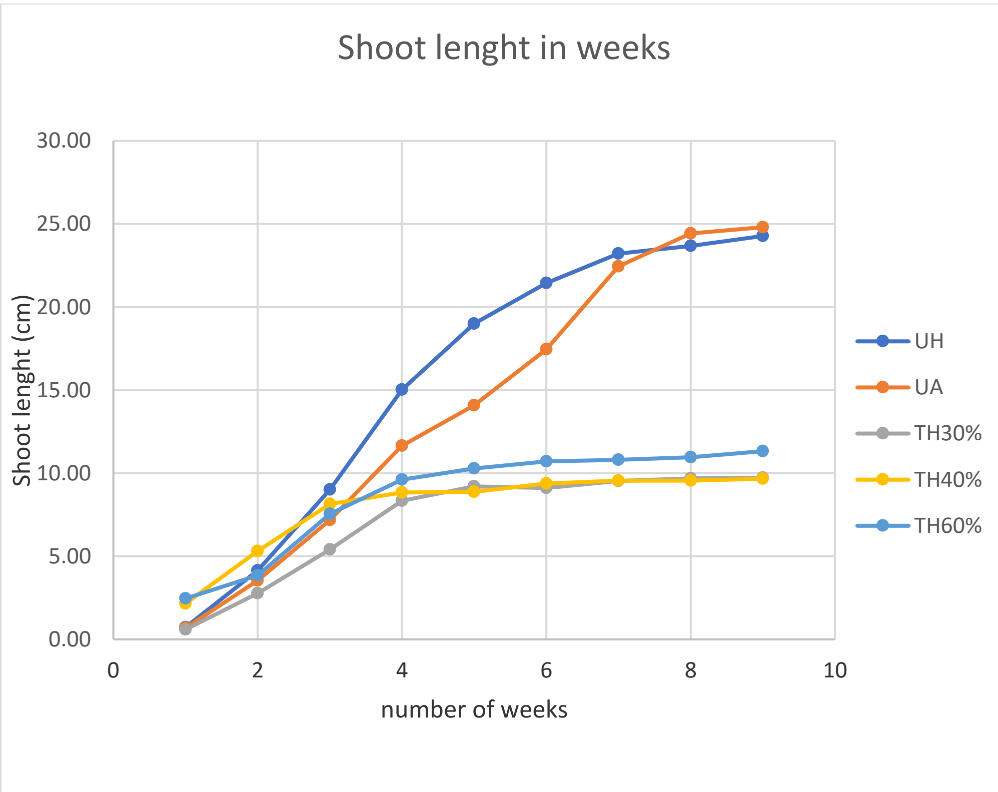

Figure 9: Shoot length presented in weeks

Both UH and UA had a large leaf area as compared to lettuce plants in treatment TH30%, TH40% and TH60%. There was no significant difference in the final leaf area was observed in between lettuce plants grown using the various dilutions of water hyacinth-based vermicompost tea. In terms of growth rate, UH and UA proved to grow better as compared to vermicompost tea treatments.

Plant head weight and Dry weight from both UH and UA were not significant between each other but rather with the rest of the treatments. Whereby the minimum average head weight was observed in TH30% and the maximum from UA. Despite TH30% having the least head weight, there was no significance among the treatments dosed with WHBVCT at 30%, 40% and 60%. The root-shoot ratio was between 0.11 and 1.23 with the lowest ratio recorded from UA and the highest from TH30%. There was no significance between UH and UA, but UA had a lower ratio as compared to UA. UH and UA were both significant when compared- with TH30%, TH40% and TH60%. There was also no significance among TH30%, TH40% and TH60%, but the minimum and maximum ratio were observed in TH60% then TH40% and lastly TH30%.

Table 3: Growth performance parameters of lettuce grown using water hyacinth-based vermicompost tea at various dilution levels (30%, 40% and 60%), standard hydroponic solution and aquaponic systems with mean ± SE

	Treatment					
Parameter	**UH-Standard nutrient solution**	**UA-Standard nutrient solution**	**TH Vermicompost tea 30%**	**TH Vermicompost tea 40%**	**TH Vermicompost tea60%**	**P-Value**
Shoot Length initial	0.73±0.05[a]	0.68±0.05[a]	0.6±0.04[a]	0.61±0.04[a]	0.72±0.03[a]	0.097
Shoot Length final	24.22±0.86[a]	24.79±1.17[a]	9.72±0.31[b]	9.56±0.27 [b]	10.99±0.47 [b]	0.00
Leaf area	70.52±3.52[a]	80.21±12.23[a]	12.38±0.91[b]	15.80±0.91[b]	18.13±2.54[b]	0.00
Growth Rate	0.77±0.04[a]	0.87±0.14[a]	0.13±0.01[b]	0.17±0.01[b]	0.19±0.03[b]	0.00
Dry weight	4.03±0.31[a]	4.87±0.90[a]	1.21±0.09[b]	1.21±0.09[b]	1.38±0.15[b]	0.00
Root: shoot Ratio	0.18±0.01[a]	0.19±0.02[a]	0.76±0.04[b]	0.67±0.06[b]	0.69±0.05[b]	0.00

Values in the same row with different superscripts are significantly different at ($P < 0.05$).

