STATUS, PHYSIOGNOMIES AND ECONOMIC VIABILITY OF HYDROPONIC LETTUCE PRODUCTION IN SELECTED AREAS OF NORTHERN TANZANIA AND CENTRAL UGANDA

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A Thesis Submitted in Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Life Sciences of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

There is an increasing interest and research in soilless farming due to its ability to enhance food production amidst challenges presented by urbanization. However, the adoption of this technology is still very limited in East Africa. This main objective of the research was to study the appropriateness of hydroponics as a feasible urban cropping system for improved vegetable production and accessibility in Uganda. An assessment on status of hydroponics in Northern Tanzania and Central Uganda was carried out using google questionnaires and face-face interviews which revealed limited uptake of the technology majorly due to the high initial costs required. An experiment was set up in central Uganda to evaluate the performance of red and green leafy lettuce produced using a non-greenhouse and non-circulating hydroponic system. Parameters assessed included; plant height, root length, number of leaves, leaf width, fresh weight and dry matter content. Data was analyzed using 2 sample T-test under origin software. A significant difference was noted at harvest for dry matter content (P=0.02, P=0.01), fresh weight (P=0.03, P=0.02) and root length (P=0.01, P=0.02) between red and green lettuce grown under soil and hydroponics in that order at $P < 0.05$. An economic analysis was done on the system to assess its profitability. Budgeting techniques results showed: Net present value (16.37$), Internal rate of return (12.57%), Profitability index (1.1) and non-discounted payback period (4,5) for annual crop production. Net present value was sensitive to changes in discount rate and unit price while revenue varied with a change in quantities sold and unit price. Regression analysis showed that a variation in the unit price of lettuce was stronger and negatively affected the quantity sold (R=0.91) than the influence the same independent variable on revenue earned (R=0.84). Based on the study results, hydroponics has the potential to act as a suitable alternative in vegetable production system and improve accessibility to vegetables across urban areas in a cost-effective manner. This will also assist in contributing to sustatinable develeopment goals; 3 (good health and wellbeing) and 11 (sustainable cities and communities). There is need to study the perfomance of other vegetables as well as various factors that can improve crop perfomance using the hydroponic system inorder to boost; crop yield, adoption of the system and hence vegetable accessibility and food security. Policy makers and governments should put more efforts in training farming communities about hydroponics.

DECLARATION

I, Margaret Ssentambi Gumisiriza do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this dissertation is my original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Margaret Ssentambi Gumisiriza Date

The above declaration is confirmed by:

Prof. Ernest R. Mbega Date

Prof. Patrick A. Ndakidemi Date

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by the Senate of the Nelson Mandela African Institution of Science and Technology a thesis titled "*Status, Physiognomies and Economic viability of hydroponic lettuce production in selected areas of Northern Tanzania and Central Uganda*" in Fulfilment of the Requirements for the Degree of Doctor of Philosophy in Life Sciences of the Nelson Mandela African Institution of Science and Technology.

Prof. Ernest R. Mbega Date

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DEDICATION

I dedicate this book to my children, Christon-Johnson, Christos-Miracle, Christabel-Jolly and Christelle-Favor. Thank you for being permissive and patient enough to allow me pursue my PhD studies.

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PPENDICIES

LIST OF ABBREVIATIONS AND SYMBOLS

Npv_h	NPV at higher rate
P_t	Expected net Cash Flow at end of time t
~	Approximately
<	Less than
=	Equals
>	Greater than
±	Plus or minus
∑	Summation
°C	Centigrade
Cm	Centimeters
CSA	Climate Smart Agriculture
DAAD	Deutscher Akademischer Austauschdienst
DAT	Days After Transplanting
Df	Discounting Factor
DMC	Dry matter content
DW	Dry weight
E.g	For example
E.t.c	Et cetera (and the rest)
EC	Electrical Conductivity
EAWAG	Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz
FAO	Food and Agriculture Organization
Fig	Figure
FW	Fresh weight
gm	Grams
GNP	Gross Net Product
HF	Hydroponic Farming
H-G	Hydroponic green lettuce
H-R	Hydroponic red lettuce
HPS	High-Pressure Sodium
IRR	Internal Rate of Return

Kgs	Kilograms
LDCs	Low Developed Countries
LED	Light Emitting Diodes
LW	Leaf width
m^2	Meters square
NDPBP	Non- Discounted Payback Period
NFT	Nutrient Film Technique
NL	Number of leaves
NM-AIST	Nelson Mandela African Institution of Science and Technology
NPK	Nitrogen Potassium Phosphorus
NPV	Net Present Value
OM	Organic matter
P	Probability
pH	Potential of Hydrogen
PH	Plant height
PhD	Degree of Philosophy
PI	Profitability Index
PPM	Parts per million
PVC	Polyvinyl Chloride
RL	Root length
RUFORUM	Regional Universities Forum for Capacity Building in Agriculture
SACCOS	Savings and Credit Cooperatives
SANDEC	Department of Water & Sanitation in Developing Countries
SDGs	Sustainable Development Goals
SE	Standard Error
S-G	Soil grown green lettuce
S-R	Soil grown red lettuce
SSA	Sub-Saharan Africa
UGX	Ugandan Shilling
UNCC	United Nations Compensation Commission
UNECA	United Nations Economic Commission for Africa
USA	United States of America
USD	United States Dollar
UV	Ultraviolet

VOCs	Volatile Organic Compounds
H	Higher discount rate Lower discount rate
Npv_1	Npv_l at lower rate
a	Last period with negative cumulative cash flow
b	Absolute value
c	Total cash inflow during the period following period a.
i	Discount Rate (or rate of return)
t	Project period in terms of seasons

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

Recently, agriculture has been recognized as a sector that requires practices that increase adaptation to climate change in Africa (UNCC-Secretariat, 2016). This is because the sector particularly farming, plays a significant role in improving income (employing 70% of human force) and food security in Sub-Saharan Africa (SSA) while contributing 25% to the Gross Domestic Product of majority of African countries (Lema & Majule, 2009; UNECA, 2009). However, it is predominantly practiced based on rainfall availability making it susceptible to adverse climatic conditions (Arndt *et al.,* 2012). Research has already revealed the likelihood of more pressure on water accessibility and demand in SSA due to climate change and variability (Hendrix & Salehyan, 2012). For example; in Tanzania, studies have already shown that climate change and variability is affecting 33% of the agriculture sector (Majule *et al.*, 2008; Ponsian *et al.*, 2016).

On the other hand, it is estimated that by 2050, there will be 70% or 6 billion people of the world's population living in urban areas and this is anticipated to escalate the demand for fresh produce around cities to ensure a healthy population (Silvia & Vettorato, 2021). The already increasing number of urban population alongside other factors such as; thrilling weather conditions is one of the factors causing an impact on food production around urban areas (Fernández-Cabanás *et al.,* 2020). The amount of land available for farming to each individual is anticipated to reduce by 2050 to 1/3 of the land that was available in 1970 (FAO, 2016). Unfortunately, this decline is projected to continue due to the effects of the increasing population coupled with the impacts from climate change and variability (Fedoroff, 2015).

Sub Saharan Africa currently has a population of roughly 900 million people which is projected to increase with 70% of the people living in urban and sub-urban centers in the Least Developed Countries (LDC's) (Walsh, 2009). With the high growing population, peoples' demand for farming land, water and food particularly is expected to increase (Ndalahwa, 2004; World Bank, 2017). The availability of vegetables explicitly has steadily been inadequate to meet the human commended consumption rates in general (Mason-D'Croz, 2019). Therefore, with the growing demand for food especially vegetables in the face of impacts from climate change alongside population pressure (Benke & Tomkins, 2017), there is need to investigate smart agriculture technologies that will boost crop production and food security in Africa. Soilless farming has the capability to increase per unit area food production using limited land, soil and water plus food security within the cities (Artmann *et al.*, 2021).

Hydroponic farming (HF) has been noted to be a sustainable technology which is disease-free and yields nutritious crops (Barman *et al.,* 2016). Despite its benefits, research into hydroponic farming (HF) and its adoption for vegetable cultivation within urban Africa more less East Africa is still limited. This is reflected by the limited number of farmers who are currently engaged in HF within East Africa (Gumisiriza *et al.,* 2022a). The extra difficulties and production costs connected with aeration and circulation of nutrient solution have hindered the implementation of hydroponics practices. "There is a need to identify simple, low-maintenance hydroponic systems that do not require power or complex equipment and are relatively low in cost" (Kratky, 1993).

This research study focused on assessing the performance as well as the profitability of producing vegetables using hydroponics in an urban setting in comparison with soil-based cultivation. This was aimed at improving vegetable production and availability around cities. Lettuce (*Lactuca Sativa* L.) was selected for this research study because it is one of the crops that grows well with the hydroponic farming system (Dodd & Dionysios, 2016). It is also a short season crop that requires low nutrients to grow. This makes it a profitable crop as it can be produced many times in a year using limited resources.

1.2 Statement of the Problem

Sub-Saharan Africa has been identified as one of the hotspots for food insecurity problem (Lal, 2020). This is as a result of decreasing arable land, climate change and water scarcity (Velazquez-Gonzalez *et al.,* 2022). The growing rates of population, urbanization in addition to poor urban planning in Sub-Saharan Africa (SSA) have put a threat on food security for the urban dwellers (Gumisiriza *et al.,* 2022b). The course of urbanization is likely to deter access to food for the susceptible human beings and this might result into hunger (Rezapour *et al.,* 2022; Robbiati *et al.,* 2022). This will further affect the adequate accessibility of each household to vegetables, a healthy and balanced nutrition and threatens food security in general.

Arusha is one the regions in the Tanzania where vegetable cultivation is heavily concentrated because of the presence of fertile soils which are fit for intensive cultivation and reliable rainfall. There has been an increased campaign for cultivation and consumption of nutrient-rich traditional African vegetables to boost nutrition through diet divergence in this region (Ochieng, 2017). These vegetables are known to be nutrient-rich with the potential to decrease levels of malnutrition (Mwadzingeni, 2021). On the other hand, in Uganda, vegetable production (nearly 250 000 ha) is majorly concentrated in the central region (which covers the country's' capital) because it harbors large market availability and diversity in vegetables. Unfortunately, the growing rate (4.7%) of urbanization in the country especially in this region which is estimated to increase to 30% by 2030 likewise continues to put vegetable production at risk thus threatening human accessibility to the vegetables as well. This is because it puts pressure on the existing arable land as well as increasing demand for the vegetables resulting from population increase (Lwasa *et al.*, 2013).

Therefore, there is need to identify technologies that have the potential to promote sustainable vegetable production amidst the increasing population, soil degradation, reduced soil fertility, urbanization and climate change related challenges in East Africa (Fadairo, 2020; Neiko *et al.*, 2023). Hydroponics as a soilless culture system has been extensively implemented as an urban modern farming production system because of it's potential to increase food production. Recently greenhouses have started expanding their crop production methods to include hydroponics which is majorly used for vegetable production (Du *et al.,* 2022., Koukounaras, 2021; Ahmed *et al.,* 2021).

1.3 Rationale of the Study

Small scale farmers who form the bigger percentage of urban farmers in Uganda and Tanzania rely heavily on soil based crop cultivation which is affected by human activities resulting from increased population (Barman *et al.,* 2016). This continues to affect accessibility to fresh vegetables in urban areas as earlier mentioned. Hydroponics is one of the farming technologies that can assist in addressing this challenge. This is because it is not dependent on availability of arable soil or space, uses less water, is less labour intensive, climate resilient and thus ensures consistency in vegetable production, accessibility and profitability to farmers (Murali *et al.,* 2011). However, the adoption of hydroponic farming in Tanzania and Uganda is still on a very low scale because of the high costs required to implement this system as well as limited awareness about the technology (Nelson & Bugbee, 2014) among other factors. This study thus aimed at refining the existing high-tech hydroponic systems through testing the effectiveness of an outdoor hydroponic system for vegetable production as a means to increase accessibility to vegetables in urban centers as well as promote awareness and adoption of the technology.

1.4 Research Objectives

1.4.1 Main Objective

To study the suitability of a low-tech hydroponic system as a viable cropping system for improved vegetable production and availability in urban areas of Tanzania and Uganda.

1.4.2 Specific Objectives

(i) To assess the status and perception of hydroponics in central Uganda and northern Tanzania.

(ii) To compare the physical characteristics of lettuce produced using hydroponics and soil under non-controlled environmental conditions.

(iii) To estimate the economic feasibility of producing lettuce under hydroponics under non-controlled environmental conditions.

1.5 Research Questions

(i) What are the social, economic and agricultural factors related to hydroponics in central Uganda and northern Tanzania?

(ii) What is the effect of hydroponic farming system on the yield of lettuce under a non-controlled environment?

(iii) What are the costs and benefits of producing vegetables using hydroponics without a greenhouse in an urban area?

1.6 Significance of the Study

Information regarding the practices and factors related to hydroponics in Uganda and Tanzania will assist the researchers, organizations, farmers, government bodies and communities to know which factors to consider when deciding on adopting or promoting the technology. These highlighted influential factors and benefits can generally be used to boost the adoption of the technology within urbanities and farming communties at large. The challenges faced in hydroponic farming were identified which will help farmers, researchers, scientists to identify solutions based on the suggested recommendations and improve on the adoption of the technology especially in East Africa.

The analysis on the profitability of growing lettuce using hydroponics outside a greenhouse will be essential in highlighting the financial costs and benefits related to the technology. This can assist farmers and stakeholders in appropriate planning and uptake of the technology. The study identified the physical characteristics of red and green lettuce cultivated using non-circulating hydroponic system in comparison to soil grown lettuce outside the green house. These parameters are crucial in informing the farmer about the expected growth and yield outcomes of hydroponic farming versus traditional farming which can be used as baseline to adopt the technology among farmers.

1.7 Delineation of the Study

The factors associated with vegetable hydroponic farming among urban farmers in central Uganda and in Northern Tanzania were identified and categorized.

An experiment was set up to compare the growth and yield of lettuce under hydroponic and the traditional farming system outside the green house as a means to increase vegetable production and accessibility. Lettuce was used as the study crop since it responds well under hydroponic conditions. Characteristics including; plant height, root length, lettuce fresh weight, number of leaves, leaf width and dry matter content were measured during growth and at harvest time. The economic costs and benefits related to hydroponic vegetable production outside the greenhouse were also computed. Few econometric tools were used to compute this analysis, that is, capital budgeting methods, sensitivity, scenario and regression analysis. The costs of production for hydroponics and soil based farming were also computed at the start of the experiment.

CHAPTER TWO

LITRETURE REVIEW

2.1 The History of Hydroponics

Hydroponic farming dates back to 1699 when scientist John Woodward started adopting water culture without using any concrete substance (Hewitt, 1966). Hershey recognized Woodward as the first individual-English Physician to practice water culture in 1699 (Hershey, 1991). After Woodward's discovery, other scientists namely Boussingault, De Saussure and Wilhem Knop carried out research and identified the nutrients that supported plant growth and Knop's hydroponic nutrient composition (Table 1) was the most famous and this has been used for a number of years worldwide under soil-less culture (Benton, 1982). Later on, a modified hydroponic nutrients composition (Table 2) necessary for plant growth was discovered during the mid-1900s' (Russell, 1953).

Table 1: Components of Knops' nutrient solution

Component	g/l
Potassium Nitrate (KNO_3)	0.2
Calcium Nitrate ($Ca(NO_3)_2$)	0.8
Potassium dihydrogen phosphate (KH_2PO_4)	0.2
Magnesium sulfate heptahydrate ($MgSO_4.7H_2O$)	0.2
Ferric Phosphate ($FePO_4$)	0.1

Lakkireddy *et al.* (2012)

Plant pathologist Fredrick Gericke from the University of California finally popularized the hydroponic system in the 1930s' (Gericke, 1937). He initially named this system aquiculture but later re-named it hydroponics because aquiculture mainly involved growing of aquatic plants. Hydroponics was first successfully practiced on the Wake Island in the 1930s with the growth of fresh vegetables since it was the only solution for vegetable production on the Island (Mugundhan, *et al.,* 2011). Later on in the 1960s and 70s, commercial hydroponic farms were established in different countries, that is: Italy, Denmark, Russia, Holland, German, Iran, United Arab Emirates, Japan, United States of America, Belgium after which many automated farms were established worldwide in the 1980s followed popularization of home-made systems in 1990s (Mamta & Shraddha, 2013).

