EFFICACY OF FORTIFIED MOLASSES WASTE-WATER AS HYDROPONIC NUTRIENT SOLUTION FOR GROWING OF SPINACH AND BARLEY

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MAY 2021

DECLARATION

I confirm that this thesis is my original work and has not been presented for degree or any other award in any other university.

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DEDICATION

This thesis is dedicated to my creator the Almighty God for the giving me good health during the study period, my late mother Leah Talam for her inspiration and prayers, my aunt Sarah and her family, my husband David Rono for financing my education and children Collins, Cheryl, Cielo, Carlen and Carlin for their encouragement.

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
FMF	Fortified Molasses Fodder
FMV	Fortified Molasses Vegetables
FMW	Fortified Molassses Waste-water
HF	Hydropononic Fodder
HFN	Commercial Hydropononic Fodder Nutrient
HV	Hydropononic Vegetables
HVN	Commercial Hydroponic Vegetable Nutrient
LOD	Limit of Detection
MF	Molasses Fodder
MV	Molasses Vegetables
MWW	Molasses Waste-water
SNK	Student Newman’s Keuls

ABSTRACT

Muhoroni Sugar Processing Industry is a significant sugar factory in western part of Kenya. It produces huge volumes of molasses waste-water which poses challenges of pollution of water bodies and affects plant life and other organisms. Molasses waste-water is known to have substantial amounts of nutrients and has been suggested as an alternative to commercial hydroponic fertilizers. However, its efficacy as a nutrient solution has not been evaluated scientifically. This study therefore aimed at investigating its efficacy as a hydroponic solution for growing vegetables and fodder crops in a greenhouse. Greenhouse experiments were carried at the Christian Industrial Training Centre – Kapsabet in Nandi County (0.2030° N, 35.0978°). Macro-nutrients present in molasses waste-water were determined and the deficiencies remedied by fortifying with appropriate amounts of nitrogen, phosphorous and potassium (NPK) fertilizer. The standard Walkey black rapid titration was used to determine total organic carbon. Potassium and calcium were determined using flame photometry. Nitrogen and phosphorous were determined by colorimetric analysis. Magnesium was analysed using atomic absorption spectroscopy. Uv/vis spectrophotometry was used to determine the presence of sulphur.The study established that molasses waste-water has greater levels of potassium, calcium, sulphur, magnesium and carbon of 230.0 ± 1.00 mg/L, 25.9 ± 0.39 mg/L, 4.4±0.07 mg/L, 0.04 ± 0.01 mg/L and 37.3 ± 0.67%, respectively compared to commercial hydroponic nutrient solutions. Low nitrogen and phosphorus content in molasses waste-water was improved to 74.3 ± 0.18 and 47.6 ± 0.01 mg/ L, respectively. The greenhouse experiments were set up in triplicate using a Complete Randomized Block Design (CRBD). The hydroponic nutrient solutions used included molasses waste-water (MW) and fortified molasses waste-water (FMW) with commercial hydroponic nutrient solution (HN) as the control experiment. Barley was grown by improvised nutrient film (NFT) technique whereas spinach was grown in static solution culture using sand growing media. Plant growth parameters which include plant height, stem girth and leaf length were measured every after 2 days in barley and every after 7 days in spinach. The levels of macro-nutrients in plant tissues were determined in the harvested crops. The plants grown in fortified molasses waste-water showed the highest growth parameters; mean plant height of 13.0± 0.38cm, mean stem girth of 9.23 ± 0.43 mm and mean leaf length of 5.6±0.17cm in barley, mean plant height of 20.97 ± 0.18 cm, mean stem girth of 16.2±0.12 cm and mean leaf length of 13.0±0.38 cm in spinach. Mean fresh weight of 0.6±0.06 kg for spinach and 12.0 ± 0.57 kg for barley grown in fortified was obtained. Crops grown in fortified molasses waste-water also recorded the highest values of macro-nutrients at 210.6± 0.07 and 205.9 ± 0.14 mg/kg nitrogen, 94.9 ± 0.01 and 90.7± 5.79 mg/kg phosphorus, 3.3 ± 0.05 and 6.4 ± 0.01mg/kg magnesium, 632.7± 7.54 and 616.5± 2.30 mg/kg potassium, 48.8±0.71 and 38.0±0.34 mg/kg calcium and 15.8±0.04 and 15.8±0.05 mg/kg sulphur in spinach and barley, respectively. Organic carbon content was also highest in spinach and barley grown in fortified molasses waste-water at 84.0 ± 1.15 and 82.7 ± 0.67% respectively. The results show that molasses waste-water contains adequate amounts of potassium, calcium, sulphur and magnesium macro-nutrients essential for plant growth but lacks sufficient nitrogen and phosphorus. Appropriate amendments in the amounts nitrogen and phosphorus macro-nutrients make it efficacious for application as a hydroponic solution for growing crops and, therefore, a possible alternative to commercial hydroponic nutrient solution.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Farming system that use soil may not provide enough food to the world's rising population due to increased pollution levels and alternations in climatic conditions (Al-Karaki and Al-Hashimi, 2010). In this regard, soilless system of cultivating food crops should be taken into account. Hydroponics is a farming method in which plants are cultivated in plant mineral nutrient solutions (Resh, 2013). Mineral nutrients refer to chemical elements needed by living organisms. Since the commencement of hydroponics, their systems have relied on commercial hydroponic nutrients solutions which are composed of inorganic salts that provide essential elements necessary for healthy crop production. The elements are classified into two groups: macronutrients (C, N, P, K, Ca, S, and Mg) and micronutrients (Zn, Fe, Mn, B, Cu, and Mo). Macro-nutrients must be present in higher concentrations, typically ranging from 10 to 400 milligrams per liter (mg/L), depending on the nutrient (Resh, 2013) as shown in table 1.1.

Table 1.1: Macro-nutrients Required for Healthy Plant Growth, Their Function and Source (Adapted from Resh, 2002)

Micro-Element	**Range (mg/L)**	**Plant Function**	**Inorganic Salts Used in Nutrients**	**Available Form of Macro-nutrient**
Nitrogen	70-250	Forms portion of amino acids, proteins, co-enzymes, nucleic acid and chlorophyll	KNO_3 $Ca(NO_3)_2$ $Mg(NO_3)_2NH_4NO_3$ $(NH_4)_2SO_4$ $(NH_4)_2HPO_4$ $NH_4H_2PO_4$	NO_3^-, NH_4^+
Potassium	150-400	Needed for protein synthesis and acts as a co-enzyme.	K_2SO_4 KNO_3 KH_2PO_4 KH_2PO_3 KCl	K^+
Phosphorous	15-80	Essential in hydrolysis of starch to simple sugars. Vital in fruit development.	KH_2PO_4 KH_2PO_3 $(NH_4)_2HPO_4$ $NH_4H_2PO_4$ H_3PO_4	$H_2PO_4^-$ HPO_4^{2-}
Magnesium	15-80	Required in the formation of chlorophyll and as carrier of P	$MgNO_3$ $MgSO_4.7H_2O$	Mg^{2+}
Calcium	70-200	Sustains cell integrity, aids reduce the toxic effect of other salts by precipitating as calcium oxalate in vacuoles	$Ca(NO_{3)2}$ $CaCl_2.6H_2O$	Ca^{2+}
Sulphur	20-200	Structural unit in manufacture of protein and amino acids	$MgSO_4.7H_2OK_2SO_4(NH4)_2SO_4$	SO_4^{2-}

Use of large quantities of expensive chemical plant nutrients may affect the health of users owing to the buildup of toxic substances in crops. Ammonium ions and nitrates

are important macronutrients for plant growth and development; however, long-term use may result in nitrate accumulation in plant leaves (Gent, 2003). When nitrate levels in plants reach high levels, it endangers living organisms (Ishiwata *et al*., 2000). Therefore, using organic hydroponic nutrient solution such as molasses waste-water as an alternative to commercial hydroponic nutrient solutions is a good solution for soilless farming. Molasses waste-water from sugar processing and distillation industries contains high levels of macro-nutrients comprising of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), sulphur (S), micronutrients and organic matter (Srivastava, 2012). It also contains high amount of suspended and dissolved solids (Baskaran *et al*., 2009). These macronutrients are valuable to plant growth and development and could partially substitute chemical fertilizers needed for crop cultivation, lowering production costs and increasing resource recycling. In most cases organic nutrients do not dissolve in water, they are availed slowly for plant use as they are transformed to soluble forms by microbes. The nutrients contain organic compounds regarded phytotoxic and inhibitive to plant growth (Lee *et al*., 2009). Usage of organic fertilizers only, in crop growing has been stated to be insufficient due to unavailability of the required quantities of nutrient contents. Intergrated nutrient management methods, which employ both organic and inorganic fertilizers, have been developed (Palm *et al*., 1997). Macro-nutrients supply from organic fertilizers may be supplemented to enrich nutrient levels by fortifying them with inorganic nutrients such as NPK fertilizer which are released at a faster rate and used by plants to compensate for their delayed nutrient release (Satyanarayana *et al*., 2002).

Previously, most of the studies were based on the direct irrigation of molasses waste-water in sugarcane farms, whereas few studies have researched on how molasses waste-water influences the growth of crops. Insufficient information exists about prospective use of fortified molasses waste-water as hydroponic nutrient solution. Thus, this study assessed the usability of molasses waste-water from Muhoroni sugar factory as a hydroponic nutrient solution and evaluated its efficacy in the promoting plant growth, plant yield and macro-nutrient levels in hydroponically grown spinach and barley. Hydroponically grown barley fodder will take a period of 7–8 days to mature and needs a small piece of land for crop growing (Al-Karaki, 2011). It produces high quality animal feeds with high protein content, vitamins, fiber and minerals (Ansar *et al*., 2010). Hydroponic spinach allows for several short-time production series and abundant monetary return (Brandenberger *et al*., 2007). Furthermore, spinach contains a high concentration of macronutrients (Ko *et al*., 2014).

1.2 Statement of the Problem and Justification

Muhoroni Sugar Company is among the Kenya's major sugar processing companies; it generates approximately 1000 m^3 of waste water daily. The company has to incur cost on waste-water treatment plants to minimize pollution of the nearby River Nyando. Studies on use of unlined lagoons as sugar mills waste-water treatment management practice was found to contaminate underground drinking water supplies, thus sugar processing industries should work towards pollution prevention by utilizing waste-water in agricultural practices. Research on impacts of sugar mill effluents on development

and organic properties of native and marine plants showed that growth promoting constituents such as sulphates and chlorides are not only involved in mineral and salt formation but also stimulate plant growth. Nevertheless, there is scanty information on studies to investigate macro-nutrient levels in molasses waste-water and its usability as hydroponic nutrient solution. The purpose of this study was to see how effective molasses waste water was as a hydroponic nutrient solution in a greenhouse. Macro-nutrients levels in molasses waste-water was determined and compared with commercial hydroponic nutrient solutions available in the market with the objective of remedying the nutrient deficiency in the waste-water by fortifying with nitrogen, phosphorous and potassium (NPK) fertilizer in order to attain recommended plant macro-nutrient levels. Growth parameters (i.e. plant height, stem girth and leaf length) and plant yield in spinach and barley grown using molasses waste-water, fortified molasses waste-water and commercial hydroponic nutrient solution was determined in order to establish the efficacy of molasses waste-water and fortified molasses waste-water in promoting plant growth. Levels of macro-nutrients in spinach and barley plants grown using molasses waste-water, fortified molasses waste-water were determined so as to establish nutritional value and quality of plants compared to those grown in commercial hydroponic nutrient solution.

1.3 Null Hypothesis

Fortified molasses waste-water is not efficacious as a hydroponic nutrient solution in promoting growth, macro- nutrient levels and yield of spinach and barley.

1.4 General Objectives

To determine the efficacy of molasses waste-water as a hydroponic nutrient solution

1.4.1 Specific Objectives

i. To determine the levels of nitrogen, potassium, magnesium, sulphur, phosphorous, carbon and calcium macro-nutrients available in molasses waste-water and compare with the commercial hydroponic nutrient solution.

ii. To determine growth parameters (i.e. plant height, stem girth and leaf length) in spinach and barley grown using molasses waste-water, fortified molasses waste-water and commercial hydroponic nutrient solution.

iii. To determine yield parameters (i.e. plant fresh weight) in spinach and barley plants grown using molasses waste-water, fortified molasses waste-water and commercial hydroponic nutrient solution.

iv. To determine levels of nitrogen, potassium, magnesium, sulphur, phosphorous, carbon and calcium macro-nutrients in spinach and barley plants grown using molasses waste-water, fortified molasses waste-water and commercial hydroponic nutrient solution.

1.5 Scope and Limitations

This research study only examined levels of seven essential plant macro-nutrients namely nitrogen, potassium, magnesium, sulphur, phosphorous, carbon and calcium. The only plant growth parameters investigated were plant height, stem girth and leaf

length. The only yield parameter determined for the crops grown was plant fresh weight after harvesting.

1.6 Significance of the Study

If molasses waste-water is taken up for hydroponic farming after a larger greenhouse piloting, it is likely to deal with the water pollution challenge, minimize the water treatment cost incurred by sugar factories, and provide an alternative hydroponic nutrient solution for crop hydroponic crop production.

CHAPTER TWO

LITERATURE REVIEW

2.1 Hydroponics Development and Progress

Researchers in 18th century found out that plants absorb vital mineral nutrients such as inorganic ions in solution form. Soil acts as a mineral nutrient reservoir (Brady and Weil, 1999). There are numerous 'recipes' for hydroponic solutions. Diverse quantities of chemicals have been used to attain similar total final compositions. Frequently used chemicals for macro-nutrients preparation include: potassium phosphate, potassium nitrate and magnesium sulphate. Numerous micro-nutrients are added to hydroponic nutrient solutions to provide necessary nutrients which include: Fe (iron), Mn (manganese), Zn (zinc), B (boron), Cl (chlorine), Cu (copper), and Ni (nickel). Nearly all plants will grow in hydroponics (Adani, Patrizia and Grazian, 1998).