There was a total of 66 lettuce plants in each treatment, at the end of the experiment UH had the least of plants harvested from its system (Table 4). Sixty-three plants were harvested from UH, UA, TH30% and TH60% 65 plants were harvested and TH40% had 66 harvested. Plants in UH were infested with fungi (powdery mildew) and aphids, UA was attacked by fungi while TH30% and TH60% the plant just dried. Large plant biomass, shoot and root were observed in UA, with the least recorded form TH40%.


a)


b)

Plate 8: a) Powdery mildew and b) Aphids

Plate 8.: vegetable showing some nutrient deficiency in treatments dosed with WHBVCT

Table 4: Plant biomass

Treatment					
Parameters	UH	UA	TH30%	TH40%	TH60%
Total number of plants	66	66	66	66	66
Number of plants harvested	63	65	65	66	65
Total biomass (m^2)	4919	6064.10	1727.48	632.28	1034.37
Average Wet shoot weight (g)	4364.12	6232.67	374.44	389.28	517.22
Average Wet root weight (g)	555.77	995.01	271.89	261.16	398.60

Plant root-shoot ratio can be used to determine the plants nutrient uptake, biomass and growth, plants that are between 0-25 cm their expected ration is 18% and a lower root-shoot ratio stands for a higher plant performance (Bláha, 2019). This means that a plant has a probability to take up more nutrients and increase its biomass and also increase the resistance to stress. Both treatments in hydroponics and aquaponics controls had lower ratio, which is in line with Blaha's report that these plants perform better than the ones dosed with the Vermicompost. This can be a probable reason why UA had a high moister content, followed by UH, TH60%, TH40% then TH30%.

4.3 Lettuce is grown from hydroponics and aquaponics system

Comparing the growth of lettuce plants from UH and UA did not show differences, but UA had a better plant survival, biomass. The lettuce plants from both UH and UA did not show a significant difference in the root-shoot ratio, leaf area and shoot length. Lettuce plants from UH were attacked by aphids and fungi, while the UA was only attacked by fungi.

 a)

 b)

Plate 9: Plants from a) the aquaponics system and b) hydroponics system

Plants grown from both hydroponics and aquaponics system were not significant, but during the experiment, the aquaponics system performed much better than hydroponics system. There are several reasons why aquaponics did better, some of which were due to continuous flow of nutrient water and the supplementary nutrients which is rich in magnesium, calcium, potassium and sodium that came from the fish (Pantanella *et al.*, 2012). The effluent water from the fish tank is also rich in ammonia and decay material. When this has been nitrified by bacteria it is converted to nitrate which can be used by plants for growth. This supplementary process is absent in hydroponics system which makes aquaponics system better. The continuous flow of water to the plant roots allows the plant to take up nutrients and oxygen through the plant system. The nutrient is used for growth and another metabolic process, while the oxygen allows gas exchange and transpiration (Lolium, 2016). This is one of the reasons why lettuce from aquaponics grew better, had higher biomass and was not curving in when growing.

In the past papers revealed that the use of vermicompost manure suppressed the damage from aphids, spider mites and jassids for plants in both the field and greenhouse (Joshi *et al*., 2014;

Ersahin, 2014). The worms used in vermicomposting release a compound containing chitinase enzyme which helps in controlling arthropod pests by breaking down the chitin of insects exoskeleton (Munroe, 2007; Edwards *et al*. 2010). The brewing of aerated vermicompost aqueous extract could pose and release soluble nutrients, free enzymes, humic and fulvic acids, plant growth hormones, plant regulators, soluble phenolic compounds, alcohols and a wide range of microorganisms (Edwards *et al*., 2006). These compounds are passed to plant tissues from aqueous extracts of vermicompost which may be the reason for the suppression of pests due to antagonisms between pathogens and other microorganisms competition for pathogen infection site or destruction of pathogen propagules such as spores (Arancon *et al*., 2005; Edwards *et al*., 2006; Edwards *et al.* 2010). Vermicompost that has some component of cattle manure inhibits fungi growth, foliar pathogens and pests (Ersahin, 2014). These could be the probable reasons why lettuce plants which were dosed with WHBVCT were infested with neither aphids nor fungus.