Table 2: A modified list of elements of the current hydroponic solution

Macro elements		Microelements	
Element	**Researcher and year of discovery**	**Element**	**Researcher and year of discovery**
Nitrogen	Not known -1750	Boron	Sommer *et al.* year not known
Phosphorus	Liebig -1839	Chlorine	Broyer *et al*. (1954)
Potassium	Birner & Lucanus -1866	Copper	Sommer *et al.* (1931)
Calcium	Knop-1860	Iron	Gris (1843)
Magnesium	Not-known-1860	Manganese	Gabriel (1897)
Sulphur	Knop-1860	Molybdenum	Broyer *et al.* year not known
		Zinc	Sommer *et al.* (1927)

Russell (1953)

2.2 The Science of Hydroponics

Hydroponics also known as: "*Hydro culture*", "*Nutri-culture*", "*soil-less culture*", "*soil-less agriculture", "water culture" "tank farming" or "chemical culture*" (Lakkireddy *et al.,* 2012) is an agricultural science, which involves the cultivation of crops in a water-based solution rather than soil and this agri-system was substantiated by Jean Boussingault in 1860. The term "Hydro" generally refers to "water" while Ponics refers to "working (Rajkumar *et al.,* 2018). Hydroponics is a soilless culture cropping system which involves cultivating crops using water to deliver nutrients to the plant roots and it has been widely adopted as a modern urban crop production system (Du *et al.*, 2022; Yohannes, 2023). The water-based solution is composed of artificial chemical nutrients, which support crop growth (Steinberg *et al.,* 2000) and the crops can be cultivated with or without a medium which generally provides support to the plant (Jensen, 1999).

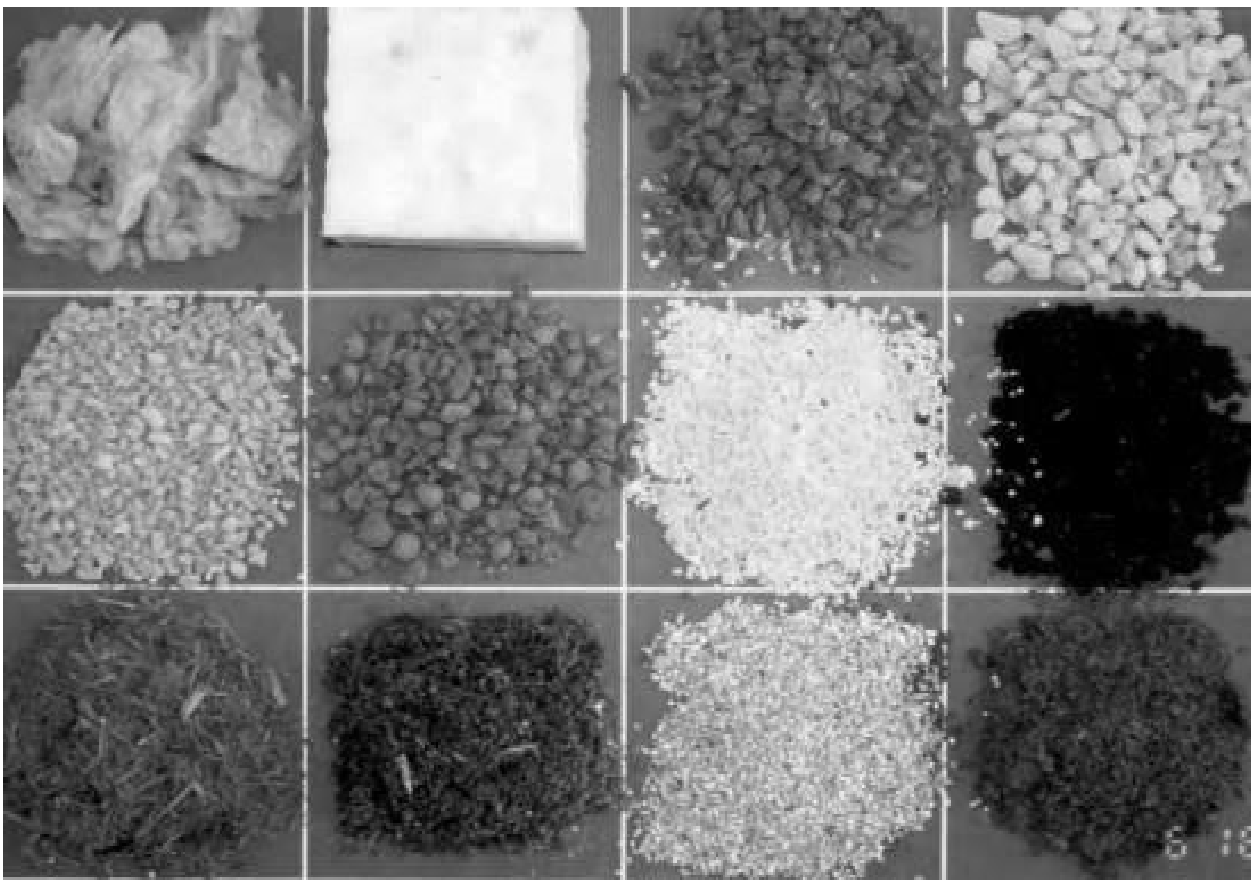

Figure 1: Substances used as growing media; Left to right and top to bottom: rock wool, polyurethane foam, expanded shale, volcanic material, open porous clay granulate, expanded clay, perlite, black peat, coarse wood fibre, fine wood fibre, vermiculite, and light peat (Food and Agriculture Organisation, 2013)

The medium (Fig. 1) used include organic substances such as; rock wool and inorganic materials such as; vermiculite, perlite, volcanic porous rock, expanded clay granules as well as synthetic materials (Lakkireddy *et al.,* 2012). In addition to the varieties of medium used, there are also factors and characteristics that should be considered while selecting the medium for crop production (Table 3).

Table 3: Factors to consider when selecting media for hydroponic crop production

Characteristics	Factors for consideration
Stable structure	Type of hydroponics adopted
Low volume weight	Access to information on properties of the medium
No pests and diseases	Cost of the medium
Right PH suitable for the crop	Re-usability

Food and Agriculture Organisation (2013)

Much as hydroponics was initially developed mainly to cater for the production of fresh produce in the non-arable areas of the world (Murali *et al.,* 2011), some congested cities such as; New York in the United States of America (USA) and Montreal in Canada, have advanced the technology to the extent that it can be easily performed on apartment rooftops. This is a form of hydroponics called "vertical hydroponic farming", that is; growth of crops on vertically inclined planes or on skyscrapers (Despommier, 2011). In Africa, hydroponic farming has been reported in South Africa for production of high-quality vegetables (Baumgartner & Belevi, 2001; Gruda, 2009). Hydroponics has been used to grow a number of plants as shown in Table 4.

Table 4: A Selection of plants that can be produced commercially using soil-less culture

Herbs	Fruits	Vegetables	Flowers	Fodder
Mint	Cantaloupes	Tomatoes	Roses	Sorghum
Parsley	Watermelon	Green pepper	Marigold	Alfalfa
Rosemary	Strawberries	Coriander	Carnations	Barley
Basil	Blue berries	Lettuce		Bermuda grass
Cilantro		Cabbage		Carpet grass
Thyme		Spinach		

Murali *et al.* (2011), and Sardare and Admane (2013)

2.3 Hydroponic Nutrients

The composition of hydroponic nutrients plays a crucial role in determining the electrical conductivity (EC) of the solution. The Potential of Hydrogen (pH) of the nutrient solutions is also a vital factor in hydroponic farming where the solution must contain ions that can be absorbed by the plants. A pH range of 5.5-6.5 is generally ideal for nutrient availability in these farming systems but this can keep fluctuating as the crop grows and different crops have different pH requirements (Alexopoulos *et al.,* 2021). With this agricultural technology, crops can be grown with or without the support of a medium (Fig. 1) that not only acts as a conduit for nutrients and water but also offers plant support (Gumisiriza *et al.,* 2020). Figure 2 summarizes the nutrients and media considered beneficial for effective hydroponic farming.

Primary nutrients	**Secondary nutrients**	**Non-organic medium**	**Organic medium**
☐ Nitrogen	☐ Iron	☐ Rock wool	☐ Sugar cane bagasse
☐ Phosphorus	☐ Manganese	☐ Vermiculite	☐ Rice hulls
☐ Potassium	☐ Boron	☐ Perlite	☐ Coco-coir
☐ Calcium	☐ Zinc	☐ Gravel	☐ Coffee husks
☐ Magnesium	☐ Copper	☐ Peat moss	☐
		☐ Clay granules	☐

Figure 2: Summary of nutrients and essential medium for hydroponic farming

2.4 Types of Hydroponic Farming

In general hydroponics is principally categorized into two groups which are closed and open systems. Under the open system the nutrient solutions are not recycled as with closed system where the nutrient solution is "recovered, replenished and recycled" (Jensen, 1997; Gumisiriza *et al.,* 2023). The same nutrient solution is re-circulated as nutrient levels are checked and adjusted consequently. The aim of nutrient recycling in hydroponics is to decrease wastage (Miller *et al.,* 2020). With open hydroponics, a new nutrient solution is delivered for each cropping cycle (AlShrouf, 2017). The hydroponic systems can further be classified as; passive (does not require use of pumps) or active (use pumps to supply the nutrient solutions from the solution tank to the plant roots), (Fig. 5) (Macwan *et al.,* 2020). The two common passive hydroponic methods (Fig. 4) are: Wick and kratky hydroponic methods and these mainly don't necessitate re-circulation of the nutrient solution as the solution is filled in the growing container prior to transplanting. This implies that the plant should be given the right amount of nutrients that support the plants' growth up to maturity stage. Passive hydroponic methods therefore support growth of mainly small plants which don't require a lot of nutrients and have a short maturity period.

2.4.1 Kratky Hydroponics

This is a passive hydroponic method where plants are suspended above a nutrient rich solution which is filled in a container at once prior to transplanting (Kratky, 2009). The plants are automatically watered since the entire media is automatically moistened by capillary action. The nutrient solution reduces as the plant grows thus creating an increasing aeration space (Fig. 3). The method is slightly similar to DWC method as they both dot require refilling of the nutrient solution during the growth cycle. The difference between the two methods is that with Kratky, the pots must be exposed to air at least 50% since it does not use air pumps. This hydroponic method was named after Bernard Kratky who invented it (Kratky, 1993). It favors mainly growth of lettuce and herbs which have a fast rate of growth because these small crops can be grown with one initial application of the nutrient solution for the entire cropping period (Kratky, 2005). The extra costs incurred in other hydroponic methods are eliminated as the Kratky does not necessitate the use of timers, air pumps or additional labour (Kratky, 2009).

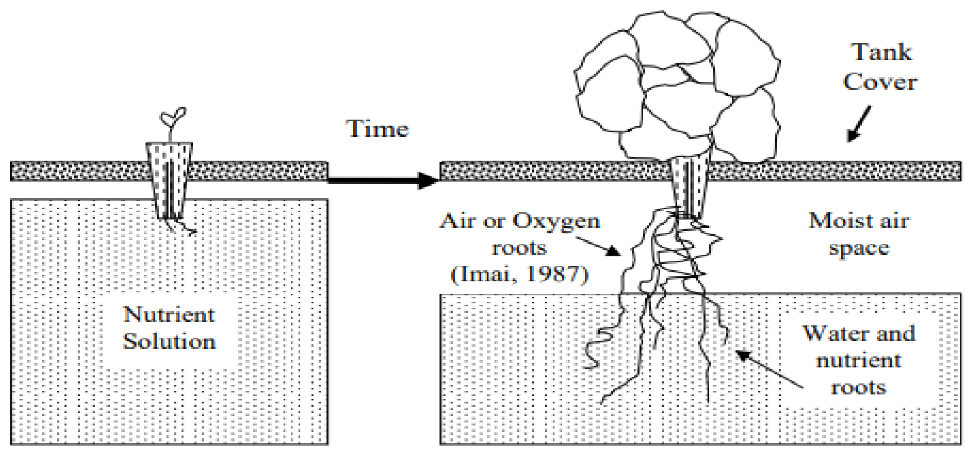

Figure 3: A model of a suspended pot using non-circulating hydroponic system (Kratky, 2009)

The roots that occupy the air space above the nutrient solution which are usually horizontal in nature are called air /oxygen roots whose function is aeration (Imai, 1987). Submerging these roots causes suffocation or plant damage. On the other hand, the longitudinal roots which extend into the nutrient solution are the nutrient roots responsible for supplying nutrient uptake. The Kratky hydroponic method does not also need refilling of nutrient solution or monitoring of EC and pH (Kratky, 1993). Death of the plant can occur resulting from increase of the nutrient solution after the plant is acclimatized to the moist air conditions in the grow container (Kratky, 1993). Under Kratky hydroponics, the lower 2cm or more are immersed in the solution and plant growth usually continues till the nutrient solution is lower than 10% of the initially filled solution. This is when the plant is harvested (Kratky, 2004). The growing vessels or tanks should often be cleaned between 3 cropping cycles. In a nut shell, Kratky hydroponics operates under four major principles (Kratky, 2004), which are:

(i) Air roots should have relatively highly moisture and exposed to air

(ii) Roots must not run out air.

(iii) Nutrient roots are responsible for nutrient and water uptake.

(iv) The nutrient solution level should not be increased but can remain the same or be decreased.

2.4.2 Wick System

This is a passive hydroponic system which uses a string or a wick to draw the required nutrients from the container into the growing medium through capillary action. The wick can be of cotton or nylon material to enable nutrient absorption and delivery to the plant. This is the simplest hydroponics methods as it does not necessitate the use of electricity, aerators or timers (Sharma *et al.,* 2018). Much as it is the simplest and inexpensive system, it is more suitable for small plants such as: Vegetables, spices and herbs since the wicks do not offer quick supply of the nutrients (Keith, 2003).

2.4.3 Ebb and Flow (Flood and Drain)

This is a system which works by flooding the plant tray which has the grow media with the nutrient solution using a pump connected to the solution pool at given time intervals with the use of a timer (Sharma *et al.,* 2018). The solution streams through and fills the grow tray to a level of about 5-10 cm from the base where it remains ebb in the media for a certain period of time (Suhardiyanto *et al.,* 2001). The un absorbed nutrient solution is then drained back to the tank. However, the use of timed nutrient refilling to the plant try often causes in efficient intake of the nutrient solution by the plants (Daud *et al.,* 2018). This method of hydroponics basically works on the principle of flood and drain as the name suggests. During the non- nutrient flow period, the plant roots absorb oxygen.

2.4.4 Nutrient Film Technique (NFT)

With this technique developed by Allen Cooper in the 1960s a set of channels/tubes is set at varying angles to grow plants in a thin stream of nutrient solution which is circulated from the tank to the tubes and later drained back to the tank (Gumisiriza *et al*., 2020). The plant roots are immersed in the tubes where they constantly supplied with water rich in dissolved nutrients required for plant growth without a timer (Wilcox, 1982). The system also favors growth of mainly small plants which take a short time to mature. Under NFT, the nutrient solution is reused and the nutrient flow is supported by forces of gravity. It has an advantage of the exposing the plant roots to sufficient supplies of nutrients, oxygen and water and doesn’t require a timer (Omics, 2017). None the less, it is tough to monitor the pH of the nutrient solution in this hydroponic system as it considered difficult (Suhardiyanto *et al.,* 2001).

2.4.5 Deep Water Culture (Direct Water Culture)

This is a non-circulating hydroponic system where the plants are put in net cups and roots are suspended directly in a highly oxygenated nutrient solution. The air is supplied to the solution using an air stone and plants are able to survive because of addition of dissolved energy (Sandlers, 2016). It is easy to construct and operate (Railey, 2018). One of the most used equipment for this system is the dutch buckets.

2.4.6 Drip Hydroponic System

With the drip hydroponic system, the plant nutrients are delivered to the plant roots using small emitters which drain the nutrient solution using water pump at timed intervals (Macwan *et al.,* 2020). The plants are supported by porous media such as; vermiculite, coco-coir, which can maintain slow dripping of the nutrient solution to the roots (Sharma *et al.,* 2018). The nutrients are provided to each plant using in the suitable amounts. The system is widely used to grow fruiting vegetables such as; tomatoes, sweet pepper and cucumbers.