According to Dunn (1991) the initial published literature on growing plants in nutrient solutions without soil was in 1627 by Bacon. Following that, water culture became a common research system. John Woodward experiments dealing with water culture spearmint were published in 1699. He discovered that crops grown in waste- water grew healthier than those grown in purified water. A list of nine elements important for plant growth was compiled in 1842, and the findings led to the expansion of hydroponic farming. In 1938, Hoagland and Arnon established that hydroponic crop yields were equivalent to crop yields grown in fertile soils. The two researchers came up with Hoagland solution made from numerous formulas of mineral nutrient solutions.

Hydroponic farming methods have been extensively established, and are useful for plant production internationally (Hewitt, 1996). Managing of the recycled nutrient solutions is considered as an effective approach to regulate the quality and yield of the crops; subsequently plant nutrients are the key factors affecting plant growth and development. Nutrient solutions are basically composed of macro-nutrients and micro-nutrients. Plant macronutrients include: nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium. Micronutrients include: iron, manganese, zinc, boron, molybdenum, copper, and nickel (Hewitt, 1996).

There are several benefits of hydroponic farming techniques which include faster plant growth, which enables numerous crop harvests per season, greater yields, and reduce threat of plant unproductivity because of hostile climatic conditions, disease or pests attack. Besides, crops are grown in closer proximity to one another compared to those grown in soil, frequently through perpendicular training or in columns, resulting in bigger space efficiency and greater yields. It has been determined that hydroponic farming improved output production by fourfold for cucumber, tenfold for tomatoes, and threefold for lettuce. Regulated settings result in a more consistent crop harvest quality and the earlier discovery and improvement of nutritive insufficiencies than conventional soil-based cultivation (Seaman and Bricklebank, 2011). These gains can be attributed to crop nutrition optimization as well as improvements in water and nutrient effectiveness. Soilless technique provides productivity in regions where soil

conditions are unfavorable for crop production because of poor soil texture, erosion, or high salinity (Gorbe and Calatayud, 2010).

Onanuga (2013) points out the use of hydroponic technique for many years to assess growing and developing of root vegetables and yields. In Asia, there has recently been an augmented attention in hydroponics to assess the growing and developing of plants such as wheat and rice. The hydroponic medium was found to increase growth and yield of rice plants (Nemati, *et al*., 2011). Hydroponic techniques also make it easier to track nutrient absorption, root structure, physical growth, and crop harvest (Lynch *et al*, 1995).

2.2 Hydroponic Techniques

The term hydroponic includes several methods which can be divided into two broad categories: media hydroponics and non-media hydroponics. A media-based technique involves planting plants in mineral nutrient solution in a synthetic medium that provides mechanical support to the plants (Jensen, 1999). Mineral nutrient solutions are distributed over drip-feeding or ebb-and-flow, whereby crops are immersed in nutrient solution at predetermined points, drawing oxygen in air to the root zone (Seaman and Bricklebank, 2011). The nutrients can be recycled (closed system) or discarded by draining it back into a header tank (Bugbee, 2004). In an open technique, the nutrient solution is not recirculated after going through the crop roots (Jensen, 1999). Nutrient film technique (NFT), in which crops are grown in an 'open root system' in recycled

nutrient solutions, is an example of non-media growing system. Deep-water culture entails submerging plant roots in an aerated nutrient solution in order to retain adequate levels of dissolved oxygen and avoid unproductivity (Resh, 2013). Bags are arranged on the greenhouse ground at standard row space. Drip irrigation is used to deliver mineral nutrient solution. Rockwool hydroponics is an open technique that involves growing seedlings in small rock wool cubes that are flooded with nutrient solution. Rock wool is made from crushed heated rocks that are whirled into threads to create wool. It is lightweight and is frequently available for sale in cubes. Rock wool may store water and maintain adequate air space, allowing for optimal root development (Resh, 2013).

2.3 Nutrients Required for Plant Growth and Productivity

Plant nourishment must be stable in order for crops to be productive (Bryson and Barker, 2002). The components of the growing medium influence the amount of fertilizer that should be applied to ensure optimal plant growth (Tattini and Traversal, 1992). During crop management practice development, it is critical to provide a balanced fertilizer application specific to the growth medium, as well as to ensure that nutrients are accessible for crop uptake. Nitrogen is a necessary component of amino acids, which control all bodily functions. The availability of adequate nitrogen supply in plants promotes leaf development and an intense green colour (Brady and Weil, 1999). Nitrogen deficiency in plants causes pale yellowish-green colouration (chlorosis), stunted growth, and tinny, thin stems. Carbon is the building block of many living biological structures, as well as starch and fiber. Carbon is fixed from carbon dioxide in

the air during photosynthesis and forms carbohydrates that are useful for storing energy in plants (Epstein and Bloom, 2005).

Phosphorous improves many aspects of plant function, including the major processes of photosynthesis, nitrogen fixation, flowering, and fruit ripening. Dark plant foliage indicates phosphorus deficiency (Brady and Weil, 1999). Potassium is essential for plant root growth and disease resistance (Brady and Weil, 1999). It decreases the rate of transpiration and allows plants to absorb water from the soil. Potassium deficiency causes leaf yellowing (chlorosis) and death (necrosis) (Brady and Weil, 1999). Sulphur is important in synthesizing of chloroplasts and is present in molecules of some amino acids and vitamins. It is found in Iron-Sulphur compounds, which are useful in electron transfer chains during photosynthesis. Sulphur deficiency first affects younger tissues. It causes stunted growth and leaf yellowing (Epstein and Bloom, 2005).

Calcium controls the carriage of plant nutrients and stimulates the production of plant enzymes. The nutrient is involved in the photosynthesis process. It is a component of the cell wall and is required in plant root development. It is involved in cell division, cell elongation, hydrogen ion detoxification, and organic acid neutralization, inhibiting other ions, and absorbing nitrogen (Dunn, 1991). The chlorophyll molecule is made up of magnesium. It stimulates enzymes in a variety of biochemical reactions. It is linked to a phosphorus compound, which gives energy to the cell. Magnesium insufficiency is

noted earlier older plant parts (Dunn, 1991). Table 2.1 shows the macronutrient levels that are recommended for plants.

Table 2.1: Recommended plant macro- nutrient levels (Voogt, 2016).

Element	**Range (mg/l)**
Nitrogen	70-250
Potassium	150-400
Phosphorus	15-80
Magnesium	15-80
Calcium	70-200
Sulphur	20-200
Carbon	-

2.4 Commercial Hydroponic Nutrient Solution

This term refers to nutrient solutions that are primarily composed of inorganic ions derived from soluble salts of vital components required by higher plants (Steiner, 1984). Essential elements serve distinct biological functions, and their absence has an impact on the entire plant growth (Taiz and Zeiger, 1998). Six essential nutrients are commonly found in nutrient solutions: N, P, S, K, Ca, and Mg. Steiner developed the concept of ionic mutual ratio, which is based on the mutual ratios of anions such as NO_3^-, $H_2PO_4^-$, and SO_4^{2-}, as well as cations such as K^+, Ca^{2+}, and Mg^{2+} (Steiner, 1984).

2.5 Hydroponic Growing of Fodder and Vegetables

Domesticated livestock require fodder as part of their diet (Al-Karaki and Al-Hashmi, 2010). Semi-automatic fodder growing techniques enable the quick growing of fodder sprouts in a greenhouse (Seaman and Bricklebank, 2011). Several manufacturers, including FodderTech, CropKing, H_2O Farm, and Hydro Fodder Farm, have set up hydroponic fodder nutrient solutions for fast fodder production. Hydroponic methods work by misting seed trays planted in a controlled environment with a fine mist of water. A temperature of 17-24°C is kept and humidity of 59.6 - 70.1 percent. A mat of sprouting grains forms during seed germination and is harvested 6-8 days after sowing. In the late 1930s, research studies on the use of sprouts as source of animal feeds were established (Al-Karaki and Al-Hashmi, 2010). Current systems have been restructured, to regulate irrigation rates and volumes, using thermostatically regulated environments hence allowing optimum growing conditions to be created (Marsico and Hellmann, 2009).

Spinach is a cool-season vegetable that originated in Central Asia and belongs to *Amaranthaceae* species (Morelock and Correll, 2008). It is classified as a useful foodstuff owing to its nutritive content comprising of vitamins, minerals, and phytochemicals that promote health life (Robert and Moreau, 2018). Spinach has been shown to be a basis of plant protein (10.90%), ash (7.16%), fiber (22.08%), moisture (352%), carbohydrate (21.28%), and fat (3.67%) (Kavithal and Ramdas, 2013). Spinach is also high in phytonutrients and chlorophyll (Toledo *et al*., 2003). Spinach leaves

contain natural antioxidants that are water-soluble offer protection against diseases attack (Ko et al., 2014). Spinach is a common salad ingredient that is high in iron and a good source of folic acid (Roy and Chakrabarti, 2003). It is inexpensive and can be grown successfully in partial shade if there is adequate moistness in the roots (Klein, 2007). It is grown hydroponically in greenhouse production because it allows for several production cycles and a much quicker earnings (Rosik and Grabda, 2002) (Brandenberger et al., 2007). Recommended macro nutrients levels in plant tissue are shown in Table 2.2.

Table 2.2: Recommended dose of different macro-nutrients

Macro-nutrients	**mg kg^{-1}**
N	**420.5 – 520.5**
P	15 – 25
K	200 – 300
Ca	175 – 275
Mg	30 – 40
S	20– 40

2.6 Waste-water Hydroponics

Waste-water hydroponics, in which waste-water is used as sources of hydroponic nutrient , is advancing as a bio-integrated method of producing food because it aids in

achieving sustainability goals (Diver, 2011). Ohtani *et al*. (2000) discovered significance of recycling waste-water from hydroponics so as to avoid toxic waste in the surroundings. A study done in Singapore in which crops were developed in a hydroponic system by means of fish pond to find out if the plants could use excess nutrients produced by the fish pond was a success because both the fish and the plants gained weight (Rahman, 1996). Research discovery shows that usage of waste water as hydroponic nutrients in a giant reed Rockwool hydroponic culture provides the plants with sufficient nutritive elements for improved plant development and productivity (Mavrogianopoulos *et al.*, 2002). It was also demonstrated that crops planted using hydroponic technique obtain majority of soluble nutrients from primary stagnant community waste-water (Boyden and Rababah, 1996). Using the hydroponics technique, municipal waste water was effectively recycled for lettuce cultivation (Rababah and Ashbolt, 2000). They recognized the importance of addition of nutrients such as potassium to increase crop yield. This research study uses molasses waste-water as hydroponic nutrient solution.

2.7 Molasses Waste-water from Sugar Factory

Sugarcane is the primary raw material in the cane and ethanol processing (Selladurai *et al*., 2010). Sugarcane processing yields sugar as the primary product and molasses as a byproduct (World Bank, 2007). Other products include bagasse, which is useful energy source in boilers for steam production in the generation of electricity. Distillery that produces 100m^3 of ethanol per day discharges 1,300 m^3 of vinasse. (Navarro, Sepulveda

and Rubio, 2000). Filter cake/mud produced as waste is used as a fertilizer in sugarcane plantations, whereas molasses is used to make ethanol in the distillery. Many events take place during the sugar refining process before refined sugar is collected. When sugarcane enters the plant, it is weighed, cleaned, and routed through a series of food processors. Sugarcane processing mills produce bagasse waste by extracting fluid from sugarcane. To purify the juice, phosphoric acid, lime, and organic flocculants are used, and the juice is then evaporated to make syrup (Hugot, 1986). The sweet liquid is decolourized with sulphur IV oxide and is separated by a vacuum crystallization process to separate sugar crystals and molasses (Hugot, 1986). The last stage involves production of ethanol using molasses in the distillery. Molasses comprises of: monosaccharide (glucose, 4.39% and fructose, 6.67%), disaccharide (sucrose, 30.8%), and Lactose, 8.14% (Dionex, 2003). Disaccharide is transformed into monosaccharaides and then changed to alkanol. Molasses are taken to a fermentation column in which dilution, supplementation and inoculation with yeast is carried out. The processes of fermenting usually take around 24 to 30 hours for sugars to be converted using yeast to 7.5 – 9.5 % alcohol. Fermented wash refers to the mixture of fermentation broth and alcohol. After completing fermentation process, fermented wash is distilled so as to obtained aqueous alcohol as distillate (Suksri *et al*., 2007).

Main waste-water sources are those from the sugar mills and the discharge from distillation of the cane molasses (Wei and Xu, 2004). Sugar mill waste water includes cane yard, mill building, and boiling house washings (Vawda, 2009). Molasses waste

water contains a high concentration of organic waste (Ryznar-Luty et al., 2008). Nitrogen and phosphorus fertilizers are applied in the field to improve sugar cultivation (Ovidio and Melgar, 1998). Sugarcane is harvested with earth material that contains nutritive elements. During the sugar refining process, these nutrients make their way into the waste-water. Molasses waste-water has a brown hue, a burnt-sugar flavor, a high temperature, a low pH, chlorides, sulfates, nitrates, calcium, magnesium, and other contaminants (Memon et al., 2006). Nutrients present in high concentrations typically result in increased ecological yield and a tendency for Lake Eutrophication (Daniel *et al*., 1998). As a result, it is important to re-use molasses waste water in hydroponic farming.

2.8 Organic and Inorganic Nutrient Solutions

Many experiments have compared the effects of inorganic and organic nutrients on growing of plants and found varied results. Despite the fact that many studies show that inorganic fertilizers provide better outcomes, especially in improving crop production (Mader *et al*., 2002), market demand on organically grown food has exploded. As opposed to food grown conventionally using inorganic fertilizers, consumers also consider organic food to be safe (Ekelund and Tjarnemo, 2004). Organic nourishments do not provide well-adjusted amounts of various nutrients at the right moments (Kirchmann *et al*., 2002) since they release nutrients slowly. Organic plants grow at a slower rate compared to plants raised with mineral fertilizers (Guichard *et al*., 2001).

According Heeb *et al*. (2006), the sufficient quantity of nutrients is an important feature in tomato development, yield, and flavor.

Research studies on development of sweet basil in nutrient poultry manure as an organic fertilizer supply indicated that sweet basil plants administered with inorganic fertilizers mature earlier than plants planted in organic nutrients alternatives (De La Pena *et al*., 2002). Worthington (2001) found that organic crops had slightly higher amounts of iron, magnesium, phosphorus, and vitamins than crops grown with inorganic fertilizers. The insights provided by the study will help in the production of a new and improved hydroponic nutrient that can provide increased growth, macronutrient levels, and yield.