4.4 Quality of VCT and vegetables dosed with various dilutions of hyacinth based vermicompost tea

4.4.1 Nutrient quality and composition of VCT and lettuce plants

The following nutrients were analyzed N, P, NO^-_3, Na, and B, from both the vegetable samples and VCT to determine the nutrient quality of the vegetables as presented in table 5 below. VCT was rich with nitrogen, but the concentration was lower in the plants. Plants dosed with TH60% and TH40% did not have a difference in the level of nitrogen and TH30% had the lowest. Phosphorous concentration in the vegetables decreased with the increased dose of the VCT in the lettuce plants. The TH30% had the highest P concertation followed by TH40% and the TH60% recorded a lower P concertation.

Potassium concentration was high in the plants dosed with TH40% followed by the TH60% then the TH30% had a lower concentration of potassium. VCT had a high nitrate concentration in its solution compared to the available NO^-_3 in the plants. The concentration of nitrate in the plant tissue increased with an increased level of dose, TH30% had a lower nitrate concentration than the TH40% and TH60%. But there was no difference between plants dosed with TH40% and TH60%. Sodium was low in the VCT but was high in the plants dosed with TH30% while TH40% and TH60% sodium concentrations were low (TH40% was the lowest).

Table 5: Nutrient quality analysis for VCT and lettuce plants grown under various dilutions of water hyacinth-based vermicompost tea (TH30% while TH40% and TH60%).

Parameters	Method	Acceptable limit	VCT	TH30%	TH40%	TH60%
N	Wet dejection, Kjeldahl distillation		22000	7000	8300	8300
P	Colorimetric method	900-1200mg/day	337	130312.50	89362.50	43300
K	Flame Photometry	400-5500mg/day	235	27250	40000	37500
NO^{-}_3	Wet dejection, Kjeldahl distillation	2500	970	310	390	390
Na	Flame Photometry	920-2300mg/day	195	6500	4000	4625
B	Azomethine-H, hot water extraction	50-200	16.75	17	24.56	17.75

Note: The results are in mg/kg

Nutrient quality of vegetables can determine if the vegetable can be consumed and cause no harm to humans and the plant. Across the world, leafy vegetables are important sources of different nutrition for most of the human diet. But if the vegetables have excess or limiting amount of nutrients, they can affect human health, food production and also animal health. The amount of nutrient analyzed from this experiment in VCT and the lettuce dosed with the VCT were within the acceptable limits for human consumption table 5 (Anjana *et al.,* 2007). Nutrients for example nitrate can be limiting in plants due to low light availability and nitrate concertation in the nutrient solution, and nitrate accumulation occurs if there is an imbalance between absorption and assimilation of nitrate ions or ammonium, and surplus quantities are stored in the vacuoles (Cometti *et al.,* 2011).

The VCT and Lettuce dosed with WHBVCT had nitrate and sodium concentration which were within the acceptable limit for human consumption *table5*. Consumption of lettuce plants from the hydroponics system which has been dosed with WHBVCT at 30%, 40% and 60% can be considered safe for consumption. Because the excess amount of these nutrients can cause harm to the human population and can also affect plant growth and development. Nitrate content is strictly regulated because its toxicity can cause methemoglobinemia (Blue baby) in infants, and there is also a risk of specific cancers and birth defects (Ward *et al*., 2018). The actual toxin is not the nitrate ion itself but rather the nitrate ion, which is formed when nitrate is reduced by intestinal bacteria (Uwah and Abah, 2009). High accumulation of Sodium can cause hypertension in humans, and the same thing happens in plants. Excess Na causes plants to divert the water in their system (osmotic) which can result in plant wilting, stunted growth and arrest cell development (Doyle and Glass, 2010).

Potassium is a nervous system regulator in the human system which helps to balance fluid flow, muscle contraction and nerve signal (He and McGregor, 2008). In plants, it plays a role of regulating plant growth, leaf quality, shelf life and prevent the plant from being susceptible to diseases, and an increasing the dose of K and reducing the Na concentration as the nutrient sources increased growth and yield of lettuce (Ucar *et al.*, 2007).

Phosphorous analyzed from VCT and lettuce plants were within the required amount for human consumption. Limiting or excess amount of phosphorous can cause health damage to humans such as kidney damage (Tucker *et al.*, 2014). P is an essential nutrient to plants, because of the role it plays in both plants structure development and plants biochemical reactions. But P deficiency in plants is difficult to identify but plants can show a discolouration which was one of the signs observed in the treatments dosed with the VCT.