2.4.7 Aeroponics System

This method doesn't require any growing medium for crop production (Runia, 1995). The nutrients are supplied to the plant roots suspended in air in form of mist. The plant roots are positioned in a setting where they are occasionally or endlessly supplied with a mist of the nutrient solution (Schwarz, 1995). The system uses a pump that is timed. The timer ensures that after every few minutes, mist is released. The disadvantage with this system is that any interference with the pump can lead to drying of the plant roots (Murali *et al.,* 2011).

Aeroponics coincides as a hydroponic method as it depends on a nutrient rich solution to feed the plants. However, the two differ in the means in which the nutrients are delivered to the roots. Aeroponics uses a mist while hydroponics uses a growing media to deliver the nutrients to the roots (AlShrouf, 2017). Figure 4, 5 and 6 illustrate the different hydroponic classifications and methods while Table 5 summarizes the methods of hydroponics, their benefits and disadvantages.

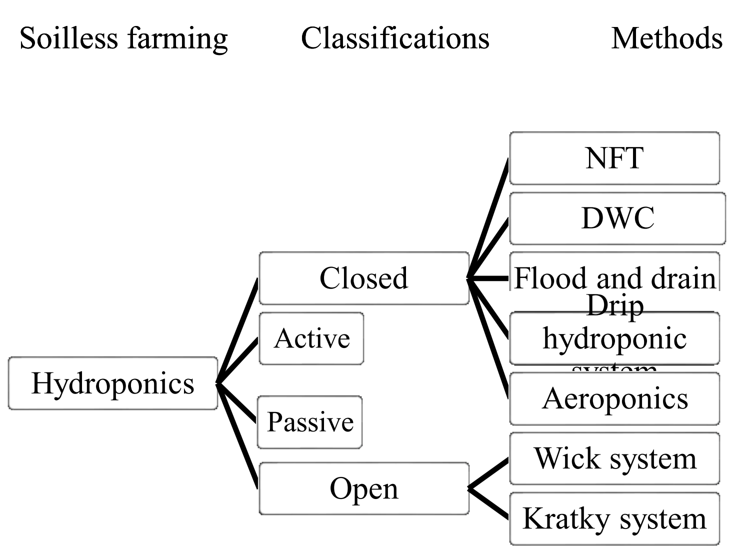

Figure 4: Classification of hydroponics

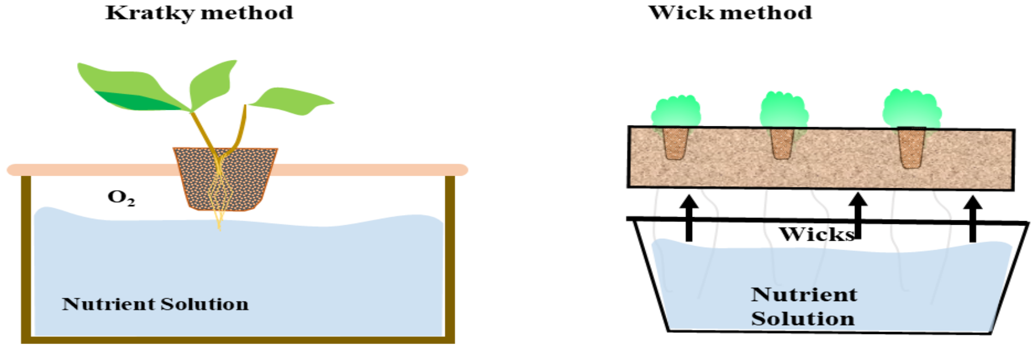

Figure 5: Methods of hydroponics under passive systems

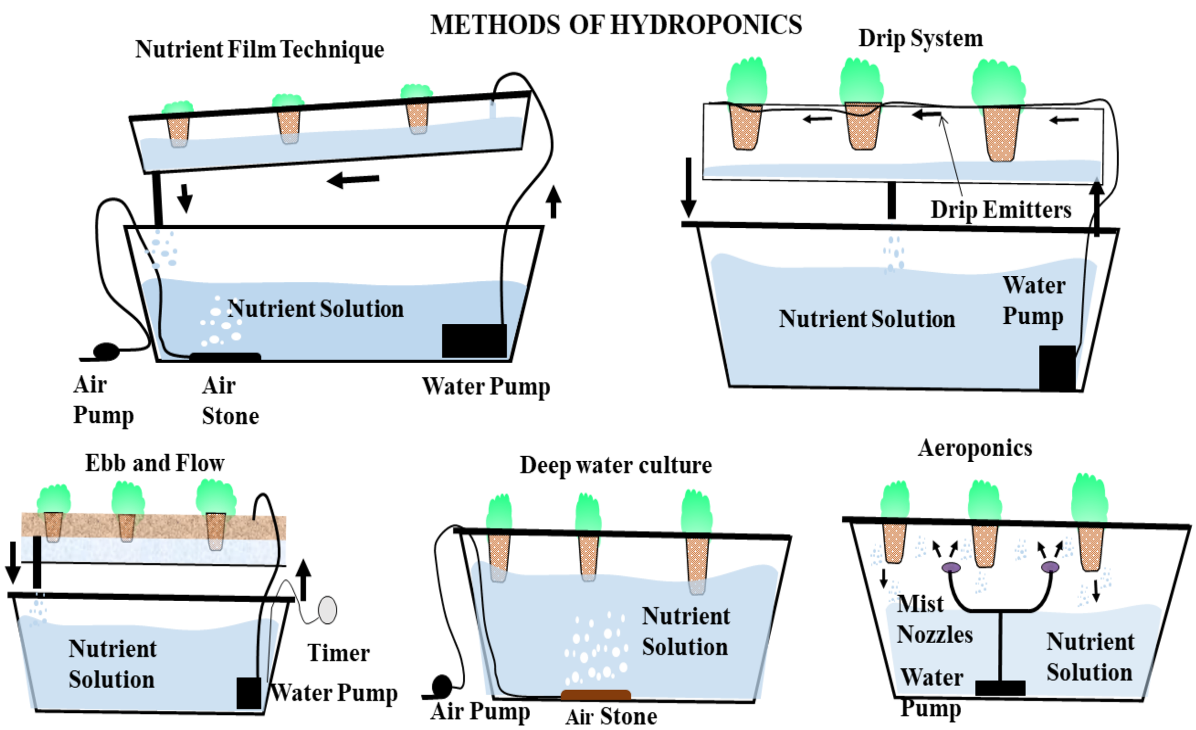

Figure 6: Methods of hydroponics under active systems

Table 5: Methods, benefits and disadvantages of hydroponic farming

	System	Technique	Mode of flow	Benefits		References
Low technology and cost	Wick system	Passive	Non-circulating system	Simple to build. It is cheap.	Favors small plants with low nutrient necessities. No recirculation of nutrients. Susceptible to algae.	Nisha (2019)
	Deep Water Culture (Direct Water Culture)	Active	Non-circulating system	Easy to build and operate. Presence of enough dissolved energy. It is cheap.	Roots are prone to rotting if not cleaned often. Requires solution refilling. Slow rate of growth.	Nisha (2019)
	Ebb and Flow (Flood and Drain)	Active	Circulating system	Low maintenance costs.	Susceptible to algae Malfunctions can lead to crop failure. Prone to blockage.	Seungjun and Jiyoung (2015)
	Nutrient film technique (NFT)		Circulating system	Plant roots receive enough nutrients, water, and oxygen. No need for a timer.	Malfunctions can lead to crop failure. Prone to blockage.	Domingues *et al.* (2012), Mamta and Shraddha (2013), Omics (2017), and Wilcox (1982)
High technology and cost	Aeroponics	Active	Circulating system	Does not require any growing medium. Ensures adequate nutrient absorption.	Pump interference can lead to root drying. High and expensive technology. Consumes time. Malfunctions can lead to crop failure.	Mazhar (2020)

2.5 Light Sources under Hydroponic Farming

2.5.1 Hydroponic Farming using Light Emitting Diodes

Light Emitting Diodes (LED) lights were first identified as a source of light for indoor agriculture (Robert, 2008) that is practiced under controlled environments (Yano & Fujiwara, 2012) in 1980s. They were invented by Engineer Henry Joseph Round in 1907 (González, 2012). A LED is a semi-conductor source of light which has capability of converting electricity to light when an electric current (electrons) is applied (Shaw *et al.*, 2004). Studies have revealed that LED lights offer a high source of visible radiation (Bula *et al.,* 1991) for cultivating agronomic and horticulture crops indoors especially with the use of white, blue or red-blue LED lights (Duong *et al.,* 2002; Kurilcik *et al.,* 2008; Yanagi & Okamoto, 1997). Red and blue light play a key role during plant development, photosynthesis and physiology (Kopsell & Sams, 2013; Olle & Virsile, 2013). For example, the quality of blue light can be used to control plant shape, height and influence photosynthesis (Cope & Bugbee, 2013). The LED systems have been reported to have minimal red radiation, which affects flowering time for short day crop species (Craig & Runkle, 2013). Results from a study by Sabzalian *et al.* (2014) indicated that plants grown under LED lighting exhibited better flowering and productivity than those grown in a greenhouse.

They further highlighted that blue and red wavelengths play a role in controlling the closure and opening of the stomata, which affects the height, and size of the plant as also indicated by Folta, Deng and Maruhnich (2007). An experimental study carried out by Tehrani *et al.* (2016) further revealed that 2 hours of red light resulted into maximum germination (83%) as compared to 8 hours of blue light (59%). None the less, blue light further plays a role in stimulating; Vitamin C; polyphenol and carotenoid components (JohnKhan *et al.,* 2010; Lefsrud *et al.,* 2008). On the contrary, green LED light has the potential to drive photosynthesis (Folta *et al.,* 2007; Kang *et al.,* 2013). These lights have benefits of; having a long-life span; providing ideal light spectrum for growth of crops/plants (Murali *et al.,* 2011); producing limited heating compared to high- intensity light sources (Bula *et al.,* 1991); and producing quality yield among vegetables (Demers *et al.*, 1998; Hao & Papadopoulos, 1999). Nevertheless, they have a drawback of being costly compared to other lightening systems such as; High-Pressure Sodium (HPS) (Nelson & Bugbee, 2014).

However, Scientist, Robert (2008) highlighted LED lights as having the potential of being cost-effective in the long-run due to their long-life span as compared to other horticultural lamps. Likewise, according to Haitz law, LED light costs have dropped by a factor of 10 each decade as their performance keeps doubling (Steigerwald *et al.*, 2002).

2.5.2 Hydroponic Farming using Solar Energy

This hydroponic farming system can take place either indoors or under a greenhouse. Indoor farms are further divided into; store front glasshouses (double skin building) and leveled indoor farms (Kathrin *et al.*, 2013) which majorly favor shade-tolerant plants. These indoor growth systems use the natural energy from the sun instead of LED lights for food production and are thus more eco-friendly and energy-efficient. This necessitates access to a window in order to access solar energy (Brooke, 2016). High-pressure vapor sodium (HPS) lamps are also used as a lighting source in greenhouse production and offer a suitable light spectrum required for photosynthesis (Christina, 2011). Greenhouse hydroponics is categorized under urban agriculture because it assimilates environmental and urban economics especially in the growth of horticultural crops (Mougeot, 2008; Pearson *et al.,* 2010). Farmers can also cultivate high-quality vegetables (Gruda, 2009) and flowers with solar powered hydroponics.

2.6 Comparison between Soil-Less Culture and Soil-Culture

Hydroponics, when compared to soil culture systems has been considered superior in terms of plant nutritional balance in its composition and other attributes (Table 6).

Table 6: Differences between soilless and soil culture farming systems

Soil-less culture (Hydroponics)	Soil culture (Conventional farming system)
Fertilizer formulations contain balanced nutrient composition.	The nutrient composition may be unbalanced unless laboratory analysis is done.
Availability of nutrients all the time	Requires nutrient supply to the crop
Automatic irrigation of plants	Requires consistent crop irrigation
Produces high and consistent yields	Yields vary with environmental conditions
Requires no soil	Requires good disease-free top soil with good drainage
Eliminates soil-borne diseases	Soil diseases can develop in the soil
Produce is non-organic since artificial nutrients are used under soilless conditions	Use of organic fertilizers such as manure can result in production of organic crops
Farming can take place in areas without soil for instance; snow covered areas	Requires good soils to produce good yields
There is full control of the root system since it can be seen	Root system can't be controlled since its hidden underground
It can have automatic fertilizing of crops/plants with the use of a timer	Crops are fertilized manually
Requires no wedding	Necessitates weeding

Murali *et al.* (2011)

2.7 Advantages and Disadvantages of Hydroponics

Hydroponic farming has a number of benefits over traditional farming (Szekely & Jijakli, 2022). It is more efficient in water utilization and favors the production of high and consistent yields in soil-less areas (Gruda, 2009). This farming system is also less labor-intensive as it requires no weeding and land preparation like most conventional farming practices (Pignata *et al.,* 2017). According to several researchers, hydroponic systems may also be used to improve vegetables and fruits both in terms of nutrition, quality, and shelf life according to the market and consumer needs (Amalfitano *et al.*, 2017; Buchanan & Omaye, 2013; Islam *et al.,* 2018; Selma *et al.,* 2012; Sgherri *et al.,* 2010). There is reduced use of pesticides and fungicides since the system often occurs under a climate-controlled environment (Benke & Tomkins, 2017). This farming technology favors efficiency in nutrient and water utilization thus reducing on their wastage (Gonnella & Renna, 2021; Martina, 2023). Hydroponic farmers are not affected by climate change conditions since they have control over climatic conditions such as; humidity, temperature, light among others under greenhouse conditions. (James *et al.,* 2000; Velazquez-Gonzalez., 2022) .This enables them to have all year round food production thus increasing their profit margin (Max, 2017).

Since it is a soil-less farming system, there are no soil-borne diseases and pests under this technology (Mamta & Shraddha, 2013). Studies have shown that hydroponic farming system has the potential of removing atmospheric carbon dioxide (Park *et al.,* 2010).

This air which is produced through human respiration and Volatile organic compounds (VOCs) heavily contaminates indoor surroundings (Aydogan & Montoya, 2011; Kim *et al.,* 2008; Oh *et al.,* 2011). Despite the mentioned benefits, the technology also has some drawbacks. It requires adequate technical knowledge and high investment costs (Gumisiriza *et al.,* 2022a). Hydroponic systems can also be prone to pathogens and fungal infections (Constantino *et al.*, 2013; Li *et al.,* 2014; Song *et al.*, 2004). The current food insecurity challenges caused by climate change impacts on agriculture which are predicted to worsen, coupled with inadequate access to healthy foods, reduced arable land caused by the increasing population call for strategic research and studies that could help fast track the adoption of hydroponic farming systems in African countries (Alkon & Norgaard, 2009; Challinor *et al*., 2014; Cohen, 2003; Gerland *et al.*, 2014; Valera *et al.*, 2009).

2.8 Lettuce as a Vegetable Crop

Lettuce is a leafy vegetable that falls in the family of *Asteraceae* and is globally recognized as the most important leafy vegetable. There a variety of lettuce cultivars which include; black seeded Simpson, butter crunch Batavia, ice berg, leaf lettuce among others (Sapkota *et al.,* 2019). This green vegetable which is an annual as well as self-pollinating crop is germinated by seed and survives best in temperatures varying from 7 to 24°C (Hassan, 2021; Sublett *et al.,* 2018). It is grown extensively across various continents especially in sub-tropical and temperate regions.

The global scale production of lettuce stands at 22 million tons with China being the chief producer and Africa producing roughly 270.6 metric tons as of 2005 (Mou, 2008). China produces four times as much as the United States and contributes to roughly half of the world's lettuce (Han, 2021). In most countries, the vegetable is produced as a commercial and home garden crop (Křístková, 2008) which makes it suitable for urban farming in terms of income generation and home consumption purposes. Lettuce is a crop with a taproot system and horizontal swallow lateral roots, used for nutrient and water uptake. It comes in a number of colors and texture. The vegetable is mainly consumed by leaves either in fresh (as salad) or cooked form and rich with minerals, fiber and vitamin C (Mulabagal*, et al*., 2010). It is also consumed widely because of its nice aroma, crispness and high phytonutrients (Xylia, 2021). Lettuce is one of the vegetables which gives high yield when cultivated under hydroponic systems (Qadeer, 2020).