2.9 Fortification of Organic Nutrients

Low concentrations of macro-nutrients are found in organic nutrients and are not instantly available for direct absorption (Taiwo, Godson and Oloruntoba, 2020). Therefore, organic wastes should be fortified in order to sustain crop production. Fortified nutrients improve their efficiency and lowers production costs (Taiwo *et al*, 2020).

Indigenous nutrients, as a whole, have reduced amounts of natural usable macro-nutrients (Taiwo, Godson and Oloruntoba, 2020). As a result, fortification of organic wastes is critical for long-term agriculture sustainability. Fortification of organic

nutrients with synthetic fertilizers improves the agronomic efficacy (Taiwo *et al*., 2020). Bindraban *et al*. (2015) found that decomposed maize cob fortified with nitrogen enhances maize plant tallness and heaviness of roots and shoots. Molasses waste-water is enriched with NPK in the analysis to optimize macronutrient levels.

2.10 Hydroponics and Economics

Fahey (2012) asserted that the introduction of advanced technology and lower-cost construction resources has led to hydroponics being the most common farming method among Controlled Environment Agriculture (CEA). The study concur with Baumgartner and Belevi (2001), that hydroponically cultivated crops are of high-value and make a significant contribution to small-scale and commercial farmers' production.

The revenue of hydroponic crops rose from $31.7 million in 1988 to about $553.2 million in 2019, as per statistics from the 2019 UNDESA Agriculture Census. In 2009, 78 percent of the crops grown within protection were hydroponically grown (UNDESA, 2019). This sharp rise in revenue demonstrates that hydroponically cultivated crops are in high demand. The majority of these hydroponic crop sales are cultivated on a wide scale in greenhouses that occupy several acres (Fahey, 2012).

2.11 Analytical Methods

The techniques for determining macronutrients that are most often used are discussed in the subsection below:

2.11.1 Atomic Absorption Spectrometry

It's an elemental analytical method focused on the detection of electromagnetic radiation by elemental atomic vapour. The vapour containing the atoms under investigation absorbs the characteristic radiation of a certain element released from a suitable source. The power of the radiation is reduced as it travels into an absorption material, such as a sample. The degree of absorption is measured by comparing the strength of the transmitted beam when no absorbing species is present, i.e. blank with the beam when the sample is present. Incident radiation intensity increases with the abundance of the absorbant and the wideness of the medium. The absorbance of samples of defined quantities, i.e. standards, is measured and used in drawing a calibration curve. The unknown concentrations of the samples can then be calculated after measuring their absorbance (Skoog and Leary, 1991). Magnesium was determined using this method.

2.11.2 Flame Photometry

The underlying concept is that when a cation-containing solution is aspirated into a flame, such as propane burning in air, a vapour containing the element's atoms can form. Any of these gaseous metallic atoms can be elevated to an energy level that allows them to emit radiation that is stereotypical of that substance. Evaporation of the liquid leaves a solid trace, vaporization of the solid dissociates into its constituent atoms, most of which are in the ground state, and thermal excitation of certain atoms to higher energy values by the flame achieves a situation in which they can radiate energy

as they return to the ground level. As a consequence, lines from excited atoms or ions make up the absorption spectrum. Radiation can be emitted when the excited state transitions to the ground state. At high temperatures and low excitation energies, only a small percentage of atoms are excited (Skoog and Leary, 1991).

2.11.3 Colorimetry

Some elements form colored complexes with organic and inorganic ligands, which absorb in the visible range (400 nm-700 nm). When monochromatic light passes through these colored complexes in a homogeneous medium, a portion of it is absorbed. Colorimetric measurements are made by comparing the absorbance of an unknown concentration sample with that of a known concentration sample under well-defined conditions. Only the visible region is addressed by this method (Skoog and Leary, 1991). Nitrogen and phosphorus were measured using this method.

2.11.4 Ultra Violet Spectrometry

It refers to absorption of radiation in the ultraviolet or visible range that causes electronic transitions between molecular orbitals. The energy is high, corresponding to a wavelength range of 200 to 800 nm. Electronic transitions can occur in any atom, but atmospheric absorption can occur below 200 nm, and would need the use of costly vacuum instrumentation in some situations. Source of light, wavelength selector, a cuvette, a radiation detector, a signal processor, and a readout unit are all components of the instrument (Skoog and Leary, 1991). Sulphur was assessed using this method.

2.11.5 Walkley and Black Chromic Acid Wet Oxidation Method

The chromic acid wet oxidation process, according to Bowman (1998), is used to determine organic carbon. Potassium dichromate ($K_2Cr_2O_7$) solution in condensed sulphuric acid oxidizes oxidisable organic material. The heat generated by the reaction increases the temperature to a level where significant oxidation can occur. The amount of $Cr_2O_7^{2-}$ that is decreased during the reaction is equal to the amount of oxidizable organic carbon in the sample. Back-titrating with ferrous sulphate or ammonium ferrous sulphate and using diphenylamine or o-phenanthroline-ferrous complex as an indicator is performed. The remaining unreduced dichromate will then be measured to quantify the organic carbon. Organic carbon can be calculated as follows:

$$\text{Organic C\%} = \frac{(V_{blank} - V_{Sample}) \times M_{Fe^{2+}} \times 0.003 \times 100 \times f \times mcf}{W} \qquad \text{Equation 2.1}$$

Where: $Vblank$ = volume of titrant in blank, ml

$Vsample$ = volume of titrant in sample, ml

f = correction factor, 1.3

W = weight of sample, g

mcf = Moisture correction factor

The model was used to calculate the amount of organic carbon in the air. Alternatively, the volume of chromic ion (Cr^{3+}) produced can be measured using a colorimetric technique that measures absorbance at 588 nm (Rayment and Lyons, 2011).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

Experimentations were done between April and July, 2016 at Christian Industrial Training Centre (CITC), Kapsabet, in Nandi County. The town is located at 80 10' north latitude and 40 10' east longitudes. Kapsabet's climate is tropical to temperate, with a minimum temperature of 15^{o}C and a maximum temperature of 27^{o}C. The annual average rainfall is up to 168.9cm.

3.2 Site Selection and Sampling Frequency of Molasses Waste-water

The sampling regime was created with geographical accessibility in mind and location of both the distillery and the sugar factory discharge into the River Nyando. (Figure 3.1).

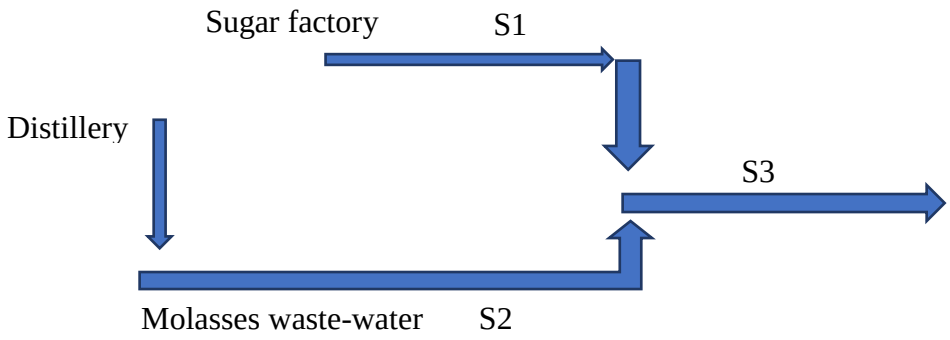

Figure 3.1: Sampling points along Muhoroni sugar effluent and distillery effluent

Sugar Processing Factory and Distillery Drainage Channel were selected as sampling locations (S1 and S2, respectively), after the distillery and plant waste-water effluents have been combined (S3). When the factory and distillery were open for business, samples were collected (between 7:00am and 6:00pm). For each point, only one sample was chosen for study. Between February and April of 2015, three samples were collected. Molasses waste-water (MWW) solutions were obtained in clean 500 mL containers for laboratory study, packed , sealed, and stored in a cooler case at 4^{o}C prior to transportation to Kenyatta University Chemistry and University of Eldoret laboratories for analysis (Okalebo *et al*., 2002).

3.3 Experimental Design

Green house trials were done in a full randomized block design in order to investigate the effectiveness of molasses waste-water as a hydroponic nutrient solution for growing vegetable and fodder crops. Barley fodder and spinach vegetables were grown in three treatments, namely: commercial hydroponic nutrient solutions (Control experiment), molasses waste-water (MWW) and fortified molasses waste-water (FMW). The commercial hydroponic fodder nutrient solutions (HFN) were used as the control in growing fodder while commercial hydroponic vegetable nutrient solutions (HVN) were used as the control in growing vegetables.

Treatment A: Commercial hydroponic nutrient solutions (control experiments)

A1: Commercial hydroponic fodder nutrient solutions (HFN)

A2: Commercial hydroponic vegetable nutrient solutions (HVN)

Treatment B: Molasses waste-water (MWW) (unfortified)

Treatment C: Fortified molasses waste-water (FMW)

The treatments (experimental units) were replicated three times. Treatments were assigned once at random to the subjects in each block (replications) as shown in table 3.1.

Table 3.1: Treatment and Replications in the Greenhouse Experiments

Treatments	**Blocks (Replications)**		
	1	2	3
A: HVN/HFN	A1	A2	C3
B: MWW	B1	B2	C3
C: FMW	C1	C2	C3

Plant growth, yield parameters, levels of macro-nutrients in plant tissues were determined, recorded and compared to establish the efficacy of the fortified molasses waste-water as hydroponic nutrient solution for growing vegetable and fodder crops in a greenhouse.

Barley and spinach crops grown in various treatments were identified as follows:

HF: Barley fodder grown in commercial hydroponic fodder nutrient solutions

HV: Spinach vegetables grown in commercial hydroponic vegetable nutrient solutions

MF: Barley fodder grown in molasses waste-water

MV: Spinach vegetables grown in molasses waste-water

3.4 Commercial Hydroponic Nutrient Solutions

Commercial hydroponic fodder nutrient (HFN) and commercial hydroponic vegetable nutrient (HVN) was purchased at Grandeur Africa Limited, based in Nairobi County, Kasarani Sub County. Macronutrient levels in commercial hydroponic nutrients were not indicated, necessitating their study. The commercial nutrient solutions were made with distilled water according to manufacturer's instructions. The samples were collected in clean acid 500 ml plastic containers and transported to chemistry laboratories at Kenyatta University and the University of Eldoret for analysis using Standard Methods (Okalebo *et al*., 2002).

3.5 Standard Nitrogen Stock Solution 2500 mg/ L

The stock solution prepared by dissolving 11.793 g of ammonium sulphate in a 1000 ml volumetric flask and topping up with distilled water to the required concentration (Harvey, 2000).

3.5.1 Nitrogen Standard

Nitrogen working stock standard solutions were prepared by measuring 0.25, 0.5, 0.75, 1, 1.25, 1.5, 1.75, 2.0, and 2.25 ml of 2500 mg/L nitrogen stock solution with a micropipette into labeled 100ml volumetric flasks and filling to the mark with distilled water to produce standard solutions containing 10, 20, 30, 40, 50, 60, 70, 80, and 90 mg /L $(NH_4)_2SO_4$ used for instrument calibration (Harvey, 2000).

3.5.2 Preparation of Reagents N1 and N2

In a one-litre volumetric flask, 34.0 g of sodium salicylate, 25 g of sodium citrate, and 25 g of sodium tartrate were dissolved in 700 ml of distilled water. Sodium nitroprusside (0.06g) was applied to the mixture, which was then filled to 1000 ml with distilled water. In a 1000 ml volumetric flask, 30.0 g of NaOH was dissolved in 700 mL of distilled water. Allowing it to cool to 15^oC, 10 ml of sodium hypochlorite was applied, shaken thoroughly, and made up to the 1000 ml level (Okalebo *et al*., 2002).

3.6 Standard Phosphorous Stock Solution, 250 mg/L

Oven-dried KH_2PO_4 weighing 1.0982 g was placed in 1000 ml volumetric flask and dissolved in distilled water to 1000 ml level.

3.6.1 Phosphorous Standards

Phosphorous working stock standard solutions were prepared by measuring 1, 2, 5, 10, 15, 20, and 25 ml of 250 mg/L phosphorous standard stock solution into designated 1000 ml volumetric flasks and filling to the 1000 ml mark with distilled water to yield standard

solutions containing 0.5, 1, 2.5, 5, 7.5, and 10 mg/L for instrument calibration (Harvey, 2000).

3.6.2 Preparation of Sulphuric Acid (5N H_2SO_4)

A drain, sterile 1000 mL volumetric flask was immersed in cold water. About 500 ml distilled water was poured into it, and 148 ml sulphuric acid was slowly applied when stirring and diluted to 1000 ml when cool with distilled water (Corbridge, 1995).

3.6.3 Preparation of the Murphy Riley Solution

In a 250 ml conical flask, 6.0g of ammonium molybdate ($[NH_4]_6Mo_7O_{24}$.4H2O) was dissolved in 125 ml of distilled water held at 50^oC. In a separate experiment, 0.15g antimony potassium tartrate ($KSbC_4H_4O_6$) was dissolved in 50 mL of distilled water in a 100 mL conical flask. Both solutions were mixed into 500 ml of 5N H_2SO_4 in a 1litre volumetric flask, shaken with a mechanical shaker, and diluted to 1000 ml with distilled water. It was transfered to a reagent bottle and stored in a dark, cool position for 24 hours before being analyzed (Corbridge, 1995).

3.6.4 Preparation of Ascorbic Acid Reducing Agent

Ascorbic acid ($C_6H_8O_6$) weighing 2.108 g was dissolved in 400 ml of ammonium molybdate/antimony potassium tartrate solution and mechanically shaken. For 24 hours, the solution was kept in the dark (Corbridge, 1995).

3.7 Potassium Standard Stock Solution, 1000 mg/L

Potassium standard stock solution was prepared by dissolving 0.1907 g of potassium chloride dried in an oven at 100°C for 2 hours in 500 ml distilled water in a one litre volumetric flask, and the solution was filled to the mark with distilled water (Harvey, 2000).