Boron was also another nutrient which was observed and was within the permissible limits. Boron is an element which is need by plants in small amounts, but it is among the most abundant elements on the earth's crust. It promotes high plant growth and yield in higher-plants, provides beneficial ions but the benefits are seen depending on the concentration of ions such as NO^{-}_{3}, NH_4^+ or K^+ (Kronzucker *et al*., 2013). The ability of vegetables to absorb the elements in green leaves is related to plant type, plant variety, environmental conditions, and metal ionization, mobility, and transfer from roots to leaves (Ghasemidehkordi *et al*., 2017). Simsek *et al*. (2003) reported that levels of B in vegetables are related to concentrations of borate and borate compounds in soil that are taken up by plants from soil and water-insoluble forms (Simsek *et al*., 2003; Aweng *et al*., 2011). In human health, boron might be involved: osteoarthritis, bone health, and cancer.

4.4.2 Metal concentration in CVT and lettuce

The following metals were analyzed in both VCT and the vegetables during the experiment: cadmium, chromium, lead, zinc, copper, iron, nickel, and manganese (table 6). Cadmium was recorded only from plants that were dosed with TH30% of the VCT, it was neither recorded from the VCT nor the plants dosed with different concentrations. Both VCT and plants did not detect the presence of chromium in their systems. VCT and lettuce plants dosed with TH60% did not detect the presence of lead, but it was detected in the TH30% and TH40% whereby the TH40% recorded a higher volume of lead. Zinc was low in the VCT solution, but the concentration was high in the treatments. The concentration decreased with the increase in the volume of the VCT dilutions. The highest was recorded from TH30% and the lowest concentration was from TH60%.

Iron was detected from both the VCT and vegetables, with the highest volume recorded from the TH40%, followed by the TH60% and then the TH30%; but VCT had a lower iron concentration as compared to the treatments. There was no difference in the level of copper in vegetables dosed with TH30% and Th40% of the VCT, but the TH60% and VCT were different and TH60% was higher than the Cu concentration from the VCT. Nickel was not detected from TH40%, while TH60% and VCT were not that different from each other; nickel was recorded the highest from the vegetables dosed with TH30%. Manganese was low in the VCT, but the concentration increased in the treatments. TH40% recorded a high Mn concentration as compared to TH30% and TH60%, but TH60% had a lower Mn concentration than in TH30%.

Table 6: Metal analysis for VCT and lettuce plants grown under various dilutions of water hyacinth-based vermicompost tea (TH30% while TH40% and TH60%).

Parameters	Method	Acceptable limit (WHO/FAO)	VCT	TH30%	TH40%	TH60%
Cadmium	AOAC Official Method 985.35-AAS Method	0.2	N.D	0.05	N.D	N.D
Chromium	AOAC Official Method 985.35-AAS Method	2.3	N.D	N.D	N.D	N.D
Lead	AOAC Official Method 985.35-AAS Method	0.3	N.D	1.10	5.30	N.D
Zinc	AOAC Official Method 985.35-AAS Method	99.4	3.60	41.50	39.70	36.80
Iron	AOAC Official Method 985.35-AAS Method	425.5	1.7	533.25	982.60	565.98
Copper	AOAC Official Method 985.35-AAS Method	73.3	3.90	51.20	51.60	47.25
Nickel	AOAC Official Method 985.35-AAS Method	67.9	3.40	6.55	N.D	3.10
Manganese	AOAC Official Method 985.35-AAS Method	500	4.30	50.75	69.80	41.25

Note: N.D means not detected, the results are in mg/kg and the parameters are categorized Cadmium, Chromium, Lead, Zinc, Iron, Copper, Nickel and Manganese

The selected metals analyzed from VCT and lettuce were within the acceptable limit, except for iron and lead which were above the acceptable standard for human consumption. Metals are a naturally occurring element in the earth's crust with a relatively high density compared to water.

Naturally occurring elements that are found throughout the earth's crust, can be released through weathering, soil erosion, volcanic eruptions and other. Despite being naturally occurring there has been an increasing ecological and global public health concern associated with environmental contamination and human exposure to these metals due to anthropogenic activities (Ghasemidehkordi *et al*., 2017). The anthropogenic human activities such as mining and smelting operations, industrial production and use, and domestic and agricultural use of metals (Deverel and Delta, 2017).