Figure 7 shows the conceptual framework with the different variables that were considered for the socio-economics study. The socio-economic study focused on identifying the various attributes that are linked with hydroponic farmers in Arusha, Tanzania and Wakiso Uganda.

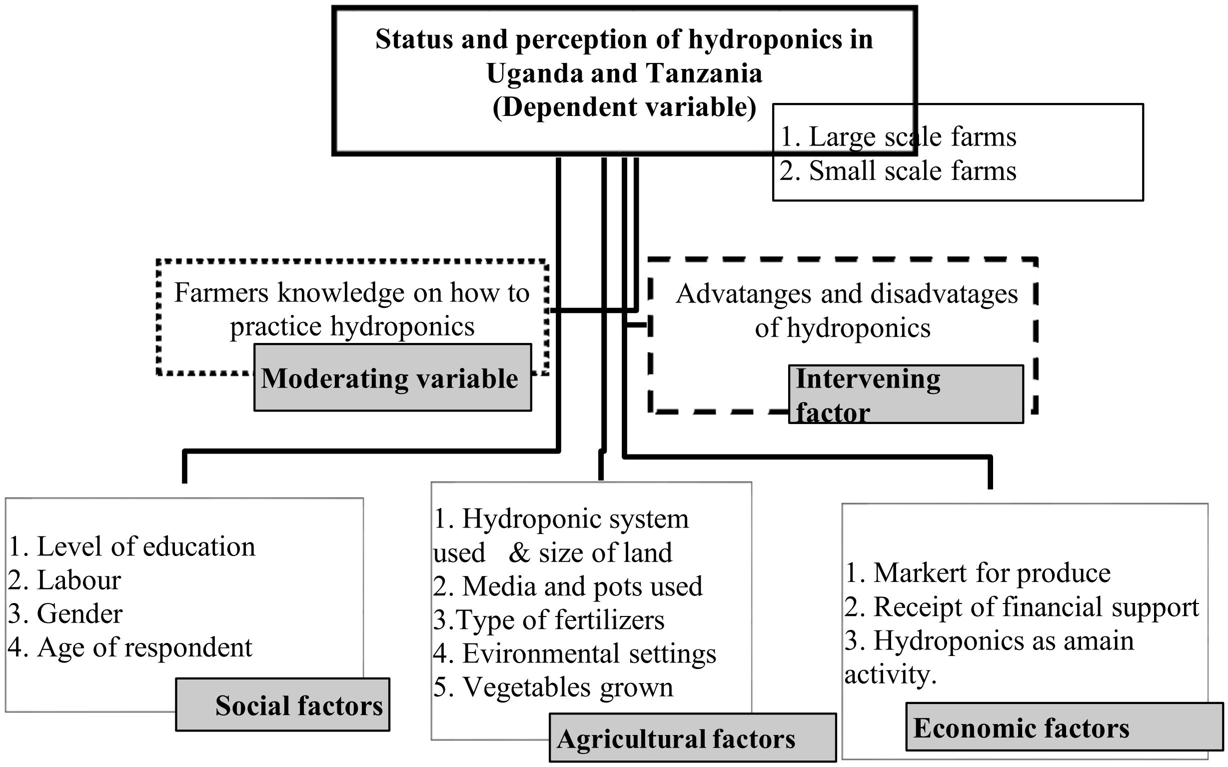

Figure 7: Conceptual framework illustrating the relationship between the study variables

CHAPTER THREE

MATERIALS AND METHODS

3.1 Status and Perception of Hydroponics in Central Uganda and Northern Tanzania

3.1.1 Study Area

This socio-economic research study was carried out in Northern Tanzania and Central Uganda during the period of March 2020 to July, 2021. This included; phases of identification and visits to a few hydroponic farms; searching and identification of different hydroponic farmers. This was done through both through direct communication with various farmers; agricultural research organizations and use of internet; questionnaire development and pre-testing among other activities. This was due to the fact that this is a practice that is not heavily adopted in the study countries and some site visits to the hydroponic farms needed prior appointment.

The areas considered for the study in Tanzania were Arusha and Meru while in Uganda, areas considered were Kampala and Wakiso. Tanzania in general covers an area of 947 300 km^2 with an estimated population of 58 388 032. The country experiences tropical kind of climate with the highest temperatures (25–31°C) between November to February while the coldest temperatures are between July-August (15–20°C). Because of the fertile sandy loam soils with good drainage, agriculture is the main source of income with horticulture being the main activity (Ngowi *et al..,* 2007; Weinberger & Swai, 2006). The main vegetables cultivated include: Leafy vegetables for example; lettuce, mchicha, Chinese cabbage, spinach etc... and non-leafy vegetables like; tomatoes, carrots and onions

Uganda on the other hand covers an area of approximately (~) 241,038 square kilometers and has a total population of about 44 million people. Roughly 3.6 million of these people live in the country's capital, Kampala as of 2022 showing a 5.2 % increase in population from 2021. This city covers an estimated area of 172 kms^2. The country experiences tropical kind of climate with the dry seasons being experienced between June-September and December to February while the rainy seasons are March to mid-May and September to December.

Wakiso district and Kampala which is engulfed within Wakiso both located in the central region of the country were selected because of the number of hydroponic farmers.

This is the second urban district in Uganda (Mugisa *et al.,* 2017). Central Uganda was selected purposely following a research study which revealed a low adoption of hydroponic farming in the country as well as the presence of a large number of hydroponics farmers compared to other areas. Northern Tanzania was selected because it is s vegetable growing hot spot in Tanzania and also has a couple of automated hydroponic firms. Figure 7 shows the study countries as well as study sites.

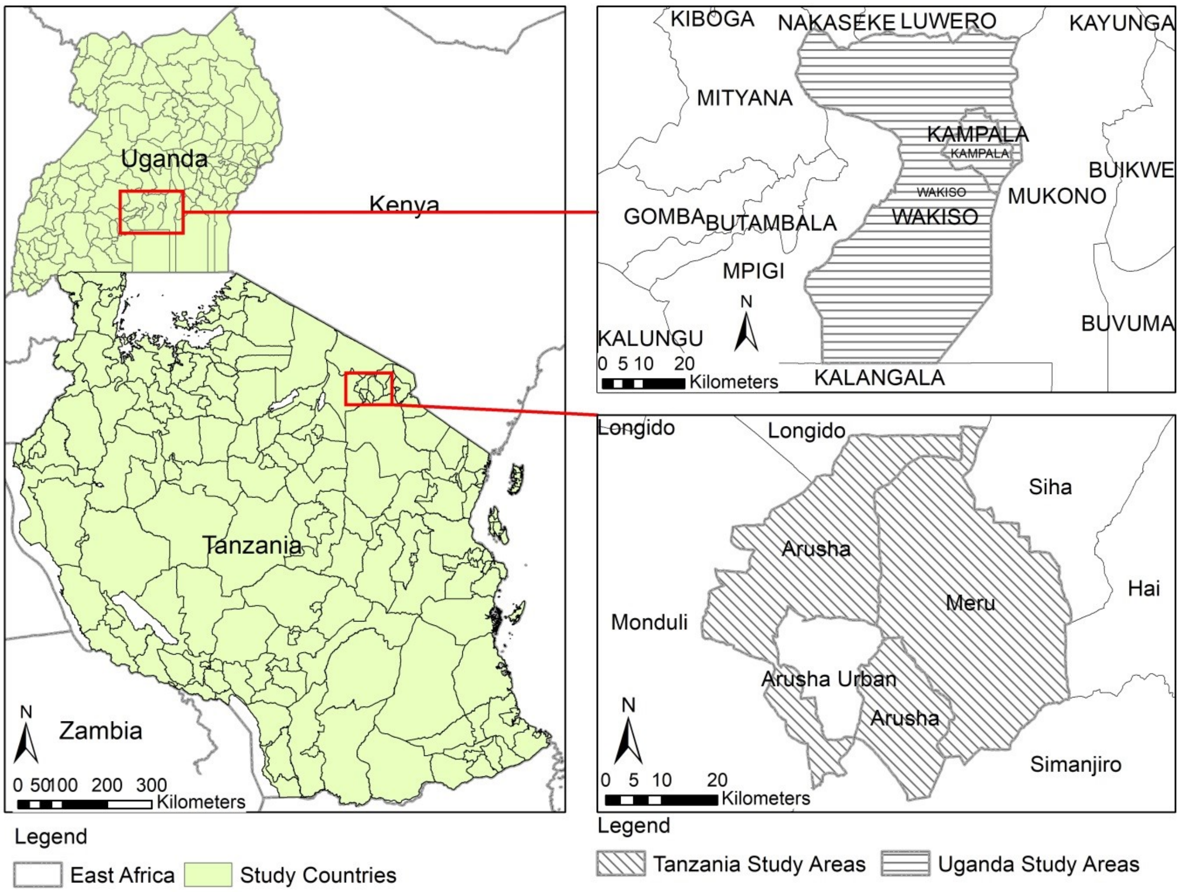

Figure 7: Map of East Africa showing study countries and study sites (ArcGIS)

3.1.2 Sampling Technique

Approximately 150 individuals who engage in vegetable farming around the study areas were identified using snowball sampling (Mariano *et al.,* 2012). These were identified through farmer groups and recommendations from urban farmers and agricultural bodies. However, only 51 participants who practice vegetable production soilless farming technology majorly hydroponics around urban and peri-urban areas took part in the study. These participants included farm owners of the hydroponic vegetable farms that as well as managers of firms that produce vegetables using hydroponics for either seed production or vegetables for sale.

3.1.3 Data Collection and Analysis

(i) Data Collection

A pre-tested semi-structured questionnaire using both closed and open-ended questions was used to capture information related to status and perception of hydroponics in terms of hydroponic practices, factors surrounding them, advantages and disadvantages and recommendations. Socio-economic factors included: age, gender, education level, labor used at the farm, whether the farmer received financial support to implement the technology or not, market for the hydroponic produce and if hydroponics is the main economic activity engaged in by the farmer.

The agricultural factors captured included: vegetables grown, type of hydroponic system used, medium used, size of land used, planters used to grow the crops, kind of fertilizer used, and the environmental setting used to grow the hydroponic crops. Furthermore, it also included questions to capture information on benefits and challenges of using soilless farming as well as the recommendations that can be put in place to enhance the adoption of the technology. The questionnaire was designed and administered using on-line google forms, site visits and face-face interviews with key informants such as; hydroponic farmers, managers of companies that were engaging in seed production using soilless farming during farm visits.

(ii) Data Analysis

Descriptive statistics was used at the data analysis stage where factors about the status of hydroponic farmers in Uganda and Tanzania were summarized into data sets. This data was recorded into frequencies using the Statistical Package for Social Sciences (SPSS) version 26.0 and presented using tables and graphs.

3.2 Physiognomic Performance of Lettuce under Open Field Hydroponic Conditions

3.2.1 Experimental Set-Up

(i) Experimental Set-Up for Hydroponic System

The experiment was set up between June and August at Kyakuwa farm located in Wakiso district in Uganda, just next to the capital city. A simple hydroponic unit for growing 60 heads of lettuce in a space of $6m^2$ under open field conditions was designed (Fig. 10). A 3-layered vertical wooden rack (600 cm in length) with a spacing of 60 cm between levels and total height of 300 cm from the bottom to top was constructed. An Ultraviolet (UV) plastic polythene roof to provide shade from direct sunlight and rainfall (control rain water from mixing with the nutrient solution) was built on top of the rack at 120 cm above the last level on top. A 600 cm (20 feet) Poly vinyl chloride (PVC) pipe in length and diameter of 10 cm was assembled on each level of the rack. The PVC pipe had 20 holes (30 cm apart) drilled on it where the cups with lettuce were to be fitted.

The hydroponic rack also had blue and yellow insect trap-cards hanging from the UV-plastic rooftop for combating pests such as; leaf miner and white flies which suck liquids from leafy vegetables. Polyfeed (19:19:19) crystalline water soluble fertilizer was thoroughly mixed with 90 liters of water (10 grams/litre) in a small tank. The nutrient solution was then filled in the PVC pipes with 30 liters per pipe to a diameter level of approximately 7 cm prior to transplanting. Evaporation was put into control through using plastic cups that were fully fitted in the PVC hole. There was no refilling of the nutrients or water during the growth period.

3-week old lettuce seedlings were placed into small white disposable cups (with diameter of ~5cm) with holes drilled around them to allow nutrient uptake through the roots. The seedlings in the cup were supported by saw dust mixed with small gravel stones. This mixture was made in a 1:1 ratio to balance the water retention and drainage. The cups with plants were then fitted onto the PVC pipe holes. An aeration space (about 3 cm) was left between the upper level of the nutrient solution in the PVC pipe and the bottom part of the net cup to further improve development of air roots and oxygen supply (Fig. 9).

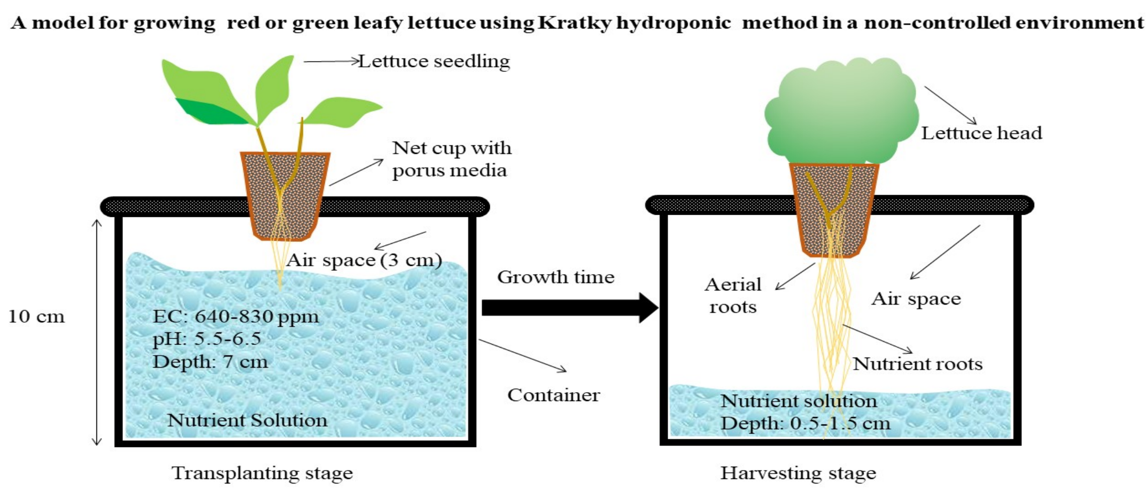

Figure 8: A model for growing leafy lettuce using Kratky hydroponics method under open field conditions

Red and green loose leaf lettuce were selected for the study as lettuce is a short season crop, easy to grow, has low nutrient requirements and responds well with hydroponics and is one of most grown hydroponic vegetables in Uganda (Gumisiriza *et al.,* 2022b). The lettuce heads were assigned to the PVC pipes using a completely randomized design.

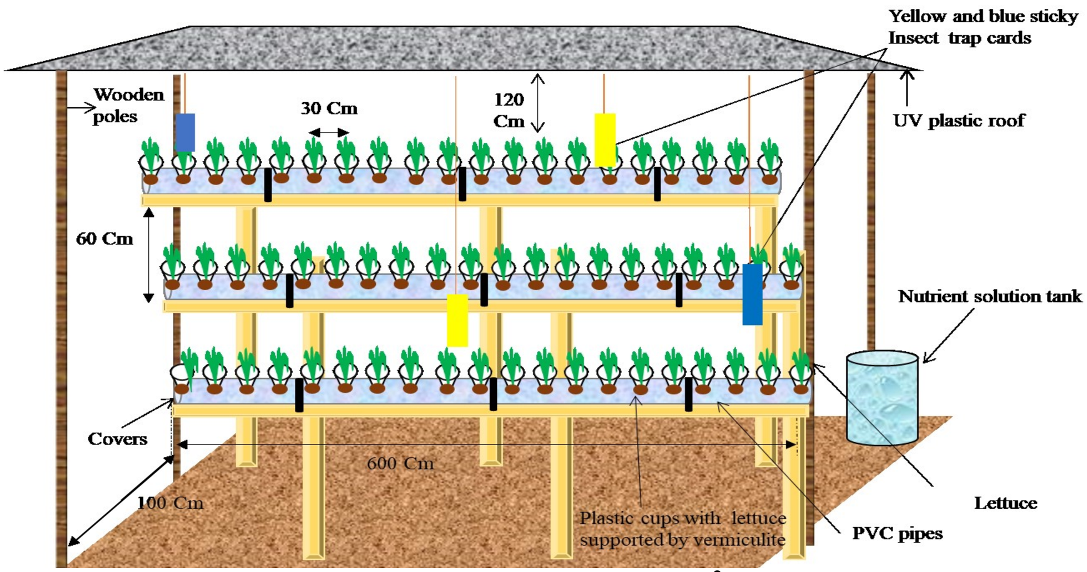

Figure 9: An image illustrating the design of a 6 m^2 vertical hydroponic unit for lettuce cultivation outside the greenhouse using Kratky hydroponics method

A Total Dissolved Solutions (TDS) meter reader was used to measure and monitor the potential of hydrogen (pH) and Electrical Conductivity (EC) in the nutrient solution. The EC gives an insight into the amount of nutrients available in the solution (Miller, 2020), while pH is an indicator of the acidity or alkalinity in the solution which determines nutrient uptake. A high EC prevents appropriate nutrient uptake by the plant while a low EC can affect the wellbeing of the plant and hence the yield. A pH control kit is used to assist with regulating the pH levels of the nutrient solution in cases of varying levels of acidity and alkalinity.