3.7.1 Potassium Standards

The potassium working standard series was prepared by measuring 1, 2, 3, 4, and 5 ml of the 100 mg/L potassium standard stock solution into labeled 50 ml volumetric flasks using a 10 ml measuring cylinder and diluting to mark with distilled water to create 2.0, 4.0, 6.0, 8.0, and 10.0 mg/L working standards (Okalebo *et al*., 2002).

3.7.2 Calcium Standard Stock Solution 1000 mg/L

Anhydrous calcium carbonate ($CaCO_3$) weighing 2.947 g was dissolved in 50 ml of 1N *HCl* in a 1000 ml volumetric flask and made to one litre with distilled water (Harvey, 2000).

3.7.3 Calcium Standards

Calcium working standard solution was made by measuring 1, 2, 3, 4, and 5 ml of the 1000 mg/L calcium standard stock solution into labelled 50 ml volumetric flasks with a 10 ml measuring cylinder and diluting to the mark with distilled water to yield standard solutions containing 5, 10, 15, 20, and 30 mg/L Ca, respectively (Okalebo *et al*., 2002).

3.8 Magnesium standard Stock Solution

Magnesium stock solution was made by precisely measuring 1.000 g of pure magnesium rod and dissolving it in 30 ml of 1:1 nitric acid in a 500 ml beaker. The solution was transferred to a 1000 ml volumetric flask and diluted to the mark with distilled water to yield a solution containing 1000 mg/L of magnesium ions. Pipetting 10.0 ml from a 1000 mg/L stock solution into a 100 ml volumetric flask and topping up with distilled water yielded a stock solution of 100 mg/L (Harvey, 2000).

3.8.1 Magnesium standard

Working solutions of 0.05, 0.1, 0.2, 0.4, and 0.8 mg/L were prepared by pipetting 0.05, 0.1, 0.2, 0.4, and 0.8 ml of 100 mg/L stock solution into separate 100 ml volumetric flasks and topping up with distilled water (Harvey, 2000).

3.9 Preparation of Sulphur Standard and Stock Solution

Sulphur stock solutions containing 1, 2, 3, 4, and 5 ml of 1000 mg/L sulphur were measured using a 10 ml measuring cylinder, transferred to a 100 ml volumetric flask, and filled to the mark with distilled water to prepare standards containing 10, 20, 30, 40, and 50 mg/L used for instrument calibration (Okalebo *et al*., 2002).

3.9.1 Preparation of Potassium Orthophosphate Extracting Solution

It was obtained by dissolving 0.5491g of KH_2PO_4 in a 1000 ml volumetric flask and topping it up with distilled water (Okalebo, Gathua, and Woomer, 2002).

3.9.2 Preparation of Gelatin- $Bacl_2$ Reagent

A precisely measured 0.6g of gelatin was dissolved in 200 ml of hot distilled water (60-70^{o}C) in a 500 ml beaker and the contents were allowed to stand in a refrigerator at 4^{o}C for 16 hours before being brought to room temperature. Reagent analytical grade barium chloride (2 g) was added and shaken until dissolved. The solution was kept cold in a refrigerator.

3.9.3 Preparation of Potassium Sulphate

Potassium sulphate was dried in a desiccator over silica gel for 1 hour at 105^{o}C. K_2SO_4 weighing 2.7175 g was transferred into a 500 ml volumetric flask, dissolved in 100 ml distilled water, made up to the level, and placed in a Pyrex bottle (Okalebo *et al*., 2002).

3.10 Reagents for Determination of Total Organic Carbon

3.10.1 Preparation of 1N Potassium dichromate solution

In a 1litre volumetric flask, 49.024 g of dry $K_2Cr_2O_7$ was dissolved in approximately 800 ml of distilled water and diluted to 1000 ml (Bowman, 1998).

3.10.2 Preparation of 0.2M Ferrous Ammonium Sulphate Solution

In a 1litre volumetric flask, ferrous ammonium sulphate (78.390 g) was dissolved in 50 ml concentrated H_2SO_4 and diluted to 1000 ml with distilled water (Okalebo *et al*., 2002).

3.10.3 Indicator solution – 1, 10-Phenanthroline Monohydrate - Ferrous Sulphate (Ferroin)

In a 1000 ml volumetric flask, 100 ml of 0.025 M ferrous sulphate solution was measured and dissolved in 100 ml of 1, 10-phenanthroline monohydrate (1.485 g). It was filled with distilled water (Bowman, 1998).

3.11 Preparation of Digestion Mixture

In a one-litre volumetric flask, 0.21 g of selenium powder was combined with 7.0 g of lithium sulfate and 175 ml of 30% hydrogen peroxide. Concentrated sulphuric acid (210 ml) was carefully applied when cooling in an ice bath. The solution was diluted with distilled water before being processed at 2^{o}C (Okalebo *et al*., 2002).

3.12 Fortification of Molasses Waste-water

Molasses waste water was found to have greater content of potassium, calcium, sulphur, magnesium, and carbon than commercial hydroponic fodder nutrient solutions and commercial hydroponic vegetable nutrient solutions. By adding NPK fertilizer, the nitrogen and phosphorus content of molasses waste water was increased to recommended levels of 70-250 mg/L and 15-80 mg/L, respectively (Voogt, 2016). The fortification was carried out in view of two major macro-nutrients in fertilizer (that is N and P). Initial levels of these nutrients in the organic fertilizer were increased to P=2.5% and N=3.5%, in accordance with the national quality standard of organic fertilizer (Otu

et al., 2014). The dilution formula (Equation 3.1) was used to fortify molasses waste-water.

$$C_1W_1 = C_2W_2 \qquad \text{(Equation 3.1)}$$

Where C_1 is an initial level of N or P in the organic fertilizer,

C_2 is the final level of N or P in the formulation,

W_1 is the quantity of the fortifier that is required to produce the quantity needed (W_2).

The amount of fertilizer needed was assessed based on the assumption that 1 ha of land is equivalent to 10,000 m^2. As such, 2.0 ton/ha was translated to 0.2 kg of fertilizer per 1 m^2 or 0.2 kg of fertilizer per litre. Solutions of one litre quantities of molasses waste water were placed into 2000 ml volumetric flasks, then about 0.30 kg of NPK (15.15.15) fertilizer was added to every container (Resh, 2013) and made up to the mark with distilled water to give 3.57 g/L N, P and K (Resh, 2013).

3.13 Extraction of macro-nutrients in Hydroponic Nutrient Solutions

About 5ml of hydroponic nutrient solution was measured and inserted in a centrifuge tube, and 25 ml of extracting solution was applied and mechanically shaken for 30 minutes. The suspension was filtered through a whatman filter paper no 42 and refrigerated at 5^oC (Okalebo, *et al*., 2002).

3.14 Block Digestion of Hydroponic Nutrient Solutions

Filtered nutrient solutions measuring 0.3 ml were put into labeled dry clean digestion tubes. Precisely 2.5 ml of digestion mixture was measured using 5 ml measuring cylinder and added to each tube and also to reagent blanks for each batch of samples. The tubes were heated in a block digester for 2 hours at 350 °C. When the digest became colourless, the digestion was over. The tubes were taken out of the digester and allowed to cool to room temperature. Then, 25ml of distilled water was applied, shaken thoroughly to blend properly, and made up to 50ml with distilled water (Okalebo *et al*., 2002). The contents were transferred to a 50 ml volumetric flask and allowed to settle, yielding solutions for P, N, K, Ca, Mg, C, and S analysis. The Standard Walkey black rapid titration was used to calculate total organic carbon. Flame photometry was used to calculate potassium and calcium, while colorimetry was used to determine nitrogen and phosphorous. Magnesium was measured using atomic absorption spectroscopy, and sulfur was determined using ultraviolet/visible spectrophotometry (Harvey, 2000).

3.15 Determination of Macro-Nutrients in Hydroponic Nutrient Samples

3.15.1 Colorimetric Analysis for Total Nitrogen

Each standard, sample, and blank were micro pipetted into clearly labeled test tubes in increments of 0.10 mL. A total of 5.0 ml of reagent N1 was added and allowed to stand for 15 minutes. Similarly, 5.0 ml of reagent N2 solution was applied to each test tube, shaken thoroughly, and left for one hour to allow for complete colour production (Okalebo *et al*., 2002). The absorbance of each sample and standard was then

determined at 655nm using a colorimeter. The readings are given in appendix I, table 7.1. A calibration curve of absorbance against concentration of total nitrogen was plotted (see Appendix II, Fig 7.1). The calibration was typically linear with correlation coefficient of 0.9973. The concentration for each sample and blank was then determined from the graph.

3.15.2 Colorimetric Analysis of Phosphorous

Sample and standard solutions of 5 ml was pipetted into a 50 ml volumetric flask. Distilled water (20 mI) was added to each flask. Then 10 ml ascorbic acid was added, stoppered and mixed by shaking thoroughly. The solution was allowed to stand for one hour to allow for full colour development (Okalebo, *et al*., 2002). A colorimeter was then used to evaluate the absorbance of each sample and standard at 880nm. Appendix I, table 7.2, contains the readings. A calibration curve of absorbance versus phosphorous concentration was plotted. (See Appendix II, Fig 7.2). With a correlation coefficient of 0.9958, the calibration was linear. The graph was then used to calculate the concentration of each sample and blank.

3.15.3 Determination of Potassium Using Flame Photometry

The instrument was calibrated using standard potassium solution and a calibration curve was plotted according to the manufacturer's standard optimum operating conditions for potassium analysis. The wet-digested sample solution (5 ml) was pipetted into a 50 mL volumetric flask, filled to capacity with distilled water, and thoroughly shaken. Starting

with standard, blank, and sample solutions, solutions were aspirated at 766.5nm.The intensities of the emitted radiations of each sample and standard were calculated. Appendix I, table 7.3, contains the readings. A calibration curve of the intensities of the emitted radiations versus potassium concentration was plotted (see Appendix II, Fig 7.3). The calibration was linear with a correlation coefficient of 0.9976. The graph was then used to calculate the concentration of each sample and blank (Okalebo *et al*., 2002).

3.15.4 Determination of Calcium Using Flame Photometry

The instrument was adjusted using the manufacturer's standard optimum operating conditions for calcium analysis. Starting with standard, the blank, and samples, solutions were aspirated. Wet-digested sample solution was pipetted into a 50 ml volumetric flask, filled with distilled water, and shaken. Starting with standards, samples, and blanks, the solutions were aspirated directly into the flame of a flame photometer (Okalebo, *et al*., 2002). At 410 nm, the intensities of the emitted radiations of each sample and standard were measured. Appendix I, table 7.4, contains the readings. A calibration curve of the intensities of the emitted radiations versus calcium concentration was plotted (see Appendix II, Fig 7.4). Calibration was linear, with a correlation coefficient of 0.9907. The concentration of each sample and blank was then calculated using the graph (Okalebo *et al*., 2002).

3.15.5 Atomic Absorption Spectrophotometry Analysis for Determination of Mg.

The atomic absorption spectrophotometer (CTA-2000) was optimized by following the manufacturer's instructions for all parameters. Table 3.2 shows the optimized conditions for the AAS during magnesium analysis.

Table 3.2: Optimized conditions for determination of Mg

Wavelength (nm)	285.2
Fuel flow rates L/min	2.5
Oxidant flow rates L/min	11.4
Burner heights	7.5

3.15.5 Procedures for determination of Magnesium

Precisely 5 ml of the wet-digested sample solution was pipetted into a 50 ml volumetric flask, which was then filled to the 50 ml mark with distilled water and thoroughly mixed. The solution was drawn into an atomic absorption spectrophotometer flame, and the absorbance at 285.2 nm was measured. The readings are in Appendix I, table 7.5. The absorbance versus magnesium concentration calibration curve was plotted (see Appendix II, Fig 7.5). The calibration was linear with a correlation coefficient of 0.9964. Using the graph, the concentration of each sample and blank was then determined (Harvey, 2000).

3.15.6 Determination of Total Organic Carbon

Total organic carbon was calculated using wet oxidation with acidified potassium dichromate ($K_2Cr_2O_7$), followed by titration of excess potassium dichromate with 0.2M ferrous ammonium sulphate (Harvey, 2000). In a block digestion tube, 0.5g of crushed plant tissues and 0.5 ml of plant nutrients were placed. To the tubes, 5 ml of potassium dichromate solution and 7.5 ml of concentrated sulphuric acid were applied, along with two reagent blanks (Bowman, 1998). The block digestion tubes were put in a preheated block at 145-155oC for 30 minutes before being cooled and transferred to a 100 ml flask with 0.3 ml of ferrous indicator and thorough shaking to ensure full mixing. The reagent blanks and digested samples were titrated to a brown end point against a 0.2M ferrous ammonium sulphate solution (Bowman, 1998). The titre values of reagent blanks and sample solutions were recorded in appendix I, table 7.6. The percentage of carbon present in samples was calculated using Equation 2.1.

3.15.7 Turbidimetric Method for Sulphur Analysis

Exactly 10 ml extract was pipetted into 50 ml volumetric flask containing about 30 ml distilled water. About 2 ml of Gelatin-Barium chloride solution was added and shaken. Absorbance of sulphur samples and standard solutions were measured at 420 nm on UV/Visible spectrophotometer after 30 minutes. The readings are given in appendix I. A calibration curve of absorbance against concentration of sulphur was plotted (see Appendix II, Fig 7.6). The calibration was typically linear with correlation coefficient

of 0.9839. The concentration for each sample and blank was then determined from the graph (Okalebo *et al*., 2002).

3.16 Efficacy studies

3.16.1 Sprouting and Growing Barley

The hydroponic unit shed external structure measured 10.0 ft. height x 10.0 ft. width x 34.0 ft. length and internal rack structure was 6.0 x 8.2 x 30.3 ft height, width, and length with a 0.4 percent slope. The interior structure was outfitted with nine hydroponic trays measuring 1.8 feet long, 1.0 foot wide and 0.15 feet tall. The trays had three replications of the HVN, MWW, and FMW treatments. The system was semi-intensive; with 75% shed net and the remaining 25% used for proper aeration.