In this experiment, the vegetables and VCT were analyzed during this experiment to determine the quality and safety of the vermicompost and vegetables for human use and consumption. The results had some of the metals detected and other metals were not detected. Some of the metals which were analyzed include; cadmium, chromium, lead, zinc, copper, manganese, iron and nickel (table 5). Cr was not detected in any of the samples but the rest of the metals were detected. Cd, Zn, Cu, Ni and Mn were within the acceptable levels of the FAO/WHO, while Pd and Fe were above the permissible limits (Mensah *et al.*, 2009; WHO/FAO, 2011).

This can be as a result of the pH and other dissolved constituents of the system which controls the solubility, mobility, and bioavailability of the elements, which affects their translocation in plants (Cataldo *et al.*, 1978; Burt *et al*., 2011). When pH is greater than 6.5 to 8, the elements are available in the system and in a form, which can be taken up by the plants. During the experiment the water pH was with the ranges above, agreeing that the lead and zinc would be available for plants uptake Cataldo *et al*., (1978), the availability of the element to the plant is associated with the solubility of the element to be taken up by plants in high volumes. The rate at which the elements are released and the form of soluble species would affect the rate and extent of uptake, perhaps the mobility can have a strong influence on the rate and extent of uptake. This could be a reason why the elements like lead and zinc were available or abundant in some of the treatments and not in others. The high concentration of trace elements can pose a threat to agricultural production, animal and human health, by accumulating in their system make it not safe for consumption (Laing *et al*., 2008).

Feleafel and Mirdad, (2012), lead is generally high in leaf vegetables; this is in line with the results in the experiment. High lead concentration is toxic to humans and can cause damage to the nervous system and can decrease the development of roots, stems and leaves in plants. This is due to the decreased number of cells which cause a reduction in chlorophyll synthesis, induced water stress to plants, decrease nitrate uptake and another nutrient uptake. Lead can be minimized from the production systems, accumulation in human bodies or the plant systems by phytoremediation, following good agricultural production practices, increasing the absorptive capacity of the water or soils by use of organic matter or humic acid, growing vegetables and cultivars with low accumulative potential and washing leafy vegetables with 1% vinegar or by peeling roots, tubers, fruit vegetables before consumption (Feleafel and Mirdad, 2012).

Chapter Five: Conclusion and recommendation

Hydroponics and aquaponics system are considered conservative agricultural production units, which do not require a lot of inputs and are environmentally friendly. These systems do not use soil, but rather recirculating water which is dosed with nutrients from either organic or synthetic solutions to mimic the natural environment and to supplement on limiting nutrients for systems like aquaponics. Synthetic nutrient solutions are commonly used in as compared to organic fertilizers but they are expensive and can contain the excess nutrient, that is why organic fertilizers are being developed to determine which one can produce high yield, be human friendly and replace synthetic fertilizers.

WHBVCT extract is a nutrient-rich solution which can be applied to plants in a hydroponics system and help inhibit aphid and fungus attack. The nutrient does not negatively affect the water quality of the system, be it pH, ammonia, nitrate, phosphate and total phosphorous. Effluent water from systems that use WHBVCT can be released into the environment and still cause no impact to the water bodies. Lettuce plants dosed with WHBVCT did not perform well as compared to the plants dosed with organic fertilizers. It had the least leaf area, shoot length, moisture content, biomass and a high root-shoot ratio. About these results WHBVCT, cannot be hand irrigated to lettuce as a nutrient source. Despite the low performance in the lettuce, both the WHBVCT and the vegetables selected nutrient quality was within the acceptable limits including nitrate. The selected metals were also within the acceptable ranges except for the plants dosed with 30% and 40% that were above the acceptable limit for lead, and all the treatments reported a high iron concentration.

- An application level of not less than 60% when using WHBVCT as a nutrient solution in non-circulating hydroponics is recommended because the higher the concentration the lower the risk on metal accumulation.
- Further, studies have to be done whereby WHBVCT can be used for pest and disease control through foliar application for both leaf and fruiting vegetables.
- WBH vermicompost extract should be tried on fruiting vegetables as a nutrient solution because leafy vegetables turn to conserve nutrients and there could be a possibility that the fruiting plants can do better than it was with the case of lettuce. Levels of WHBVCT can be employed to see which one gives out the best yield.

- It is recommended that the WHBVCT has to be tried in a circulating hydroponic and aquaponic systems to identify a recommendable level of application in lettuce production.
- A study has to be conducted to observe the impact of using WHBVCT in combination with other synthetic fertilizers at different levels to reduce the level of inorganic use in hydroponics, and to see which one is economic, productive in terms of yield and can suppress pests and diseases.

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Appendix

Appendix 1: Lettuce nursery bed and seedlings

 

Appendix 2: Vegetables showing some nutrient deficiency from Treated hydroponics system



Appendix 3:Lettuce harvesting, weighing and drying