Crop production was carried out for one cycle based on research studies which show that hydroponics is not a farming system that does not rely on rainfall seasons or climate. Being a non-greenhouse experiment, few measures were put in place to contain the severe effects of the harsh weather conditions as earlier mentioned. Further still, the period of the study (dry season) was selected centered on the assumption that, being a non-greenhouse crop production system, dry weather conditions would have a much more negative impact on the crops in terms of yield than wet weather conditions as it is with open-field soil-culture crop production.

(ii) Experimental Set-Up for the Traditional Farming System

A control experiment was set up where lettuce was grown using soil as a media. The ordinary urban conventional crop production method was considered to lay firm ground for the adoption of the technology as the greenhouse hydroponic crop production is still very limited and considered expensive within the study areas. The comparison with soil based faming system was selected on the basis of the enormous studies focusing on comparison of various aspects in greenhouse hydroponic cop production as compared to traditional farming.

Loam soil mixed with chicken manure (ratio of 2.5:0.5) was used for the experiment. Chicken manure is the most commonly used organic fertilizer based on its high nitrogen content alongside other nutrients with NPK rations ranging from (3-2.5-1.5) (Ghanbarian *et al*., 2008). Chicken manure is also readily available and highly supports vegetable cultivation because of its nutrient composition. The NPK content per kg of the mixture was 6:5:6 and organic matter content of 5%. In order to measure the pH and EC of the soil, a sample of sterilized soil to be used for the experiment was taken and placed in a small container and thoroughly mixed with demineralized water in a ratio of 1:1 and left to stay for 24 hours. The mixture was continuously stirred to ensure that the particles dissolve thoroughly in the water. The solution was sieved after wards using a white cloth filter to take out the soil particles. A TDS meter was dipped in the solution to measure the EC, pH and temperature of the soil. The soil was later filled in black potting bags (3kg / bag) to prepare for transplanting.

Four-week-old seedlings for green and red lettuce with average plant height of 5cm and average number of leaves of 3 were transplanted in the bags. The black potting bags were laid on a horizontal wooden rack in a space of 16m^2 with a spacing of 30 cm between rows and 60 cm between columns. Each column and row had 4 and 15 potting bags correspondingly. Rain water was used for watering the vegetables during the experiment. Each lettuce plant was watered with 0.1 liters (liters) of water, thrice a week (after every two days) consuming a total of 6 liters/per day and 18 liters/week for all 60 plants. Insect trap cards were used to control pests. Figure 11 shows the procedure of the control experiment for lettuce cultivation under soil conditions.

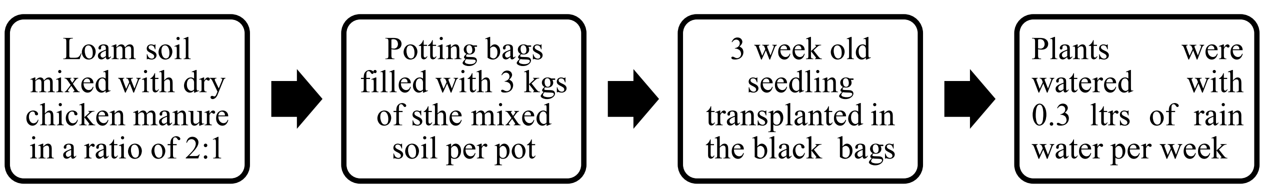

Figure 10: Procedure for lettuce production using soil

Each experiment was replicated 3 times with a total of 60 lettuce heads per system (30 lettuce heads per variety). Both experiments were set up in the same home stead outside the green house. The lettuce seedlings used in both control and test experiment were germinated from seed in plastic black grow trays using vermiculite media for 20 days before transplanting.

3.2.2 Data Collection and Analysis

Data was collected at 20 and 40 days after transplanting (DAT). The parameters that were studied were: above ground fresh weight (FW), number of leaves (NL), plant height (PH), leaf width (LW), root length (RL) and dry matter content (DM) of both lettuce varieties across the two farming systems (Plate 1).

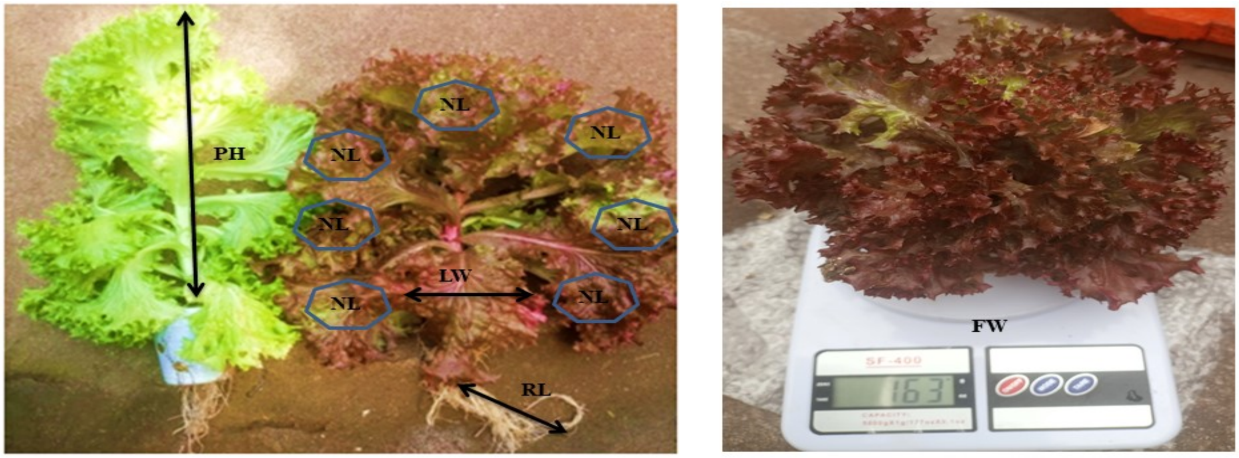

Plate 1: Illustration of plant physical characteristics measured during the study

Six lettuce heads per lettuce variety in both hydroponics and the conventional system were selected at growth and yield in order to measure the parameters. Number of leaves per head was counted manually. The plant height, leaf width and root length were measured using a ruler in centimeters. Above ground fresh weights of lettuce was weighed using a small digital weighing scale. After getting the fresh weight of the lettuce heads, approximately 2 gm of each lettuce variety was put in a dry dish and later was oven dried at 105°C for 24 hours. The weight of the dry dish was weighed before over drying process. After oven drying, the weight of the samples was measured and weight loss was taken as moisture. The dry matter (%) of the harvested lettuce as calculated using Equation (1):

$$\%\ \text{Dry mattter} = 100 - \frac{(\text{weight of moisture}*100)}{\text{sample weight}} \qquad \text{Equation 1}$$

The data collected on plant parameters was subjected to a 2 sample T-test using Origin pro software (version 9.0) to check for statistical differences between the means of the two lettuce varieties across the two farming systems. The 2-sample t-test was considered for this study purposely because the study aimed at comparing the means from the characteristics at harvest between the two faming systems, that is; hydroponics and conventional farming.

3.3 Economic Viability of Lettuce Production under Open Field Hydroponic Conditions

3.3.1 Economic Analysis Computations and Assumptions

This study included computation of input costs, market prices and expected cash flows. It was based on a number of assumptions for economic analysis. A budget was developed in which the fixed and operational costs were determined respectively and quantified based on time value of money. These costs were projected for a small-scale commercial urban farm using a production area of 6 m^2. The costs of inputs were recorded at the start of the experiment and the projected benefits were also calculated. It was also assumed that harvesting takes place between 4-8 weeks after transplanting.

Each crop production cycle lasts not more than 8 weeks after transplanting with all lettuce heads produced for commercial purposes. The calculations and projected future cash flows were made based on both low and high harvest figures as well as considering the fact that not all lettuce heads will have the same weight at harvest, thus harvest and sales will be made depending on weight or maturity of the lettuce. The price was based on average cost of lettuce heads around city markets and grocery stores. Cash flows were based on average market price of raw materials and the dollar rate (1 USD=3530 UGX) as of September 2021.

Borrowing interest rate of not more 10% from agricultural Savings and Credit Cooperative Organizations (SACCOs) which is taken as average interest rate and lower than rate from financial institutions in the country was considered as the discount factor. A production loss of 20% was estimated based on the production output and weight at first harvest within the expected maturity period. Salvage value was not included as this was assumed to be an on-going agricultural investment and sundry costs were estimated at 10%.

It was further presumed that the farmer might make more profits during the dry seasons due to the forces of supply verses demand thus counteracting previous or future losses. The economic analysis focused majorly on one investment (hydroponics) to avoid obscurity in cash flow patterns resulting from ambiguity in input and output. Since two varieties of lettuce were considered for the study, one crop was considered for the study to avoid indistinctness in the economic analysis based on factors such as; different crop maturity periods, crop nutrient requirements, fertilizer requirements among other factors.

3.3.2 Analysis Methods

(i) Capital Budgeting Analysis

Four capital budgeting techniques were used for the economic analysis, that is; Net Present Value, Internal Rate of Return, Profitability Index and Non-discounted Pay Back Period. The assessment rule was: if the N PV > 0 or PI >1 or IRR > cost of capital, the investment will be considered profitable and accepted (Grafiadellis *et al.,* 2000; Julian & Seavert, 2011). A positive NPV shows that the investment will get financial benefits greater than the cost of capital. Net Present Value which is the most common project budgeting technique was calculated based on Equation 2:

$$NPV = \sum{}_{t=0}^{t} \frac{P_t}{(1+i)^t} - I_o \qquad \text{(Equation 2)}$$

where P_t = expected net Cash Flow at end of time t . i= discount Rate (or rate of return), t = project period in terms of seasons, and I_o= initial investment (Khan & Jain, 1999). Profitability index which indicates the present value of benefits verses present value of costs (Gittinger, 1972) was calculated using the Equation 3:

$$\mathbf{PI} = \frac{\sum \textit{present value of future cash flows}}{\textit{initial investment}} \qquad \text{(Equation 3)}$$

Internal

Rate of Return and Non-discounted payback period were calculated using equations (3) and (4), respectively. The internal rate of return is an economic tool that aligns the discounted cash flows to the initial capital making the NPV equal to zero (Sulma *et al.,* 2019). The IRR indicates the financial gauge of an investment which tells the point of view from the society's' perspective as compared to NPV which indicates the economic gauge giving the point of view from the investor (Tang & Tang, 2003). The NDPBP shows the period at which the investment costs will be re-covered and it is calculated using non discounted cash flows.

$$IRR = L + \left(\frac{\mathrm{Npv_l}}{(\mathrm{Npv_l} - \mathrm{Npv_h})} \times (\mathrm{H} - \mathrm{L}) \right) \qquad \text{(Equation 4)}$$

where L is the lower discount rate; H is the higher discount rate; Npv_{l} is the Npv_l at lower rate and Npv_h =NPV at higher rate.

$$NDPBP = \mathrm{a} + \frac{\mathbf{b}}{\mathbf{c}} \qquad \text{(Equation 5)}$$

where a= last period with negative cumulative cash flow, b= the absolute value (that is to say: Value without negative sign) of cumulative net cash flow at the end of the period and c = is the total cash inflow during the period following period a.

(ii) What if Analysis

A Sensitivity analysis to provide an extra understanding on how a change in different variables or factors can affect the performance or the output of an intervention (Grafiadellis *et al.*, 2000;

Hyeongmo *et al.*, 2020) was also considered for the analysis. This type of analysis is performed through altering a given factor by a slight extent from the assumed rate (Levin, 2013).

(iii) Regression Analysis

This analysis shows how a set of independent variables will forecast an important condition (Braun, & Oswald, 2011). Equation (5) was based on for the analysis.

$\gamma = \beta_0 + \beta_1 X + \mathcal{E}\ (Revenue = \beta_0 + \beta_1 (quantity\ sold\ or\ price\ of\ lettuce) + \mathcal{E})$ (Equation 5)

Whereby, γ is the projected value of the dependent factor (γ) for any value of the independent factor (X), β_0 is the intercept, β_1 is the anticipated rate of change in γ as X varies, X is the independent variable and $\mathcal{E}$ is the approximate error. The (γ) variable represents the revenue earned versus the (X) variable which is quantity of lettuce sold or price of the lettuce per head.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Status and Perception of Hydroponics in Central Uganda and Northern Tanzania

This analysis looked into and summarized the factors that described the farmers or operators of hydroponic farms at small and large scale in Central Uganda and Northern Tanzania, respectively. A total of 51 participants took part in the research study.

4.1.1 Socio-Economic Factors with Associated with Hydroponics in Tanzania and Uganda

Results showed that 9.8% (n=5) of the respondents were from Arusha region in Tanzania (3 firms from Meru district and 2 from Arusha) while 90.2% (n=46) were from central region in Uganda. The participants in Tanzania represented hydroponic firms while the participants from Uganda represented small hydroponic farms. About 33% (n=17) of the respondents were female while about 66.7% (n=34) were male. Majority of the respondents (41.2%, n=21) were aged 26-35 years and the least age group were those aged above 56 years (9.8%, n=5).

Few participants engaged in hydroponics as their main economic activity (21.6%, n=11) whereas 78.4% (n=40) did not practice it as a main economic activity. Most of the vegetables produced were for home consumption purposes as reported by 47.1% (n=24) of the respondents while only 3.9% (n=2) reported selling their hydroponic produce to both local and international market. It is worth noting that farms who sold their produce at the international market were majorly from Meru (n=3, 5.9%) that use soilless farming for production of vegetable seeds for export (Table 7).

4.1.2 Agronomic Factors Associated with Hydroponics in Tanzania and Uganda

Regarding the agronomic factors (Table 8), the main vegetable grown with soilless farming as per the study was lettuce as reported by 43.1% (n=22) of the farmers because it has a short growth period while the least grown 5.8% (n=3) were: Bokchoy and sukuma-wich. The drip hydroponic system was reported as the most used method because it does not require full automation for growing the vegetables and is cheap compared to other hydroponic systems (54.9%, n=28).

The method involves using a drip line with emitters that deliver the nutrient solution to the plant roots at given time intervals. Majority of the vegetables were cultivated using non-automated greenhouses (62.7%, n=32) and open fields (13%, n=7.2) for production because these are cheap compared to automated greenhouses (6%, n=11.7). Results showed that most respondents used inorganic fertilizers (82%, n=41) and Polyvinyl chloride (PVC) pipes (31.4%, n=16) for hydroponics.

Only 5.9% (n=3) reported using hydroponic grow pots to grow their vegetables. Hydroponic grow pots which are not readily available were mainly used by the seed producing companies in Arusha who basically import them. Approximately 53% (n=27) of the respondents used volcanic rocks as media. Regarding the size of land used for crop production, 58.8% (n=30) of the participants grew hydroponic vegetables on land size of 0-1/4 an acre basically within their home backyards. Plates 2-4 show different hydroponic lettuce practices in Uganda and Tanzania while Fig.12 and 13 summarize the factors associated with hydroponic vegetable production in the study areas.