Clean barley seeds were soaked in water for a half day then placed in gunny bag to sprout for 24-36 hours. Following that, sprouted seeds were distributed at a rate of 300 gram per tray on the hydroponic trays. Barley was grown using the improvised nutrient film technique (NFT), in which crops are grown without the use of a substrate by keeping a film of nutrient solution near the roots. The technique comprises of a trough with a slope of 0.3 percent to 2%; the plant's roots are located within the bottom of the trough (Barrett *et al*., 2016). At the elevated end, a hydroponic nutrient solution was added, and the solution slowly flowed down through the tray, holding the roots fully wet. The solution was allowed to drain into a reservoir at the tray's bottom end, and three reservoirs were placed beneath the trays for each treatment. To keep the thin layer

of nutrients in the plant roots, nutrient solutions were applied to the trays on a regular basis. Plate 3.1 depicts soaked grains being put in trays and the sprouting process.

Plate 3.1: Soaked grains, being placed in trays and the sprouting process

3.16.2 Germination and Growing of Spinach

Spinach was grown in polythene greenhouse that measured 9 m 11 m 7 m high to the ridge and was oriented east west. The growing medium was Styrofoam seedling trays (66.5 x 33.5 x 4.9 cm, 17 cc, 210 cells). Commercial hydroponic vegetable nutrient solution was used as the substrate for seed germination. One seed was sown into each cell of the seedling trays (1.5 g seed per m^2). Seedling trays were held in the

germination chamber (dark, day/night 18-20°C, 80 percent humidity) for four days. After emergence, excess plantlets were thinned. They were then transferred to an adaptation greenhouse until they sprouted. Seedlings were watered manually in the morning and evening with a watering can. Spinach seedlings were transplanted to a hydroponic static solution culture, in which plants were grown in two-litre plastic containers filled with nutrient solution (Jones, 2004). Since it is inexpensive and readily accessible, small rocks and sand were used as growing media to support plant roots (Barrett *et al*., 2016). The solution level was kept low so that the root could get enough oxygen. The seedlings were grown in hydroponics for 28 days. Throughout these times, depleted nutrient solutions were resupplied on a weekly basis to maintain the original solution level, which was marked in each container with a permanent marker pen. Plate 3.2 depicts spinach vegetables grown in a rock wool medium.

Plate 3.2: Hydroponic vegetables in a rock wool growing medium

3.16.3 Determination of Growth Parameters, Yield and Harvesting of Barley

The growth parameters were determined every two days and harvesting was done on the eighth day. Appendix III, tables 7.8a, 7.8b, and 7.8c indicate the plant height, stem girth, and leaf length of barley fodder on days 2, 4, 6, and 8. On the eighth day, fresh fodders were weighed to estimate yield. Ten plants that were nearly identical were chosen from each replication and used to calculate plant growth parameters (namely: plant height, leaf length and stem girth). The distance between the tip of the highest leaf and the stem just above the roots was measured to calculate plant height (Badu-Apraku *et al*., 2009). The stem girth was determined by wrapping a string around the stem just above the root (mm). Leaf length was determined with a tape measure and the average was computed. On a precise electronic weighing balance, the fresh weight (g) of the

plants in each tray was measured to one decimal place. Appendix III, table 7.10a, shows the total fresh weight of barley.

3.16.4 Determination of Growth Parameters, Yield and Harvesting of spinach

The spinach growth parameters were determined every seven days. Appendix III, tables 7.9a, 7.9b, and 7.9c show the plant height, stem girth, and leaf length of spinach vegetable in weeks 1, 2, 3, and 4. Harvesting of spinach began when the outer, older leaves reached a length of 10 cm. The first harvest was done 7 days after the seedlings were transplanted to the hydroponic culture. A total of four harvests were carried out. Mature leaves were neatly cut by hand during each harvest, and their weight was taken and recorded. Harvesting was halted after the fourth harvest due to a decrease in leaf quality. Plants harvested from each replication were weighed separately from the first to the last harvest, and yields per harvest (g) and total yields (g) were calculated. Table 7.10b in Appendix III indicates the total fresh weight of spinach.

3.17 Block Digestion and Macro- Nutrient Analysis of in Leaf Samples

For the study, representative plant leaf samples (100 g each) of barley and spinach from the three treatments, as well as the three replications, were used. For 5 days, the samples were dried in the oven at 80°C and were ground to powder. Oven dried material (1.0 g) was weighed into a 25 ml silica evaporating dish for each sample. The dish was heated in a muffle furnace at 450 degrees Celsius for 2 hours, with a small amount of air allowed in to aid in combustion. The dish was cooled, and 5 ml of 6N *HCl* was added

and covered with a clock glass. The basin was placed in a water bath while the clock glass was still covering the dish, and the contents were digested for 15 minutes. The dish was rinsed, the contents were evaporated to dryness, and heating was continued for ten minutes. The digestion process was repeated a second time. The contents were quantitatively transferred to a 100 ml volumetric flask, cooled, and diluted to mark with distilled water. The extract was filtered through a Whatman filter paper no.40, with the first 8 drops of filtrate being rejected. The same protocol was followed with the reagent blank. The resulting solutions were stored for macronutrient analysis.

3.18 Determination of Macro-Nutrients in Plant Leaf Samples

3.18.1 Colorimetric Analysis for Total Nitrogen

The total nitrogen colorimetric analysis was performed using the method mentioned in section 3.15.1 of the literature (Okalebo *et al*., 2002). A colorimeter was then used to calculate the absorbance of each standard and sample at 655nm. Appendix I, table 7.1, contains the readings. A calibration curve of absorbance against concentration of total nitrogen was used to calculate the concentration of nitrogen for each sample and blank (see Appendix II, Fig 7.1).

3.18.2 Colorimetric Analysis of Phosphorous

Phosphorous colorimetric analysis was carried out using the method defined in section 3.15.2 (Okalebo *et al*., 2002). A colorimeter was then used to evaluate the absorbance of each sample and standard at 880nm. Appendix I, table 7.2, contains the readings. To

calculate the concentration of phosphorous for each sample and blank, a calibration curve of absorbance against concentration of total phosphorous was plotted (see Appendix II, Fig 7.2).

3.18.3 Determination of Potassium Using Flame Photometry

Potassium concentration was calculated using flame photometry, as defined in section 3.15.3 (Okalebo *et al*., 2002). At 766.5 nm, the intensities of the emitted radiations of each sample and standard were determined. Appendix I, table 7.3, contains the readings. The calibration curve of the intensities of the emitted radiations against potassium concentration was plotted (see Appendix II, Fig 7.3) and was used to calculate the potassium concentration for each sample and blank (Okalebo *et al*., 2002).

3.18.4 Determination of Calcium Using Flame Photometry

Calcium was calculated using flame photometry, as defined in section 3.15.4 of the literature (Okalebo *et al*., 2002). The intensities of emitted radiations from each sample and standard were calculated at 766.5nm by aspirating standard, blank, and sample solutions into the flame of a flame photometer. The calibration curve was used to determine the Ca concentration in the sample. Appendix I, table 7.4, contains the readings. The calibration curve of the intensities of the emitted radiations against calcium concentration was plotted (see Appendix II, Fig 7.4) and was used to calculate the calcium concentration for each sample and blank (Okalebo *et al*., 2002).

3.18.5 Atomic Absorption Spectrophotometry for Determination of Mg

Magnesium was measured by atomic absorption spectrophotometry using the method defined in section 3.15.5 (Harvey, 2000). Atomic absorption spectrophotometer (CTA-2000) was optimized by following the manufacturer's instructions for all parameters. Magnesium standard series and sample solutions were aspirated into an atomic absorption spectrophotometer flame and their concentrations were measured at 285.2 nm (Okalebo *et al*., 2002). Appendix I, table 7.5, contains the readings. To evaluate the concentration of magnesium for each sample and blank, a calibration curve of absorbance against concentration of magnesium was plotted (see Appendix II, Fig 7.5).

3.18.6 Determination of Total Organic Carbon

Carbon was estimated using the method mentioned in section 3.15.6 of the literature (Bowman, 1998). The reagent blanks and digested samples were titrated to a brown end point with a 0.2M ferrous ammonium sulphate solution. Titre values of reagent blanks and sample solutions were recorded in appendix I, table 7.6b. The percentage of carbon present in samples was calculated using Equation 2.1.

3.18.7 Turbidimetric Method for Sulphur Analysis

Sulphur was measured using the turbidimetric method mentioned in section 3.15.7 of the literature (Okalebo, *et al*., 2002). After 30 minutes, the intensities of the emitted radiations from sulphur samples and standard solutions were calculated at 420 nm using a UV/Visible spectrophotometer. Appendix I, table 7.7, contains the readings. The

calibration curve of the intensities of the emitted radiations against sulphur concentration (see Appendix II, Fig 7.6) was used to calculate the concentration of sulphur for each sample and blank (Okalebo *et al*., 2002).

3.19 Statistical Analysis

The results were presented as mean values. Analysis of data was done using SPSS (version 16.0, SPSS Inc.). Statistical analysis of the results was based on one-way Analysis of Variance ANOVA. Means for significant effects were compared using Student Newman's Keuls (SNK) at $p<0.05$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter is divided into four sections. Section one (4.2) reports on and discusses, findings related to levels of nitrogen, potassium, magnesium, sulphur, phosphorous, carbon and calcium macro- nutrients available in molasses waste-water, fortified molasses waste-water, commercial hydroponic nutrient solutions and recommended plant nutrients levels. Section two (4.3) reports and discusses findings on the various growth parameters of spinach and barley grown in different hydroponic nutrient solutions. Results and discussion on yield of spinach and barley are in section (4.4) and section (4.5) has the results and discussions on macro- nutrient levels in spinach and barley leaves grown in different nutrient solutions.

4.2 Macro- Nutrient Levels in Hydroponic Nutrient Solutions

The levels of the macro-nutrients in the commercial hydroponic solutions were determined before use in growing the crops. Tables 4.1a and 4.1b show the mean levels of nitrogen, potassium, magnesium, sulphur, phosphorous, carbon and calcium macro-nutrients available in molasses waste-water, fortified molasses waste water and commercial hydroponic nutrient solutions.

Table 4.1a: Mean Levels of Nitrogen, Phosphorous, Calcium and Magnesium in Hydroponic Solutions

Treatment	N (mg/L) $\bar{x}\pm s$	P (mg/L) $\bar{x}\pm s$	Ca (mg/L) $\bar{x}\pm s$	Mg (mg/L) $\bar{x}\pm s$
HFN	70.5 ± 0.18^{b}	38.0 ± 2.90^{b}	9.7 ± 0.00^{a}	<LOD
HVN	69.5 ± 0.15^{b}	47.0 ± 0.01^{a}	$17.6\pm .20^{b}$	<LOD
MWW	41.3 ± 0.26^{a}	29.9 ± 0.01^{c}	25.9 ± 0.39^{c}	0.04 ± 0.01^{a}
FMW	70.3 ± 0.18^{b}	47.6 ± 0.01^{c}	25.8 ± 0.39^{c}	0.04 ± 0.01^{a}
P-values	0.021	0.005	0.031	0.000

Mean values followed by the same small letter(s) within the same column do not differ significantly (one-way ANOVA, SNK-test, $\alpha=0.05$)

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Table 4.1b: Mean Levels of Potassium, Calcium and Sulphur in Hydroponic Solutions

Treatment	K (mg/L) $\bar{x}\pm s$	C (%) $\bar{x}\pm s$	S (mg/L) $\bar{x}\pm s$
HFN	118.4 ± 4.60^{a}	<LOD	3.9 ± 0.33^{a}
HVN	114.9 ± 3.04^{a}	<LOD	3.9 ± 0.02^{a}
MWW	230.0 ± 1.00^{b}	37.3 ± 0.67^{b}	4.4 ± 0.07^{b}
FMW	250.7 ± 1.15^{c}	37.3 ± 0.67^{b}	4.4 ± 0.07^{b}
P-values	0.012	0.000	0.028

Mean values followed by the same small letter(s) within the same column do not differ significantly (one-way ANOVA, SNK-test, $\alpha=0.05$)

Key

FMW	Fortified Molassses Waste-water
HFN	Commercial Hydropononic Fodder Nutrient
HVN	Commercial Hydroponic Vegetable Nutrient
LOD	Limit of Detection
MWW	Molasses Waste-water
SNT	Student Newman's Keuls

The results showed that Molasses waste water contains more potassium, calcium, sulphur, magnesium, and carbon than commercial hydroponic nutrient solutions. Levels of nitrogen and phosphorus were lower in molasses waste-water than those of commercial hydroponic nutrient solutions.

It is clear from table 4.1 nitrogen nutrient levels ranged from 41.3 ± 0.26 to 70.5±0.18mg/L. MWW had the lowest nitrogen level of 41.3 ± 0.26 mg/L that was significantly lower ($p<0.05$) than that of commercial hydroponic nutrient solutions. This value was fortified to 70.3 ± 0.18 mg/L (Resh, 2013) in FMW by adding basal NPK fertilizer. Mean phosphorus content ranged from 29.9 ± 0.01 to 47.6±0.01 mg/L. Molasses waste-water, MWW, had a mean Phosphorus level of 29.9±0.01 mg/L, a value that was lower and significantly diferent ($p<0.05$) from 38.0±2.90 and 47.0±0.01 mg/L found in hydroponic fodder nutrient solution, HFN and hydroponic vegetable nutrient solution, HVN respectively. Fortification increased the value to 47.6±0.01

mg/L (Resh, 2013). Fortified molasses waste-water, FMW and molasses waste-water, MWW had mean carbon level of 37.3±0.67%. These value was higher and significantly different ($p<0.05$) from the levels found in commercial hydroponic nutrients which were below the limit of detection (LOD). Mean potassium content ranged from 114.9±3.04 to 250.7±1.15 mg/L in the hydroponic nutrient solutions. Molasses waste-water had a mean potassium level of 230.0±1.00 mg/L, a value that was higher and significantly diferent ($p<0.05$) from 114.9 ± 3.05 and 118.4± 4.04 mg/L found in HFN and HVN respectively. Amendment increased the value to 250.7±1.15 mg/L. Calcium concentration ranged from 9.7 ± 0.00 to 25.9±0.39 mg/L. Molasses waste-water, MWW and fortified molasses waste-water, FMW had a mean calcium levels of 25.9±0.39 mg/L, a value that was higher and significantly diferent ($p<0.05$) from 0.9 ± 0.00 mg/L in hydroponic fodder nutrient and 17.6± 0.20 Mg/L in hydroponic vegetable nutrient. Molasses waste-water and fortified molasses waste-water had mean magnesium levels of 0.04±0.01 mg/L. Hydroponic fodder nutrient, HFN and hydroponic vegetable nutrient, HVN contained significantly ($p<0.05$) low levels of magnesium which could not be detected. Mean sulphur levels ranged from 3.9±0.33 to 4.4±0.07 mg/L for all samples analyzed. Molasses waste-water and fortified molasses waste-water had a mean sulphur levels of 4.4±0.07 mg/L, a value that was slightly higher and significantly diferent ($p<0.05$) from 3.9±0.33 and 3.9±0.02 mg/L found in hydroponic fodder nutrients, HFN and hydroponic vegetable nutrients, HVN respectively.

Higher levels of potassium, calcium, sulphur, magnesium, and carbon in molasses waste water are due to a high percentage of organic and inorganic matter, mainly present as reducing sugars. High carbon content in molasses waste-water can be attributed to high decomposition of residues in molasses waste-water by micro-organism (Jiranuntipon *et al*., 2009). The results agree with that of Ball (2006) which demonstrated a positive correlation between organic matter and organic carbon. Organic carbon was found to be important for fertility. Low carbon percentage in hydroponic fodder nutrient solution, HFN and hydroponic vegetable nutrient solution, HVN may be due to the fact that nutrients are made from inorganic salts namely: NO^{3-}, $PO4^{2-}$, $SO4^{2-}$, K^{+}, Ca^{2+} and Mg^{2+} and lack organic carbon. Phosphorus P and nitrogen N levels in molasses waste-water were below recommended levels (Resh, 2013) and not sufficient to maintain heath plant growth hence their levels were improved by fortifying it with NPK fertilizer according to Otu, *et al*. *(*2014).

4.3 Growth Parameters

4.3.1 Plant Height

Table 4.2a and 4.2b shows mean plant height of barley and spinach respectively.

Table 4.2a: Mean Plant Height of Barley in Day 2, 4, 6 and 8

Mean Plant Height (cm)				
Treatment	**Day 2**	**Day 4**	**Day 6**	**Day 8**
Molasses waste-water	0.7±0.15[a]	2.6±0.12[a]	4.9±0.18[a]	10.5±0.17[a]
Commercial hydrophonic nutrients	1.7±0.15[b]	4.5±0.28[b]	8.6±0.17[b]	12.7±0.43[b]
Fortified molasses waste-water	1.7±0.15[b]	5.2±0.21[b]	10.6±0.06[c]	13.0±0.38[b]
p-value	0.005	<0.001	<0.001	0.004

Mean values followed by the same letter(s) within the same column do not differ significantly (One-way ANOVA, SNK-test, α=0.05)

Table 4.2b: Mean Plant Height of Spinach in Weeks1, 2, 3 And 4

Mean Plant Height (cm)				
Treatment	**Week 1**	**Week 2**	**Week 3**	**Week 4**
Molasses waste-water	10.2±0.15[a]	12.7±0.09[a]	14.9±0.12[a]	18.1±0.32[a]
Commercial hydrophonic nutrients	10.3±0.03[a]	12.9±0.09[a]	15.5±0.15[b]	20.2±0.28[b]
Fortified molasses waste-water	10.4±0.09[a]	13.2 ±0.24[a]	16.1±0.21 [c]	20.9±0.18[b]
p-value	0.523	0.226	0.006	0.001

Mean values followed by the same letter(s) within the same column do not differ significantly (One-way ANOVA, SNK-test, α=0.05)

Significantly taller (13.0 cm) mean plant height of barley in the 8th day was obtained from application of fortified molasses waste-water followed by commercial hydroponic nutrient solution. Lower values of 10.5 cm were obtained in molasses waste-water treatments. Significantly taller (20.9 cm) mean plant height of spinach in the fourth week was obtained from the application of fortified molasses waste-water followed by commercial hydroponic nutrient solution. Lower value (18.1 cm) was obtained in molasses waste-water treatments.

Plant height is an important parameter in the estimation of rate of growth and describes the relationship between the growth vigour and plant chemical composition (Hendrik and Eric, 1996). Plant height is fortified through balanced nutrition. Fortified molasses waste-water increased plant nutrition hence increase in plant height. The results correspond to earlier findings reported by Getachew and Tilahun (2017) who found that organic manures fortified with mineral fertilizers maximized plant height.

4.3.2 Stem Girth

Table 4.3a and 4.3b shows the mean stem girth of barley and spinach respectively.

Table 4.3a: Mean Stem Girth of Barley (*Hordium vulgare* L.) in Days 2, 4, 6 and 8

Mean Stem Girth (mm)				
Treatment	**Day 2**	**Day 4**	**Day 6**	**Day 8**
Molasses waste-water	0.4±0.06 [a]	2.4±0.19 [a]	4.4±0.18 [a]	8.4±0.26 [a]
Commercial hydrophonic nutrients	0.4±0.12 [a]	2.6±0.15 [a]	4.6±0.17 [a]	9.1±0.33 [b]
Fortified molasses waste-water	0.5±0.12 [a]	2.8±0.24 [a]	4.6±0.30 [a]	9.2±0.43 [b]
p-value	0.870	0.514	0.672	0.255

Mean values followed by the same letter(s) within the same column do not differ significantly (One-way ANOVA, SNK-test, α=0.05)

Table 4.3b: Mean Stem Girth of Spinach (*Spinacea olerecea* L.) in Weeks 1, 2, 3 and 4

Mean Stem Girth (mm)				
Treatment	**Week 1**	**Week 2**	**Week 3**	**Week 4**
Molasses waste-water	12.1±0.09[a]	13.3±0.15[a]	14.5±0.12[a]	14.7±0.26[a]
Commercial hydrophonic nutrients	12.2±0.06[a]	14.1±0.15[b]	15.1±0.15[b]	15.8±0 .21[b]
Fortified molasses waste-water	12.2±0.10[a]	14.2±0.18[b]	15.1±0.09[b]	16.2±0.12[b]
p-value	0.816	0.011	0.017	0.004

Mean values followed by the same letter(s) within the same column do not differ significantly (One-way ANOVA, SNK-test, α=0.05)

Significantly high stem girth mean of 9.2 mm in barley was obtained in the eighth day in fortified molasses waste-water treatment. Lower mean of 9.1 mm in commercial hydrophonic nutrient treatment and lowest mean of 8.4 mm in molasses waste-water treatment were obtained. Significantly low mean stem girth of 14.7 mm in spinach was obtained in the fourth week in molasses waste-water treatment. Lower mean stem girth of 15.8 mm was obtained in commercial hydrophonic nutrient treatment. Highest mean of 16.2±0.12cm was obtained when fortified molasses waste-water was used.

The girth of a plant is important in determining the size and records of growth of living and standing plants. Applications of fortified organic waste improved the supply of nitrogen and phosphorous, resulting in increased plant growth and stem girth. These findings are consistent with those of Chen *et al*. (1994), who discovered that increasing the nitrogen and phosphorus levels in organic nutrients increased the thickness and width of the maize plant significantly..

4.3.3 Mean Leaf Length

Table 4.4a and 4.4b show the effect of using different plant nutrients solutions on leaf length of barley and spinach respectively.

Table 4.4a: Mean Leaf Length of Barley in Days 2, 4, 6 And 8

Mean Leaf length (cm)				
Treatment	**Day 2**	**Day 4**	**Day 6**	**Day8**
Molasses waste-water	1.1±0.07[a]	2.3±0.09[a]	3.4±0.18 [a]	4.7±0.20[a]
Commercial hydrophonic nutrients	1.2± 0.15[a]	2.6±0.12[a]	3.7±0.12 [a]	4.9±0.20[a]
Fortified molasses waste-water	1.3±0.06[a]	2.8±0.07[b]	3.9±0.12 [a]	5.6±0.17[b]
p-value	0.542	0.024	0.105	0.045

Mean values followed by the same letter(s) within the same column do not differ significantly (One-way ANOVA, SNK-test, α=0.05)

Table 4.4b: Mean Leaf Length of Spinach in Weeks 1, 2, 3 and 4.

Mean Leaf length (cm)				
Treatment	**Week 1**	**Week 2**	**Week 3**	**Week 4**
Molasses waste-water	0.7±0.15 [a]	2.1±0.31 [a]	4.2±0.12[a]	10.6±0.21[a]
Commercial hydrophonic nutrients	0.7±0.15 [a]	2.4±0.15 [a]	4.9±0.17[b]	12.8±0.38[b]
Fortified molasses waste-water	0.7±0.15 [a]	2.6±0.12 [a]	4.9±0.18[b]	13.0±0.38[b]
p-value	1.000	0.304	0.025	0.004

Mean values followed by the same letter(s) within the same column do not differ significantly (One-way ANOVA, SNK-test, α=0.05)

The mean weekly leaf length of barley grown in molasses waste-water was the shortest and significantly different from those grown in fortified molasses waste-water and commercial hydroponic fodder nutrient. Plants grown in fortified molasses waste-water had the longest mean leaf length, whereas plants grown in commercial hydroponic

fodder nutrients had intermediate length. There was no statistically significant difference in mean leaf length between barley grown in fortified molasses waste-water and those grown in industrial hydroponic fodder nutrients. Spinach grown in fortified molasses waste-water had the longest mean length which was significantly different from mean leaf length of spinach grown in commercial hydroponic fodder nutrient and molasses waste-water. Spinach grown in molasses waste-water had the shortest mean leaf length. Fortified molasses waste-water increased the availability of plant nutrients in the growing media which enhanced plant growth thus resulted in increase in leaf lengths. Nutrient-limited environment is often dominated by short leaved species (Cramer, Hawkins and Verboon, 2009). Fortified molasses waste-water is rich in plant nutrients which enhanced plant growth thus lead to increase in leaf length. The findings are consistent with previous findings published by Oyedeji *et al*. (2014), who discovered that applying poultry manure and NPK significantly increased leaf length in three *amaranth* species.

4.4 Plant Yield

Mean barley sprout yield and mean spinach total fresh weight are presented in Table 4.5a and 4.5b respectively.

Table 4.5a: Mean Barley Sprout Yield per Kg Input of Grain (Kg)

Treatment	**Mean ± SE**
Molasses waste-water	10.8 ± 0.17 [a]
commercial hydroponic nutrient	11.2± 0.44 [a]
Improved Molasses waste-water	12.0 ± 0.57[a]
p-value	0.2

Mean values followed by the same small letter(s) within the same column do not differ significantly (One-way ANOVA, SNK-test, α=0.05)

Table 4.5b: Mean Spinach Total Fresh Weight (Kg)

Treatment	**Mean ± SD**
Molasses waste-water	0.4± 0.05 [a]
Commercial hydroponic nutrient	0.5± 0.05 [a]
Fortified Molasses waste-water	0.6± 0.06 [a]
P-value	0.209

Mean values followed by the same small letter(s) within the same column do not differ significantly (One-way ANOVA, SNK-test, α=0.05)

Fortified molasses waste-water produced the highest mean fresh weight of barley and spinach. These results were not significantly different from those crops grown in molasses waste-water and commercial hydroponic nutrient solutions. Higher yield of crops grown in fortified molasses waste-water can be attributed to elevated nutrient concentration hence increased biological productivity (Daniel *et al*., 1998). The results agree with findings by Shaheen, Khan and Jilani, (2014) who reported high fresh foliage yield for spinach fertilized with fortified organic liquid press. These findings

were also consistent with those of Fayed et al. (2008), who recorded a high yield fresh weight of hydroponic fodder.

4.5 Mean Macro-nutrient levels of Plant Tissues

Nutritive mineral elements levels of plant leaf tissues planted in different nutrient solutions are presented in tables 4.6a and 4.6b.

Table 4.6a: Mean Nitrogen, Phosphorous, Calcium and Magnesium Concentration in Plant Tissues

Treatment	N (mg/kg) Mean±SE	P (mg/kg) Mean±SE	Ca (mg/kg) Mean±S E	Mg (mg/kg) Mean±SE
HV	107.3±0.19^{a}	87.8±0.01^{a}	12.7±0.00^{b}	1.4±0.03^{a}
HF	128.7±0.29^{b}	75.7±0.01^{b}	18.6±0.34^{a}	1.9±0.01^{b}
MV	102.7±0.2^{a}	74.7±0.01^{b}	48.2±0.71^{e}	1.8±0.02^{b}
MF	174.3±0.11^{c}	69.5±0.02^{a}	25.1±0.30^{c}	5.9±0.0^{a}
FMV	210.6±0.07^{d}	94.9±0.01^{d}	48.8±0.71^{e}	3.3±0.05^{a}
FMF	205.9±0.14^{d}	90.7±5.79^{c}	38.0±0.34^{d}	6.4±0.01^{c}

Mean values followed by the same small letter(s) within the same column do not differ significantly (one-way ANOVA, SNK-test, α=0.05)

Table 4.6b: Mean Potassium, Calcium and Sulphur Concentration in Plant Tissues

Treatment	K (mg/kg) Mean±SE	C((%) Mean±SE	S (mg/kg) Mean± SE
HV	170.2±3.05b	27.0±0.00a	6.5±0.03a
HF	139.1±5.02[a]	35.3±0.00 [b]	6.5±0.01[a]
MV	601.6±2.30[d]	82.7±0.67[d]	14.1±0.01[b]
MF	525.6±3.05[c]	74.0±1.15[c]	13.2±0.29[b]
FMV	632.7±7.54[d]	84.0±1.15[d]	15.8±0.04[b]
FMF	616.5±2.30[d]	82.0±0.00 [d]	15.8±0.05[b]
p-value	0.002	0.014	0.001

Mean values followed by the same small letter(s) within the same column do not differ significantly (one-way ANOVA, SNK-test, α=0.05)

Vegetables and fodder grown in molasses waste-water had significant lower nitrogen levels of 102.7±0.20 and 107.3±0.19 mg/kg respectively. Vegetables and fodder grown in commercial hydroponic nutrients had moderate nitrogen content of 174.3±0.11 and 128.7±0.29 mg/kg respectively. Vegetables and fodder grown in fortified molasses waste-water had significantly higher phosphorus levels of 210.6±0.07 and 205.9±0.14mg/kg respectively.