Table 7: Socio-economic elements associated with hydroponic vegetable farming in selected areas of Uganda and Tanzania

Factors	Group	Frequency	Percentage
Country	Uganda	46	90.2
	Tanzania	5	9.8
Gender	Female	17	33.3
	Male	34	66.7
Age of respondent	15-25	5	9.8
	26-35	21	41.2
	36-45	14	27.5
	46-55	6	11.8
	Above 56	5	9.8
Level of education of respondent	Primary	2	3.9
	Secondary	10	19.6
	University	33	64.7
	Other tertiary institutions	5	9.8
	None	1	2
Labor used at the farm	Hired labor	18	35.3
	Home labor	31	60.8
	Hydroponic specialists	2	3.9
Hydroponics as main economic activity	Yes	11	21.6
	No	40	78.4
Receipt of financial support	Yes	8	15.7
	No	43	84.3
Market for hydroponic produce	Local	22	43.1
	International	3	5.9
	Both local and international	2	3.9
	None	24	47.1

Table 8: Agricultural factors associated with hydroponic vegetable production in selected areas of Uganda and Tanzania

Factors	Grouping	Frequency	Percentage
Vegetables grown	Spinach	6	11.7
	Lettuce	22	43.1
	Bell pepper	9	17.6
	Tomatoes	11	21.5
	Others	3	5.8
Hydroponic system used	Drip hydroponic system	28	54.9
	Nutrient Film Technique	17	33.3
	Deep Water culture	4	7.8
	Wick system	2	3.9
Environment used for hydroponics	Fully automated green house	6	11.7
	Open field	13	7.2
	Non-automated green house	32	62.7
Planting pots used	Normal grow bags	22	43.1
	Hydroponic grow pots	3	5.9
	PVC pipes	16	31.4
	Plastic containers	10	19.6
Type of fertilizer used	Organic	7	13.7
	In organic	44	86.3
Medium used	Saw dust	8	15.7
	Coco-peat	11	21.6
	Volcanic rocks	27	52.9
	Others	5	9.8
Size of the land	0-¼ acre	30	58.8
	¼- ½ acre	10	19.6
	½ - 1 acre	6	11.8
	More than 1 acre	5	9.8

Plate 2: Hydroponic lettuce production using PVC pipes and plastic buckets as grow containers in Uganda

Plate 3: **Cucumber production inside a locally made non automated greenhouse using normal grow bags and drip hydroponic system in Wakiso Uganda**

Plate 4: **Hydroponic lettuce production outside the green house at a demo farm in Meru, Tanzania**

Figure 12 and 13 show the socio-economic and agricultural factors associated with hydroponic vegetable farming in central Uganda and northern Tanzania, respectively.

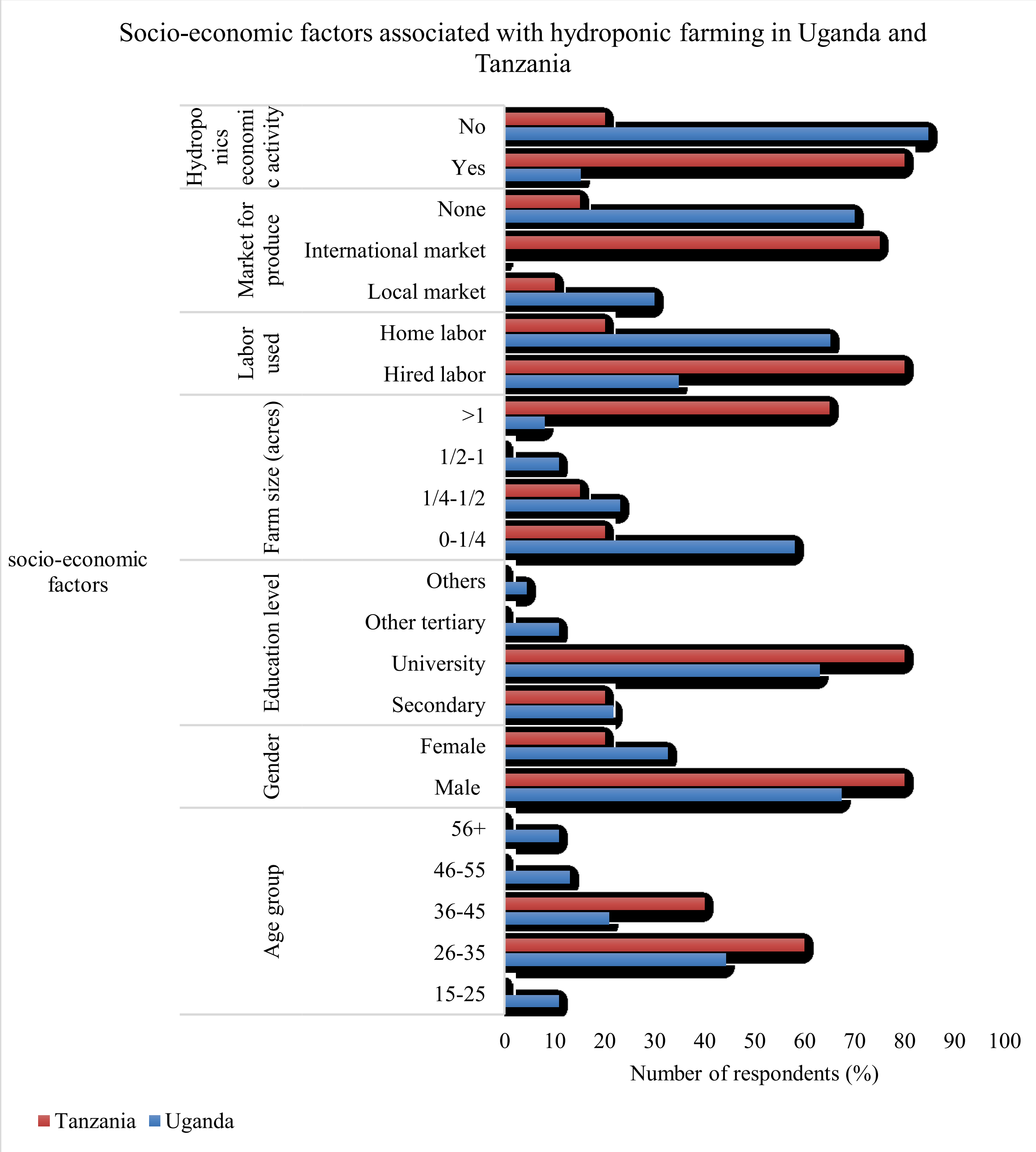

Figure 11: Socio-economic factors associated with vegetable production using hydroponics in selected areas of central Uganda and northern Tanzania

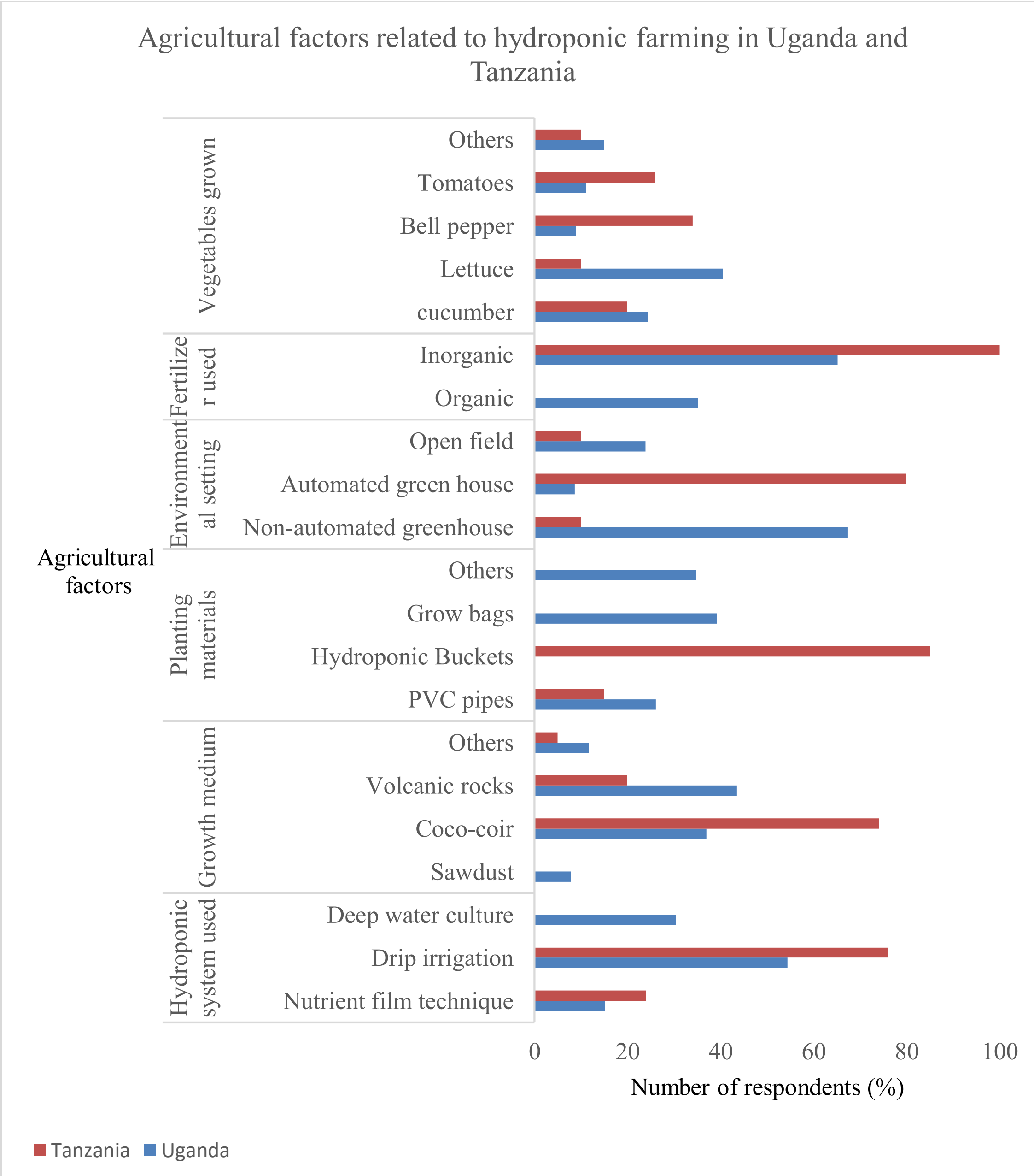

Figure 12: **Agricultural factors associated with vegetable production using hydroponics in selected areas of central Uganda and northern Tanzania**

Few studies have looked into factors enhancing adoption of hydroponics in East Africa but majorly on fodder production which somehow identified the same factors as seen in the results of this study. For instance, a study on factors influencing production of hydroponic fodder in Kenya also indicated majority of the farmers being male in the middle age group of 18-45 years (Njima, 2016). This could be possibly be due to the complex nature of the technology attached to the farming system which attracts deep knowledge search from the internet of other sources and of which the youth form a big majority of the job searching and internet usage category.

The study revealed that the largest number of hydroponic farmers (64.7%) were university degree holders and only 2% (n=1) did not have any education background. This shows that educated individuals are more willing to take on this complex technology as compared to traditional farming systems that don't have a lot of technicalities. Hydroponics generally requires adequate knowledge regarding the mechanisms related to the type of crop, fertilizer, and EC requirements for proper implementation and success.

According to the study, soilless farming in Arusha is mainly practiced for large scale vegetable seed production thus the respondents were majorly operators/farm managers from large scale commercial hydroponic companies representing large scale hydroponic farming. The region is one of the hot spot vegetable production areas in the country. A number of the farmers from Uganda were noted to be using media such as; volcanic rocks is because it is readily available and less expensive as compared to other media such as: peat moss that are also not readily available. Majority of the factors identified in the study such as: the use of non-automated greenhouses for crop production, use of local materials like: ordinary grow bags as planting pots, among others were majorly due to the low cost associated with them as well as the limited access to the standard hydroponic equipment. For instance in Uganda, it was noted that some of the farmers using standard hydroponic equipment were getting them from Kenya or from agricultural input companies that import them for sale.

4.1.3 Benefits of Hydroponic Farming in Northern Tanzania and Central Uganda

Hydroponic farming has been noted to have many advantages as compared to other traditional farming system. The research respondents mentioned some of the benefits they have noted while using hydroponics. Approximately 24% (n=12) of the farmers acknowledged that hydroponic vegetables are clean with consistency in texture and size. About 26% (n=13) of respondents also reported hydroponics to be a climate smart agriculture (CSA) system. This implies that the crop production using this technology is not dependant on rainfall seasons. About 24% (n=12) of the respondents noted that hydroponics allows high yield production within a small space or in areas with unfertile soils. Another advantage noted by roughly 20% (n=10) of the participants was the absence of soil borne pests and diseases with the farming system as compared to soil farming. About 4% (n=2) reported having control over the environmental conditions through the monitoring of climatic factors such as: Temperature, EC, pH and humidity. This was reported majorly by those who were cultivating under fully automated green houses. Other advantages for hydroponic farming noted by about 4% (n=2) of the farmers were: No weeding is required, source of income from sale of vegetables and training other farmers, requires little attention during growth as well as production of surplus food for home consumption. Figure 14 shows the advantages of hydroponic farming within Tanzania and Uganda.

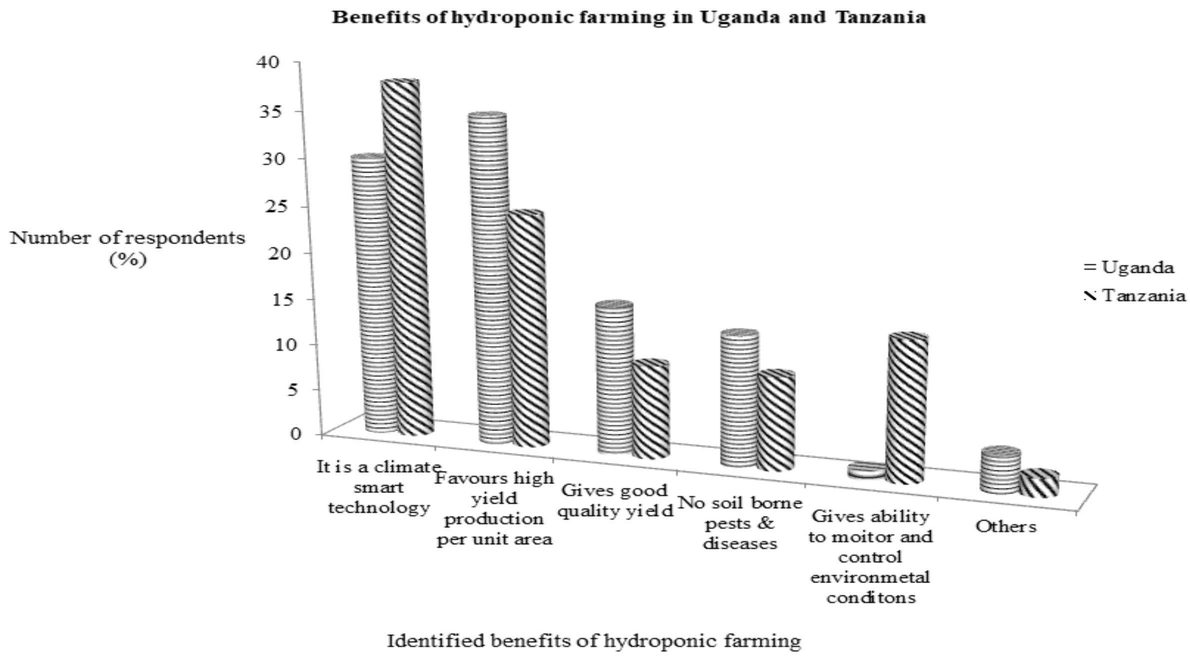

Figure 13: Benefits of hydroponic farming in Northern Tanzania and Central Uganda

Hydroponic in general promotes environmentally friendly measures with the ability to improve commercial food production and perform better than traditional open field farms (Buehler & Junge, 2016; Daina *et al.,* 2018). One of its advantage is the production of good quality crops (José & Diego, 2020; Nisha *et al.,* 2019; Pace *et al.,* 2018).