Vegetables and fodder planted in molasses waste-water had lower phosphorus levels of 74.7±0.01 mg/kg and 69.5±0.02 mg/kg respectively. Vegetables and fodder planted in commercial hydroponic nutrients had moderate phosphorus levels of 87.8±0.01 mg/kg

and 75.7±0.01 mg/kg respectively. Vegetables and fodder planted in fortified molasses waste-water had higher phosphorus levels of 94.9 ± 0.01 mg/kg and 90.6 ± 5.79 mg/kg respectively. Vegetables grown in molasses and fortified molasses waste-water had the highest carbon levels of 82.7 ± 0.67 % and 84.0 ± 1.15 % respectively. Fodder grown in molasses and fortified molasses waste-water had 74.0 ± 1.15% and 82.0 ± 0.67% carbon content respectively. Plant leaf tissues grown in Commercial hydroponic nutrients had significantly low carbon level of 35.3 ± 0.67% in hydroponic fodder and 27.0 ± 0.00 % in hydroponic vegetables. The high carbon content of vegetables and fodder grown in molasses and fortified molasses waste-water can be due to the high carbon content of molasses waste-water nutrients (37.3 ± 0.67 percent). Plant tissues planted in molasses waste-water had potassium levels of 525.6±3.05 mg/kg in molasses waste-water fodder and 601.54 ± 2.30 mg/kg in molasses waste-water vegetables, the values were higher and significantly diferent from 139.1 ± 5.02 and 170.2±3.05 found in hydroponic fodders and hydroponic vegetables respectively. Potassium content increased to 632.6±7.54 mg/kg in fortified molasses waste-water vegetables and 616.5 mg/kg± 2.30 mg/kg in fortified molasses waste-water fodder. The significantly high potassium levels in molasses waste-water products can be attributed to the high potassium levels in molasses waste-water as a result of the use of potassium salts and their bases in the distillery and yeast industries. Vegetables planted in molasses waste-water had significantly high calcium levels of 48.2± 0.71 mg/kg. Fodder planted in molasses waste-water recorded moderate calcium levels of 25.1±0.30 mg/kg. The values were higher and significantly diferent from vegetables and fodder planted in commercial

hydroponic nutrients which had low calcium levels of 48.8 ± 0.71 and 48.2± 0.71 mg/kg respectively. Vegetables and fodder planted in fortified molasses waste-water recorded the highest calcium levels of 48.8 ± 0.71 and 37.9±0.34 mg/kg. Fodder planted in fortified molasses waste-water and molasses waste-water had significant higher magnesium values of 6.4±0.01 and 5.9 ± 0.00 mg/kg respectively. Vegetables planted in fortified molasses waste-water had moderate magnesium values of 3.2±0.05 mg/kg. Significantly low magnesium levels of 1.9±0.01, 1.8±0.02 and 1.4±0.03 mg/kg was recorded in molasses vegetables, commercial hydroponic fodder and commercial hydroponic vegetables respectively. Level of magnesium in spinach planted in commercial hydroponic nutrients was lower than the recommended range whereas values for other samples analyzed were within the recommended range as shown in table 4.8. Low levels of magnesium are recommended in the diet (Food and Nutrition Board, 1997). Fodder and vegetables planted in fortified molasses waste-water had significantly high sulphur contents of 15.8±0.05 and 15.8±0.04 mg/kg respectively. Fodder and vegetables planted in molasses waste-water showed moderate sulphur levels of 13.2±0.29 and 14.1±0.01 mg/kg respectively. Fodder and vegetables planted in commercial hydroponic nutrients recorded significant low sulphur levels of 6.5±0.01 and 6.5±0.03 mg/kg respectively. High values of sulphur in plant tissues planted in fortified molasses waste-water and molasses waste-water can be attributed to large amounts of ammonium sulphate and magnesium sulfate in waste-water. The levels of macronutrients in all samples were significantly lower than the recommended levels in plant tissue (Reuter and Robinson, 1997). Macro-nutrient leaf analysis data in plants

gives an insight regarding nutrient uptake and mobility in plants. It also shows the nutritional value and quality of plant tissues (Resh, 2013). Barley fodder and spinach vegetables grown in fortified molasses waste-water had significantly high macro-nutrient levels compared to other treatments. Macro-nutrients levels in plants grown in molasses waste water and commercial hydroponic nutrient solutions were not significantly different. Plant nutrients in the hydroponic nutrient solutions were utilized adequately to produce quality vegetables and fodder (Omale and Ugwu, 2011).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The aim of this research was to determine the efficacy of molasses waste water as a hydroponic nutrient solution. Status of macro-nutrients (N, P, K, C, Ca, Mg and S) present in molasses waste-water in comparison with commercial hydroponic nutrients was determined in order to establish deficiency of the nutrients in molasses waste-water and thus fortify. Barley and spinach were hydroponically grown in molasses waste-water, commercial hydroponic nutrient solutions and fortified molasses waste-water in in order to determine the effects of hydroponic nutrient solutions on plant growth parameters, yield elements, and macronutrient levels in hydroponic plant leaves.

The results showed a higher content of K, C, Ca, Mg and S in molasses waste-water in comparison to commercial hydroponic nutrients. High levels of macro nutrients in waste-water including organic carbon show that molasses waste-water is a good source of organic hydroponic nutrient solution. Levels of nitrogen and phosphorous in molasses waste-water were lower compared to those of commercial hydroponic nutrients thus molasses waste-water was fortified with NPK fertilizer to increase the levels of nitrogen and phosphorous, both of which are critical for plant development. Among the three hydroponic nutrient solutions treatments applied in the experiment, fortified molasses waste-water was proved to be effective in improving plant height, stem girth, plant root of barley and spinach. Plant yield for spinach and barley in

fortified molasses waste-water was better compared to those grown in commercial hydroponic nutrient solutions. Spinach and barley plants grown using fortified molasses waste-water fully utilized plant macro-nutrient to produce high-quality plant tissues with the highest levels of N, P, K, C, Ca, Mg, and S when compared to commercial hydroponic nutrient solutions and molasses waste-water. There was no statistically significant difference between the plant growth parameters, yield elements, and macronutrient levels of spinach and barley produced in fortified molasses waste-water and commercial hydroponic nutrients. The results of this study show that molasses waste-water can be used as an alternative to commercial hydroponic nutrient.

5.2 Recommendations

Molasses waste-water contains higher levels of K, C, Ca, Mg and S macro-nutrients and lower levels of N and P compared to commercial hydroponic nutrients solutions thus should be fortified and used in hydroponic growing of high quality and maximum quantity spinach and barley. Moreover, the successful application of fortified molasses waste-water in our study suggested a rational way to reuse molasses waste-water and was effective in obtaining the best growth parameters, yield, and quality of barley and spinach. Application of fortified molasses waste-water as hydroponic nutrient solution is an effective technology in hydroponic farming and should be adopted locally in growing of crops. Further research is still needed to determine the appropriate concentration and doses of fortified molasses waste-water needed for each horticultural and food crop. It will be critical for future research to find an organic source to raise

potassium and nitrogen levels in molasses waste-water in order to correct the NPK balance.

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APPENDIX 1

ABSORBANCE / EMISSION READINGS

Table 7.1a: Absorbance Readings for Nitrogen Standards

Concentration	Absorbance
0	0
10	0.88
20	0.182
30	0.288
40	0.349
50	0.465
60	0.560
70	0.634
80	0.698
90	0.804

Table 7.1b: Absorbance readings for nitrogen analysis in hydroponic nutrient samples

Sample	Absorbance		
Blank	0.030		
FMW	0.858	0.852	0.859
HFN	0.458	0.453	0.455
HVN	0.385	0.381	0.382
MWW	0.368	0.366	0.361

Table 7.1c: Absorbance Readings for Nitrogen Analysis in Leaf Samples

Sample	**Absorbance**		
Blank	0.030		
HF	1.430	1.428	1.431
MF	1.720	1.721	1.719
FMV	1.680	1.682	1.684
FMF	1.065	1.061	1.069
MV	0.862	0.864	0.865
HV	1.107	1.103	1.110

Table 7.2a: Absorbance Readings for Phosphorous Standards

Concentration	**Absorbance**
0	0
0.5	0.08
1	0.168
2.5	0.345
5	0.640
10	1.173

Table 7.2b: Absorbance Readings for Phosphorous Analysis in Hydroponic Nutrient

Samples	**Absorbance**		
Blank	0		
HFN	0.582	0.580	0.582
FMW	0.834	0.837	0.830
MWW	0.139	0.137	1.138
HVN	0.261	0.263	0.265

Table 7.2c: Absorbance Readings for Phosphorous Analysis in Leaf Samples

Sample	**Absorbance**		
Blank	0		
HV	1.125	1.124	1.127
MF	0.894	0.894	0.892
HF	1.046	1.044	1.041
FMF	1.141	1.146	1.143
MV	0.902	0.904	0.906
FMV	2.890	2.892	1.143

Table 7.3a: Emission Readings for Potassium Standard

Concentration	**Emission intensity**
0	0
1	7
2	11.9
4	21.5
6	31.2
8	40.8

Table 7.3b: Absorbance Readings for Potassium Analysis in Hydroponic Nutrient Samples

Sample	**Emission**		
HVN	3.4	3.5	3.7
HFN	3.5	3.5	3.9
MWW	7.4	7.5	7.5
FMW	21.1	21.0	21.2

Table 7.3c: Absorbance Readings for Potassium Analysis in Leaf Samples

Sample	**Photometer Emission**		
FMF	18.1	18.8	18.7
MF	17.7	17.7	17.5
MV	18.0	18.0	18.2
HF	4.2	4.5	4.0
HV	5.1	5.0	5.3
FMV	15.4	15.6	15.3

Table 7.4a: Emissions Readings for Calcium Standards

Concentration	**Emission**
0	0
3.75	0.05
7.5	13
15	29
30	59
60	100

Table 7.4b: Emissions Readings for Calcium Analysis in Hydroponic Nutrient Samples

Sample	**Emissions**		
Blank	0		
FMW	61	59	63
HFN	3	5	6
HVN	5	4	4
MWW	61	61	61

Table 7.4c: Emission Readings for Calcium Analysis in Leaf Samples

Samples	**Photometer emission**		
Blank	0		
FMV	86	82	89
HF	13	11	13
MV	82	85	86
MF	60	54	57
HV	15	16	18
FMF	76	74	75

Table 7.5a: Absorbance Readings for Magnesium Standards

Concentration	**Absorbance**
0.05	0.060
0.1	0.122
0.2	0.227
0.4	0.422
0.8	0.754

Table 7.5b: Absorbance Readings for Magnesium Analysis in Hydroponic Nutrient

Samples	**Absorbance**		
Blank	0		
FMW	0.164	0.157	0.157
HVN	0.023	0.023	0.024
HFN	0.018	0.017	0.019
MWW	0.034	0.037	0.036

Table 7.5c: Absorbance Readings for Magnesium Analysis in Leaf Samples

Samples	**Absorbance**		
Blank	0		
MV	0.322	0.330	0.337
HV	0.200	0.198	0.203
MF	0.580	0.580	0.580
HF	0.203	0.203	0.207
FMF	0.621	0.623	0.624
FMV	0.551	0.552	0.554

Table 7.6a: Titre Values for Carbon Analysis in Hydroponic Nutrient Samples

Sample	Average Titre Values		
Blank	13.3	13.5	13.6
Blank	13.4	13.4	13.6
HFN	15.2	15.3	15.3
MWW	17.6	17.6	17.7
FMW	17.8	17.7	17.6
HVN	15.4	15.4	15.3

Table 7.6b: Titre Values for Carbon Analysis in Plant Leaf Samples

Sample	Average Titre Values		
Blank	13.3	13.5	13.6
Blank	13.4	13.4	13.6
HF	17.3	17.2	17.1
MF	23.5	23.6	23.7
FMF	23.6	23.8	23.7
MV	27.0	27.0	27.0
HV	17.6	17.6	17.6
FMV	23.6	23.5	23.8

Table 7.7a: Emissions Readings for Sulphur Standards

Concentration (Mg/L)	**Emission**
0	0.0185
10	0.0902
20	0.2377
30	0.4604
40	0.6177
50	0.8024

Table 7.7b: Emissions Readings for Sulphur Analysis in Hydroponic Nutrient Samples

Samples	**Emissions**		
Blank	0	0.0185	0.0185
FMW	0.0344	0.0353	0.0363
MW	0.0331	0.0345	0.0354
HVN	0.0261	0.0264	0.0269
HFN	0.0231	0.0231	0.0324

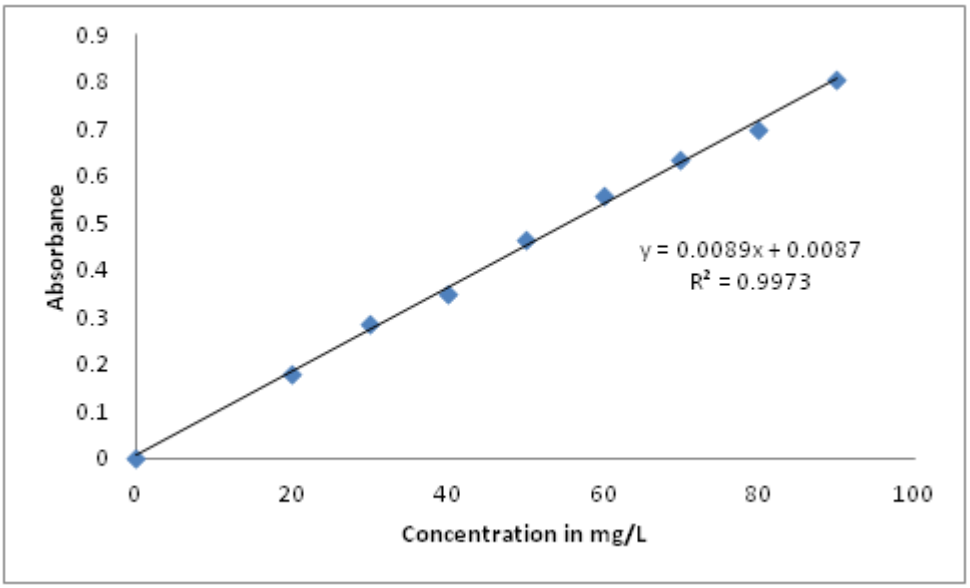
Table 7.7c: Emissions Readings for Sulphur Analysis in Leaf Samples Standards