Results from a study in Trinidad similarly reported a high willingness to pay for greenhouse-“hydroponic tomatoes” as compared to “open-field” tomatoes based on being free of pesticides (Narine *et al.,* 2014). Hydroponically grown crops are reported to have more mineral composition than soil grown plants (Sapkota & Liu, 2019). As noted by the respondents, the farming system is not dependant on weather conditions and also environmentally friendly which aspect was also pointed out by Zhigang and Qinchao (2018). Farmers established that hydroponic food production is not dependant on rainfall seasons and neither does existence of drought conditions deter an individual from cultivation hence offers an opportunity for all year crop production.

Hydroponics is a very suitable urban farming system in areas faced with scarcity of arable land. Gholamreza, Azin and Farhad (2014) similarly noted that hydroponics gives the opportunity to grow crops in non-arable areas. This farming system can take place in areas with non-fertile soils (Specht *et al.,* 2014) and can be implemented using vertical farming which increases crop production per unit area through vertical crop cultivation means (Buehler & Junge, 2016; Daina *et al.,* 2018; Dionysios *et al.,* 2016).

The controlled nature of the environment setting for hydroponics, no use of soil for cultivation, use of insect traps for both indoor and outdoor systems all play huge roles in dettering pests like white flies hence reducing use of pesticidies (Daniel *et al.,* 2019). Richard *et al.* (2020) reported that soilless faming has the benefit of restricted occurrence of pests and diseases. The use of soilless farming gives a unique chance for controlled environment seed production with limited pests and diseases (Tessema & Dagne, 2018) as reported by around 20% of the respondents. With hydroponic farming, there is control over the climatic conditions within the greenhouse environment (Milile *et al*., 2021) due to the use of automated climate monitoring systems which regulate factors such as; humidity and temperature.

4.1.4 Challenges Faced by Hydroponic Farmers in Central Uganda and Northern Tanzania

The biggest challenge reported was the high costs required to implement the technology especially for the fully automated greenhouse farms (n=16, 31%). Hydroponic farming requires enough technical knowledge to implement it. This was reported by 22% (n=11) . For example: Knowledge on the right ammount of nutrients required for a particular crop.

Majority of the respondents reported having learnt about hydroponic farming using internet which further corelates with the high number of educated participants of the study. The farm operators (6%, n=3) who practiced hydroponics were using high end technology such as: Climate control systems accordingly reported a hitch related to damage to crops in case of system failure. Another set- back reported by 12% (n=6) of the farmers was the lack of adequate innovations that use locally available resources for hydroponic farming. For example: replacement of PVC pipes with buckets or bottles for growing hydroponic vegetables. Lack of adequate options of organic fertilizers for hydroponics in agricultural shops was another drawback surrounding hydroponics as mentioned by approximately 20% (n=10) of the respondents.

Other challenges reported by 9% (n=5) were: Bias from the community towards hydroponic produce as some people consider it to be non-organic. Lack of variety of organic fertilizer alternatives and the timeliness needed by the system to avoid crop or system failure. Figure 15 shows the limitations /challenges surrounding hydroponic farming in Tanzania and Uganda.

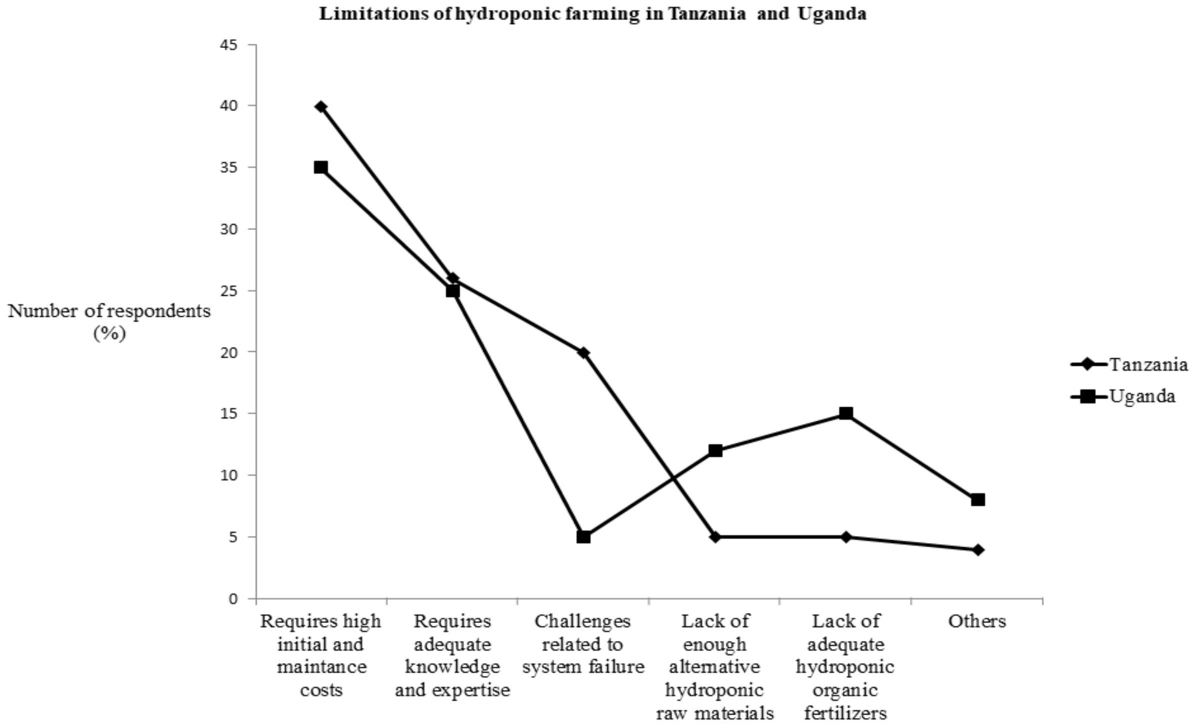

Figure 15: Limitations of hydroponic farming in Northern Tanzania and Central Uganda

Nicole *et al.* (2021) noted high startup costs as one of the challenges for adoption of hydroponic farming technology. These costs cover; greenhouse construction, fertilizers, electricity, hydroponic equipment such as: PVC pipes, hydroponic net cups, climate monitoring systems among others. Artificial lighting, for instance through use of LED lights is sometimes deemed necessary for steady production making energy costs a key factor (Daniel *et al.,* 2019). The dependency on electricity is one of the factors that make hydroponics expensive (Lee & Lee, 2015).

As earlier noted, majority of the farmers interested in the farming system adopted it at a small scale under non-controlled environments to cut down on the high initial costs needed for setting up the hydroponic units. The development of low cost and easy to use hydroponic units will not only increase adoption of technology but also help farmers produce high quality vegetables (Sapkota *et al.,* 2019) through using the technology. Controlled environment hydroponics requires some knowledge on how to run the climate control system within the green house for factors such as; humidity and temperature.

The need for technical knowledge in hydroponics is one of the challenges of hydroponics (Aurosikha *et al.,* 2021; Nisha *et al.*, 2019). A failure or mismanagement of hydroponics can cause crop damage as also noted by Specht *et al.* (2014) who indicated that it is not sustainable if not well handled. This challenge was highlighted by the managers from hydroponic firms who use high tech systems to run their hydroponic farming.

4.1.5 Suggestions for Improving the Adoption of Hydroponics in Uganda and Tanzania

Primarily, the respondents highlighted an urgent need to improve awareness and sensitization about the system among farming communities especially around the urban and semi-urban areas. This is due to the existence of limited knowledge among farmers about the mechanism related to the technology such as; costs required types of hydroponics, advantages and disadvantages. This could be done through farmer workshops, agricultural field days. There is need to set up demonstration sites where farmers can go and get trained about hydroponic farming and also gain practical experience in relation to the technology. This will help in improving access to knowledge as of when needed by the farmers or interested community members.

Besides awareness as earlier mentioned, agricultural and /or research organizations should put more efforts in highlighting the advantages aligned with hydroponics to the communities. A clear comparison between hydroponics and traditional farming should be laid out on factors such as: Costs and benefits of hydroponics as well as nutritional composition of hydroponic produce Government bodies or financial institutions can also play a key role in providing financial support in terms of loans or subsided taxes on hydroponic raw materials. This is due to the high initial capital required to set up the hydroponic units, which sum of money might not be available to some farmers might be interested in implementing the technology. Researchers can also explore more options on low-cost materials that can be used for hydroponic farming in replacement of some of the equipment used in hydroponics.

4.2 Physiognomic Performance of Lettuce under Open Field Hydroponic Conditions

4.2.1 Characteristics of Hydroponic Solution and Soil before Transplanting and at Yield

The characteristics of the soil and nutrient solution were taken before transplanting (Table 9), that is: EC, NPK, OM, temperature and water (H20) requirements. Similarly, at harvest time, the EC and pH parameters were measured to determine the strength of the nutrients and level of acidity or alkalinity in the nutrient solution and soil which ideally reflect the retained nutrients in the system (Table 10). The remaining level of nutrient solution was also measured to ascertain the amount of solution used by the vegetables over the growth period. On average pH ad EC of the 5.7 and 560 (ppm) where recorded.

Table 9: Chemical properties and NPK composition of hydroponic solution and soil before transplanting.

Media	EC (ppm)	pH	N	P	K	Average temperature	H_2O requirements
Soilless farming	707	6.2	17	17	17	~25ºC	90 liters at a depth of ~7 cm
Soil	698	6.0	17.5	15	16.5		~170 liters

Table 10: Chemical properties of hydroponic solution and soil at yield

Media	EC	pH	H_2O
Soilless farming	558	5.8	~ 3 cm depth
Soil	569	5.6	

4.2.2 Physical Characteristics of Lettuce at Growth and Harvesting Stage

A couple of factors were studied and measured during growth and at harvest including; number of leaves, leaf width, root length, plant height, weight of the lettuce and dry matter. These parameters were studied at 20 and 40 DAT. T-test results showed no significant differences in the means of the parameters for both green and red lettuce grown using soil and hydroponics at 20 DAT. Nevertheless, S-G had the highest: NL (~11), RL (~13.5 cm), PH (~14.9 cm), LW (~14.83 cm) and FW (~96.9 gm) as observed in Table 11. At 40 DAT, the mean comparison results still indicated no significant difference between PH, NL and LW. Nonetheless, a significant difference existed between the means of DM of the same lettuce variety across the two farming systems at $p < 0.05$ (Table 12). Further still, a significant difference was noted between the means of FW of S-R and H-R, ($p = 0.03$) as well as H-G and S-G, ($p = 0.02$). The DM and RL of the above mentioned two comparison groups was significant at $p < 0.05$. That is, DM of S-R and H-R, ($p = 0.02$) and H-G and S-G, $P = (0.01)$; RL of S-R and H-R, ($p = 0.01$), and H-G and S-G, ($P = 0.02$). Generally, at harvest, soil grown green lettuce had the highest; FW (~139.93 gm), NL (~16), and DM (~90.91%) as compared to hydroponic lettuce (Plate 5- right hand side). There was a 60% harvest rate under hydroponics (Plate 6) and 90% harvest rate under conventional lettuce production. The results in Tables 11 and 12 were obtained by comparing the means of parameters of each lettuce variety across the two-farming system and within the same system separately. These results were later combined and merged into the two tables (11 and 12).

Plate 5: **Lettuce under conventional farming (left) and hydroponics (right) under open field conditions. Photo by Margaret Gumisiriza**

Plate 6: **Hydroponic lettuce production using kratky method under open field conditions (Photo by Margaret Gumisiriza)**

Table 11: Characteristics of lettuce grown under hydroponics and conventional farming at growth

Parameters	Means				P-values			
	S-R	S-G	H-R	H-G	H-R*H-G	S-G*S-R	H-R*S-R	S-G*H-G
PH (cm)	14.35±1.17	14.9±0.76	13.85±0.74	14.4±0.77	0.62	0.76	0.73	0.75
FW (gm)	86.7±3.44	96.9±2.6	79.33 ±2.09	86.33±2.61	0.10	0.06	0.14	0.07
RL (cm)	13.12±0.84	13.5±0.49	13.98±0.5	14.9±0.2	0.19	0.49	0.43	0.05
LW (cm)	13.77±0.95	14.83±0.35	11.6±0.96	12.7±0.81	0.45	0.35	0.19	0.07
NL	10±0.41	10.75±0.48	9±0.41	9.5±0.65	0.54	0.28	0.13	0.17

Table 12: Characteristics of lettuce grown under hydroponics and conventional farming at harvest

Parameters	Means				P-values			
	S-R	S-G	H-R	H-G	H-R×H-G	S-G×S-R	H-R×S-R	S-G×H-G
PH (cm)	17.65±1.07	18.4±0.92	20.9±1.13	21.65±1.14	0.66	0.61	0.08	0.07
NL	15.5±1.32	16.25±0.63	14.25±1.75	15.5±1.31	0.66	0.63	0.59	0.52
LW (cm)	16.43±0.49	18.2±0.23	14.93±0.45	16.83±1.07	0.18	0.05	0.08	0.28
RL(cm)	14.58±0.9^{b}	15.25±1.07^{b}	18.8±0.9^{a}	19.56±0.89^{a}	0.56	0.56	**0.01***	**0.02***
FW (gm)	135.93±3.81^{a}	139.75±3.86^{a}	122.27±2.59^{b}	126.8±1.94^{b}	0.34	0.51	**0.03***	**0.02***
DM (%)	87.61±0.19^{a}	90.91±0.72^{a}	86.45±0.29^{b}	86.62±0.22^{b}	0.62	0.29	**0.02***	**0.01***

H-R: Red lettuce in hydroponics, **H-G:** Green lettuce in hydroponics, **S-G:** Green lettuce in soil, **S-R:** Red lettuce in soil. Values under means are; means ± standard error (SE). **PH:** Plant height, **NL:** Number of leaves, **LW:** Leaf width, **RL:** Root length, **FW:** Fresh weight, **DM:** Dry matter P-values show interaction of means of lettuce varities across the two farming systems (across rows) at 0.05 level. * and diffferent letters across rows indicate a significant difference at $p < 0.05$ under 2 sample T-test

Figure 16 and 17 show the performance of green and red lettuce under soil and soilless farming systems at 20 and 40 DAT.