Samples	**Emissions**		
FMV	0.2204	0.2213	0.2201
FMF	0.2201	0.2215	0.2217
MV	0.1932	0.1932	0.1934
MF	0.1731	0.1821	0.1800
HV	0.0691	0.0681	0.0683
HF	0.0692	0.0690	0.0691

APPENDIX II

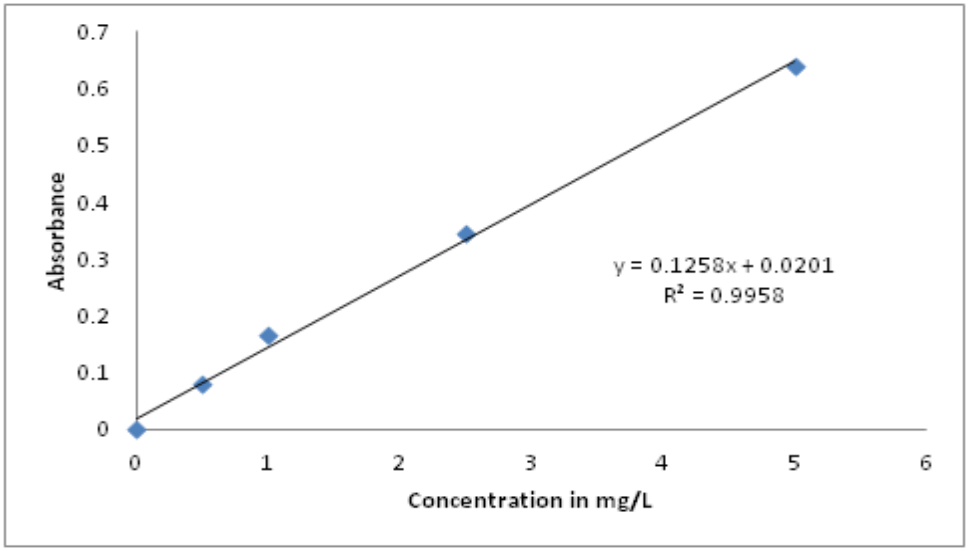
CALIBRATION CURVES

Fig 7.1: Calibration Curve of Absorbance against Concentration of Total Nitrogen



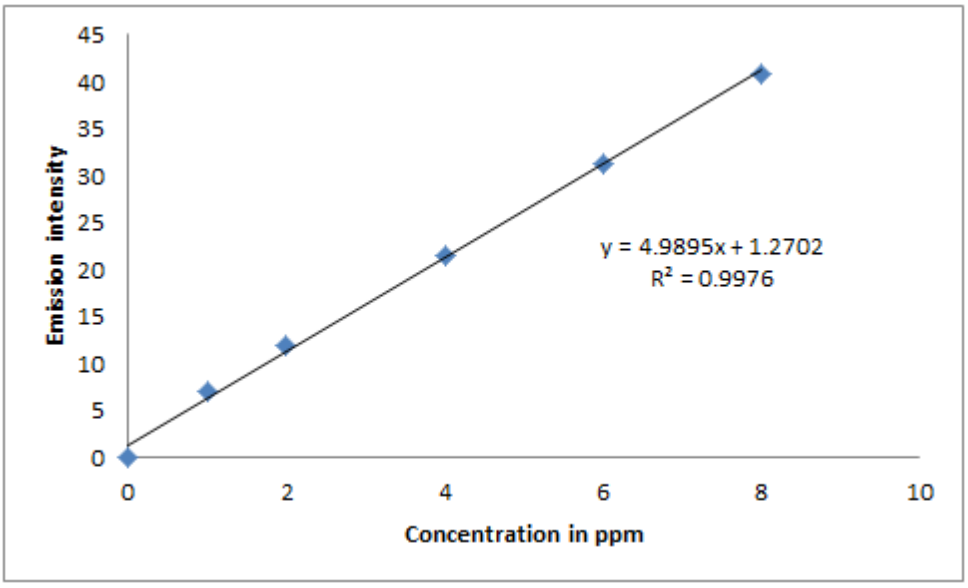
Calibration curve for nitrogen determination

Fig 7.2: Calibration Curve of Absorbance against Concentration of Phosphorous



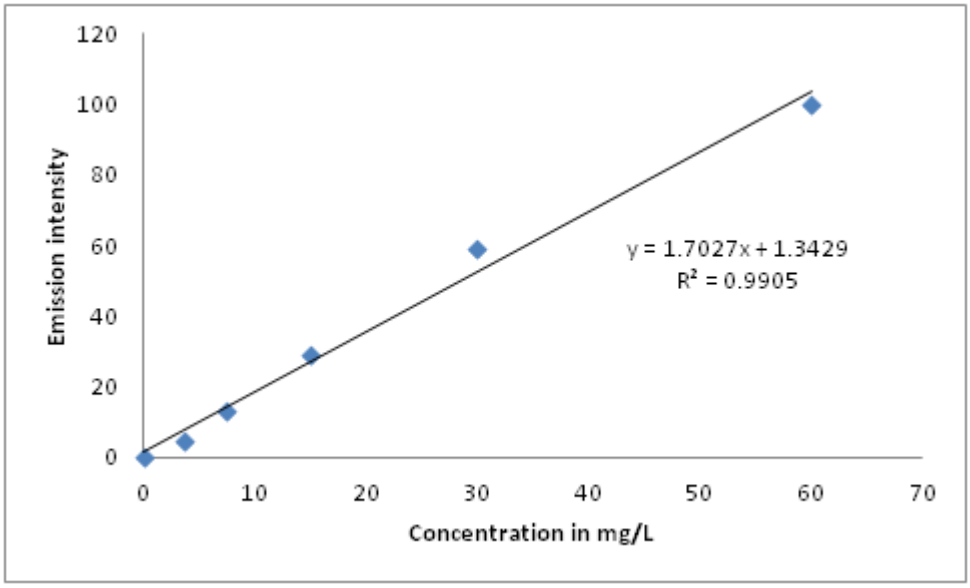
Calibration curve for phosphorous determination

Fig 7.3: Calibration Curve of Absorbance Reading against Potassium Concentration



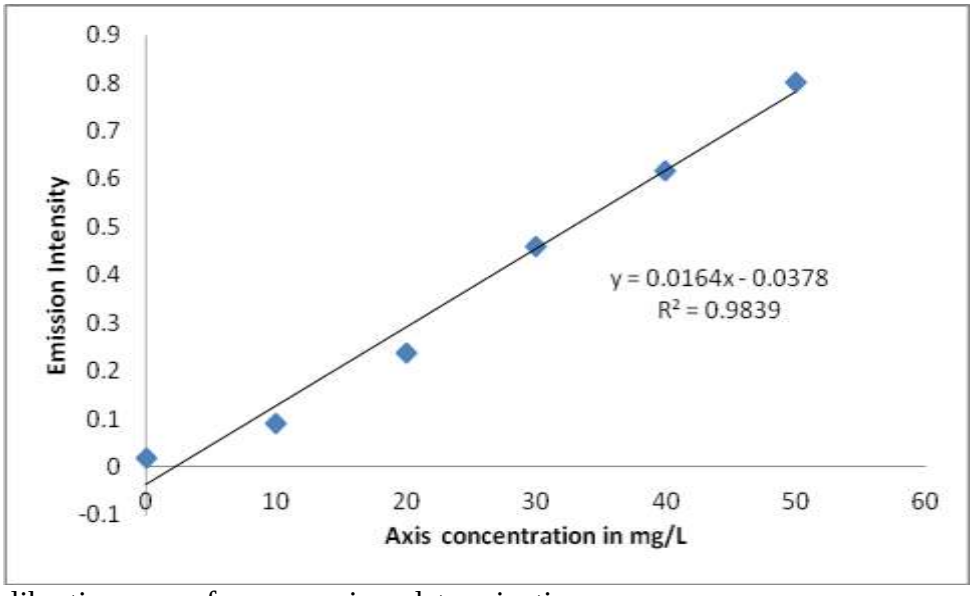
Calibration curve for potassium determination

Fig 7.4: Calibration Curve Was Constructed of Absorbance against Calcium Concentration



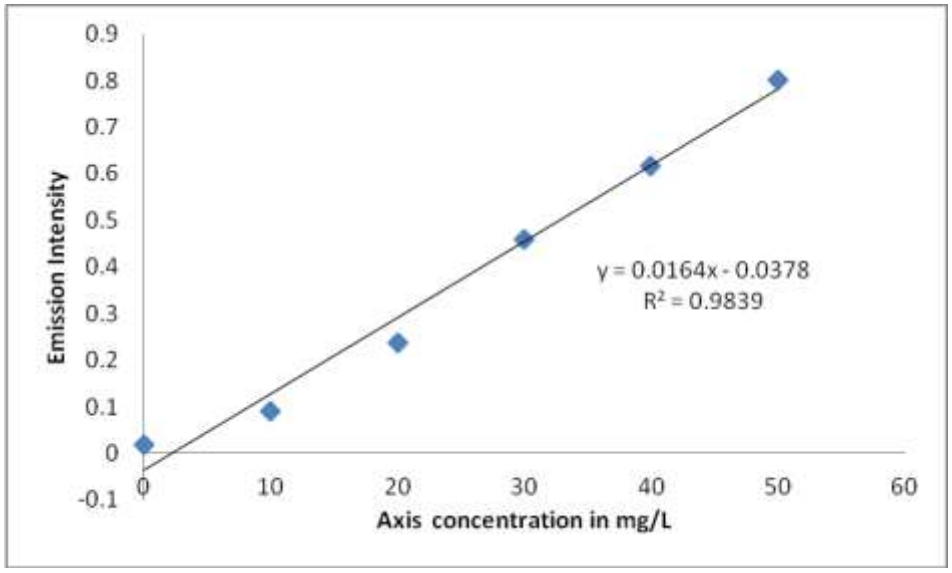
Calibration curve for calcium determination

Fig 7.5: Calibration Curve of Emission Reading Against Magnesium Concentration



Calibration curve for magnesium determination

Fig 7.6: Calibration Curve of Emission Reading against Sulphur concentration



Calibration curve for sulphur determination

APPENDIX III

TABLES OF PLANT GROWTH PARAMETERS

Table 7.8a: Plant Height (cm) of Barley Fodder in Day 2, 4, 6 And 8

Treatment	Day 2			Day 4			Day 6			Day 8		
MWW	1.6	1.5	2.0	4.3	4.2	5.1	8.3	8.6	8.9	10.5	10.2	10.8
HN	1.6	1.5	2.0	5.3	4.8	5.5	10.6	10.5	10.7	12.4	12.1	13.5
FMW	1.6	1.5	2.0	5.4	4.4	5.6	10.5	10.4	10.9	12.8	12.5	13.9

Table 7.8b: Stem Girth (mm) of Barley Fodder in Day 2, 4, 6 and 8

Treatment	Day 2			Day 4			Day 6			Day 8		
MWW	0.4	0.3	0.7	2.3	2.2	2.8	4.3	4.1	4.7	8.3	8.0	8.9
HN	0.4	0.2	0.6	2.6	2.4	2.9	4.6	4.3	4.9	9.6	8.5	9.3
FMW	0.4	0.3	0.5	2.9	2.3	3.1	4.5	4.2	5.2	9.5	8.4	9.8

Table 7.8c: Leaf Length (cm) of Barley Fodder in Day 2, 4, 6 And 8

Treatment	Day 2			Day 4			Day 6			Day 8		
MWW	0.6	0.5	1.0	1.5	2.5	2.3	4.0	4.2	4.4	10.2	10.7	10.9
HN	0.6	0.5	1.0	2.2	2.3	2.7	4.6	4.9	5.2	12.2	12.7	13.5
FMW	0.6	0.5	1.0	2.4	2.6	2.8	4.7	4.9	5.3	12.4	12.9	13.7

Table 7.9a: Plant Height (cm) of Spinach Vegetable in Week 1, 2, 3 And 4

Treatment	Week 1			Week 2			Week 3			Week 4		
MWW	10.5	10.0	10.1	12.9	12.6	12.7	15.1	14.7	14.9	18.6	17.5	18.1
HN	10.3	10.4	10.3	12.8	13.1	12.9	15.3	15.8	15.5	19.6	20.5	20.4
FMW	10.4	10.2	10.5	13.3	12.7	13.5	16.0	15.8	16.5	20.9	20.7	21.3

Table 7.9b: Stem Girth (cm) of Spinach Vegetable in Week 1, 2, 3 And 4

Treatment	Week 1			Week 2			Week 3			Week 4		
MWW	1.5	1.0	1.1	2.5	2.3	2.2	3.7	3.3	3.1	5.1	4.7	4.4
HN	1.2	1.2	1.0	2.8	2.6	2.4	3.9	3.8	3.5	5.2	4.9	4.5
FMW	1.4	1.2	1.3	2.9	2.7	2.9	4.1	3.8	3.7	5.9	5.4	5.4

Table 7.9c: Leaf Length (cm) of Spinach Vegetable in Week 1, 2, 3 And 4

Treat-ment	Week 1			Week 2			Week 3			Week 4		
MWW	12.3	12.0	12.1	13.5	13.0	13.3	14.7	14.3	14.5	15.1	14.2	14.7
HN	12.2	12.3	12.1	13.9	14.4	14.1	14.9	15.4	15.0	15.9	16.1	15.4
FMW	12.3	12.0	12.3	14.1	13.9	14.5	15.0	15.3	15.1	16.0	16.4	16.2

Table 7.10a: Total Fresh Weight (Kg) of Barley Fodder

Treatment	Tray 1	Tray 2	Tray 3
Molasses waste-water	10.5	11	11
commercial hydroponic nutrient	10.5	11	12
Fortified Molasses waste-water	11	12	13

Table 7.10b: Total Fresh Weight (Kg) of spinach vegetables

Treatment	Plant yield (Kg)		
Molasses waste-water	0.3	0.4	0.5
Commercial hydroponic nutrient	0.4	0.5	0.6
Fortified Molasses waste-water	0.5	0.5	0.7