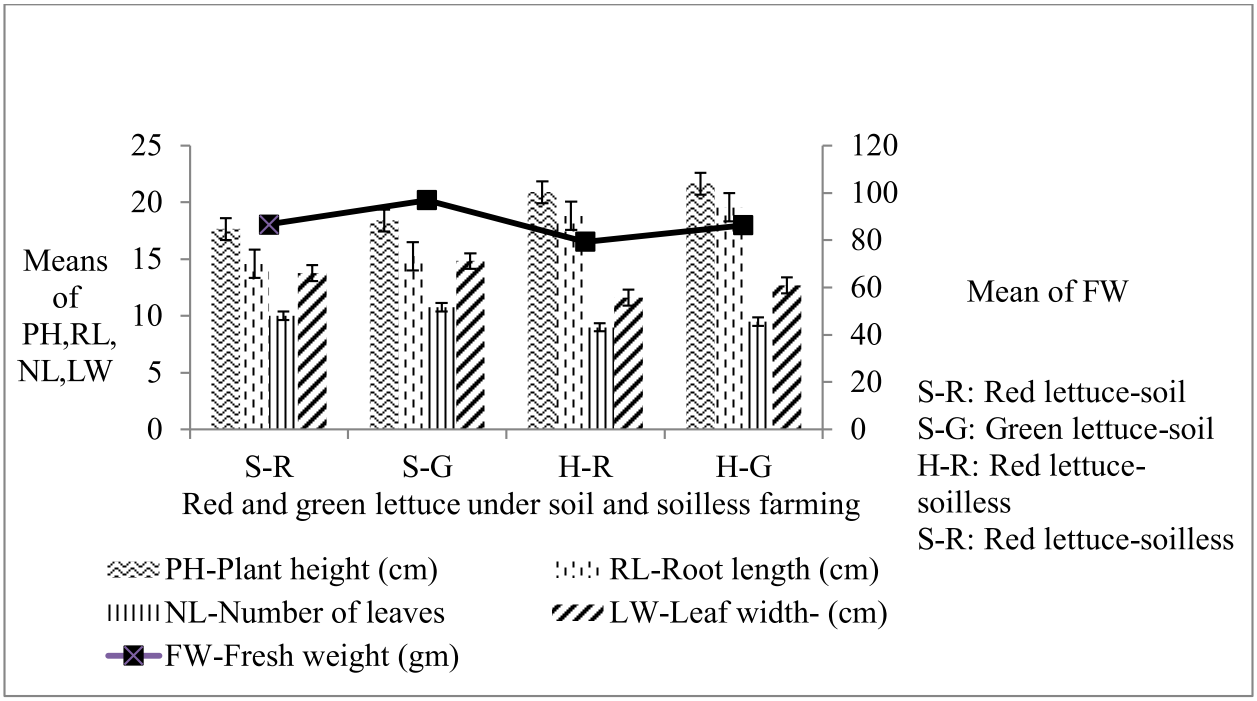

Figure 16: Characteristics of green and red lettuce under soil and soilless farming at 20 DAT

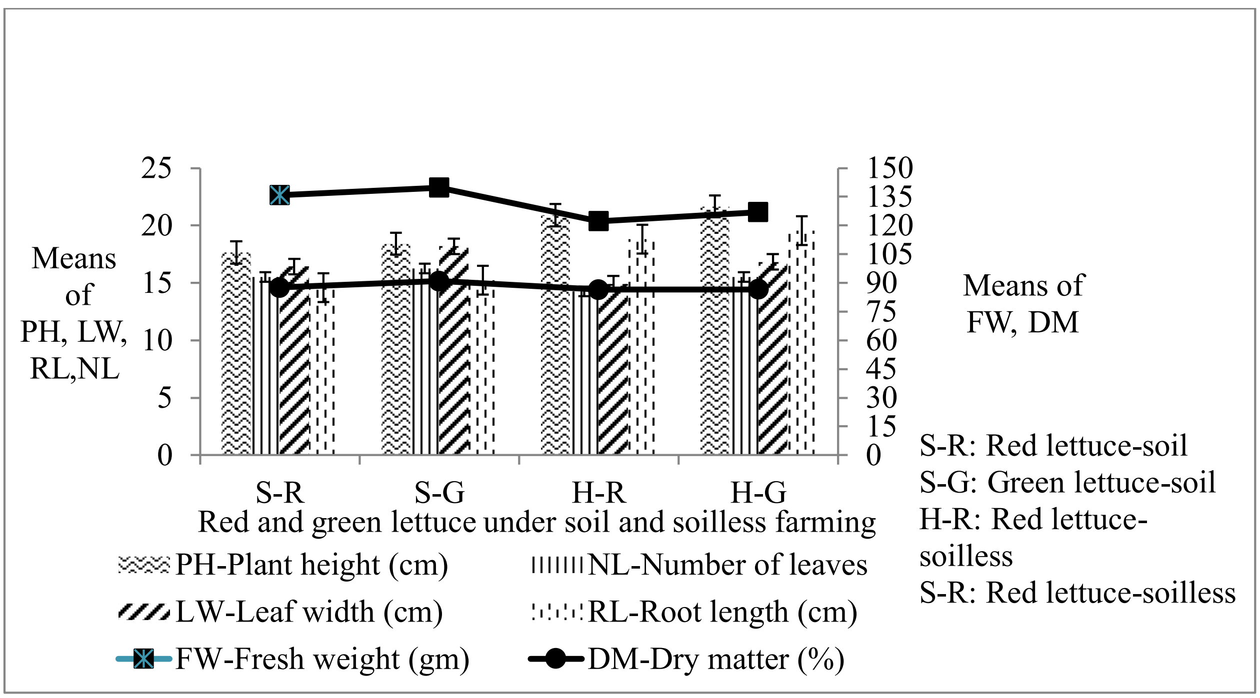

Figure 17: Performance of green and red lettuce under soil and soilless farming systems at 40 DAT

The T-test results showed no significant difference on the leaf width, number of leaves, length of the roots, plant height and fresh weight of the two lettuce varieties across the two farming systems at 20 DAT. This was possibly due to the early growth period of the vegetables that did not require a lot of nutrients as compared to the later vegetative stage. The soil grown lettuce performed slightly better than the hydroponic lettuce since the lettuce in the hydroponic system was perchance still getting acclimatized to the new liquid media as compared to the soil grown lettuce which had been transplanted from solid-to-solid media. On the other hand, the results at harvest likewise, revealed no significant difference in LW, NL, PH and FW. Nevertheless, a significant difference was noted in RL, DM and FW. There was also a low water usage in the hydroponic system as compared to the conventional cropping system.

Based on the experiment, there was no significant difference on plant height both at 20 and 40 days after transplanting. Another study similarly also reported no significant difference in the plant height of lettuce grown using circulating hydroponic system and non-circulating hydroponics in comparison with conventional lettuce production under open field conditions (Acharya *et al.*, 2021). The height of lettuce in a study by Frasetya *et al.* (2021) was between 17-20 cm at 28 days which is slightly close to the plant height results of hydroponic lettuce at harvest (20 DAT) (~13-14 cm) as expected. The plant height of lettuce at 4 weeks after transplanting was of 13.03 cm (Naz, 2020) also similar to the height of hydroponic lettuce in the experiment. The lack of significant difference in plant height reflects the impression that lettuce within the two farming systems was being possibly subjected to averagely the same amount of light, temperature, water and nutrients conditions which play a key role in this parameter. And thus revealed, the likelihood of the two farming systems performing equally the same as it plays a role in number of leaves produced by the plant.

The analysis results showed number of leaves for hydroponic lettuce at ~ 14 which is equivalent to the number of leaves identified in a study by Mahlangu *et al.* (2016) for lettuce produced under greenhouse hydroponic conditions. A study by Al-maskri (2010), also reported average number of leaves of 14 at 50 days after transplantation to the hydroponic NFT system. The lack of a difference between number of leaves of lettuce grown under hydroponics and under soil conditions at growth and harvest time was due to possibly the supply of the necessary amount of nutrients required as well as exposing the lettuce under the two farming systems to the same environmental conditions (open field conditions). Research shows that growth of lettuce is affected by natural settings and nutrition (Gent, 2017). Hydroponic systems ensure continuous supply of water and nutrients to the plant which is beneficial for plant growth and yield (in terms of number of leaves for lettuce). Lettuce as a vegetable that is ideally consumed by leaves in fresh form, therefore the higher the number of leaves and good hygiene, the better and more marketable (Frasetya *et al.,* 2018; Manolopoulou *et al.,* 2010). Thus, the lack of a significant difference between the lettuce within the two farming systems indicates that hydroponics can perform as good as soil cultivated lettuce hence making it a suitable farming system for improving vegetable availability among urban households.

The results further showed hydroponic lettuce having longer roots as compared to soil grown lettuce. The cause of longer roots under hydroponic systems is the continuous search for nutrients in the nutrient solution. Hydroponic lettuce from the experiment had average root length of ~ 18-20 cm at harvest almost close to the root length (31 cm) of hydroponic lettuce from a study by Agarwal *et al.* (2019). Long roots play an important role in retaining the freshness and long shelf life of hydroponic lettuce as they assist in retaining water conversely contributing to a reduction in the rate of weight loss (Rui *et al.,* 2021). This gives hydroponic lettuce an advantage of long shelf when the lettuce head together with its roots is retained or persevered in water in the stores or at home. The low length of the roots under soil could possibly caused by the low phosphorus content within the soil.

The T-test results showed a significant difference in the fresh weight of the lettuce at yield between the two farming systems. In another study, the fresh weight of hydroponic lettuce produced under circulating hydroponics (NFT system) was 70.74 gms at 35 days from transplanting in an experiment carried out in Indonesia (Frasetya *et al.*, 2021). This is close to the weight at growth which was between ~77-84 gm using Kratky hydroponic system outside the green house. It indicates the non-circulating hydroponic systems implemented outside the greenhouse can be as equally efficient as greenhouse circulating hydroponic systems. Idyllically, the comparative increase in weight of lettuce on a daily basis varies at a slower rate as the plant continues to grow in a constant environment (Gent, 2017).

Another study by Chunli and Nicki (2021) on comparison of cultivation of giant lettuce under hydroponics and soil based cultivation inside the greenhouse, likewise reported no significant difference in the above ground plant size after 35 from seeding which is closely related to the results from the experiment. However, Maliqa *et al.* (2021) noted that greenhouse soil-less culture produced better lettuce 3-4 times higher in terms of yield than the soil grown lettuce which was contrary to the comparative results attained in the study. Controlled environment crop cultivation whether under soil or soilless culture offers protection to crops from harsh environmental conditions (Gonzaga, 2017) which justifies the above concept by Maliqa *et al.* (2021). The same study by Maliqa *et al.* (2021) reported low dry matter content of lettuce which was similar to the results on hydroponic lettuce in the experiment.

The low dry matter content in hydroponic vegetables reflects a higher moisture content which is expected since the medium used to deliver nutrients is liquid not solid. Further still, lettuce is known to be a vegetable with high water content thus the low dry matter content generated from the analysis results confirmed this notion. Hydroponic production of lettuce under controlled environmental conditions generally produces higher yield than soil-based systems. This is expected since there is control and monitoring over climatic conditions such as; temperature and humidity which is non-existent in non-controlled environment hydroponic systems.

Knight and Mitchell (1983), noted that lettuce grows rapidly under temperatures of 25°C in a controlled environment. The average daily temperature during the experiment was ~25°C which could explain the closely related performance between the hydroponic lettuce under non-controlled environment with that the controlled environment from other research experiments as earlier mentioned. It is worth noting that the better performance of the traditional crop production system could have been based on the extra natural physical properties of the soil. According to the results, out of 100%, hydroponic production required 35% while soil cultivation required/consumed 65%. Ideally previous research has pointed out that soilless farming consumes less water as compared soil-based farming systems.

Results from the same study by Maliqa *et al.* (2021) also brought out the vital matter of a water saving rate of 64% under greenhouse circulating hydroponic system. This was nearly equivalent to the water saving rate (65%) in the non-circulating non-greenhouse hydroponic system in the study. Ordinarily, hydroponic systems utilize 5-20 times smaller amounts of water than soil-based crop production systems. This is because the systems only utilize the necessary amounts of water required as compared to traditional farming systems where the crops are irrigated depending on the need and the weather conditions thus the farmer does not have full control on when and how much water to supply the water. Hydroponics consumes merely 10% of water as compared to traditional crop cultivation which gives a planter an opportunity to regulate nutrient supply. This implies that these soilless systems also improve water consumption effectiveness as compared to soil culture systems (Alshrouf, 2017) because of continuous re-use of the nutrient solution (Mampholo *et al.*, 2016). Inadequate supply of water to the plant during the growing period can inhibit crop growth (Xu & Leskovar, 2014). The ability to use less water in hydroponic systems as compared to soil based cropping systems means that, hydroponics has the capacity to contribute to natural resource management in terms of the water resource factor as well as the ability to improve crop production and food security in areas faced with water challenges.

Vertical farming alone has also been noted to use less water as compared to other conventional farming practices (Van Delden *et al.,* 2021). This makes it a smart and sustainable urban farming technology for countries such as: African states, as there already reports of declining water resources for food production in the developing countries in general (Abdallah & Mourad, 2021; Zarei *et al.,* 2021). Generally, hydroponic vegetable production has the latent to promote sustainable agriculture (Chenin & Omaye, 2015) regardless of whether the practice is carried out under controlled or non-controlled environment. Lettuce is a suitable crop for hydroponics because of its short growth cycle (Mampholo *et al.*, 2019). Harvesting can take place at 43 DAT (Rafael *et al.,* 2017). Since the harvest part of the vegetable is the leaves, of which there was no significant difference on this parameter, it can be noted that the hydroponic system under the study has the potential to improve vegetable production around urban areas.

4.3 Economic Viability of Lettuce Production under Open Field Hydroponic Conditions

4.3.1 Capital Budgeting Techniques

At the start of the experiment, the necessary total costs of producing (TCP) lettuce using the vertical hydroponic system outside a greenhouse field for 6 CPPs over a period of 12 months were computed (Table 13). The Unit cost of production (UCP) was also calculated. Both fixed and variable/operating costs deemed necessary for producing lettuce using hydroponics over 12 months were considered. These total costs were used as the initial cost of investment. Additionally, total costs deemed necessary for producing lettuce using the traditional farming system in an urban home setting in a space of 16 m^2 were also computed (Table 15) for comparison purposes. These included costs for; construction of wooden rack, black potting bags, lettuce seedlings, spray bottle (for irrigating), water and labor.

Table 13: Annual production costs for small scale hydroponic lettuce cultivation under open field

	Item	Quantity	Unit cost ($)	Total cost ($)
	Fixed costs			
1.	Construction of wooden rack with UV plastic	1	52	52
2.	PVC pipes	3	7	21
3.	PVC pipe covers	6 covers	1	6
4.	Water tank	1 (100 litres)	9	9
5.	TDS meter reader	1	10	10
	Variable costs			
6.	Water	1 unit	2	2
7.	Lettuce seeds (2 gm/sack)	3 sacks (2 gm/sack)	0.4	1.2
8.	Poly feed fertilizer	6 kgs	4.4	26.4
9.	Insect sticky traps	1 packet (6 pieces)	7	7
10.	Disposable cups	6 dozens	0.5	3
11.	pH control kit	1	14	14
12.	Seedlings grow tray	1tray (150 seeds)	4	4
13.	**Sundry costs**		15.1	15.1
	Total			**170.7**

4.3.2 NPV, IRR, NDPBP and PI of Hydroponic Lettuce Production outside the Green House

The study used NPV as a fundamental economic tool to assess the effectiveness of the hydroponic system through discounting the future estimated cash flows to assess their worth ness at the present. Two discount rates (10% and 13%) which represented the cost of borrowing were selected to capture both low and high borrowing rates from the SACCO and thus reveal their impact on the project. The results from the analysis (Table 14) showed a positive NPV of 16.37$ at 10% discount rate which projected the investment as economically viable. This indicates the net present worth of the future cash inflows from the project at the discount rate of 10% where a positive NPV indicates that the projected benefits from the investment exceed the planned costs thus making the investment profitable.

Table 14: NPV results ($) at 10% and 13% discount rates for production of lettuce under hydroponics and conventional farming under open field

	Hydroponic lettuce production			Conventional lettuce production	
CPPs	**cash flows($)**	**NPV @ 10%**	**NPV @ 13%**	**NPV @ 10%**	**NPV @ 13%**
0	(170.70)	(170.70)	(170.70)	(129.20)	(129.20)
1	43.84	39.85	38.75	39.85	38.75
2	42.25	34.90	32.96	34.90	32.96
3	44.50	33.42	27.15	33.42	30.71
4	39.40	26.91	24.03	26.91	24.03
5	43.25	27.01	23.49	27.01	23.49
6	45.00	25.20	21.60	25.20	21.60
		∑NPV =16.59	∑NPV=(2.72)	∑NPV = 58.09	∑NPV = 42.34

$$Df = \frac{1}{(1+r)t}$$

Table 15: Economic analysis results for lettuce production under hydroponics and conventional farming

Farming system	TCP	PI	NDPBP	IRR	UCP
Hydroponics	170.7 $	1.1	4, 5 CPP (approx. 8 months)	12.57%	0.46$
Conventional	129.2$	1.45	3, 9 CPP (approx. 6 months)	20.96%	0.36$

The analysis results (Table 15) showed an IRR of 12.57% which was higher than the assumed discount rate used for computation thus deeming the investment profitable. This portrayed a positively significant annual rate of return on the investment as it also showed the systems' breakeven point that lied in between the two discount rates selected for the analysis.

The increasing cash flows on hydroponic lettuce production can thus be considered as re-investable since the IRR was greater than the 10% discount rate. On the other hand, the NDPBP was approximately 8 months. This showed that a farmer investing in lettuce hydroponic production would be able to recover his initial investment costs and break even before the end of the one year of crop production. The PI was calculated at 1.1 which also showed the hydroponics project would be profitable if taken on since a P. I ratio greater than 1 indicates ability of the project to make profits.

4.3.3 What-if Analysis

(i) Sensitivity Analysis

The study analyzed how a change in discount rate and unit cost of lettuce independently affected NPV as well as revenue generated respectively from sale of 60 heads of lettuce (Fig.18) respectively. Results showed that a 50% reduction in discount rate improved the NPV of hydroponic lettuce to 47.65$ while a 50% increase in discount rate lowered the NPV to -8.0$. On the other hand, a 50% reduction in unit cost of lettuce reduced the revenue generated from 60 heads of lettuce from 45$ to 15$ while an increase of 50% in unit cost of lettuce increased revenue to 75$ keeping other factors constant.

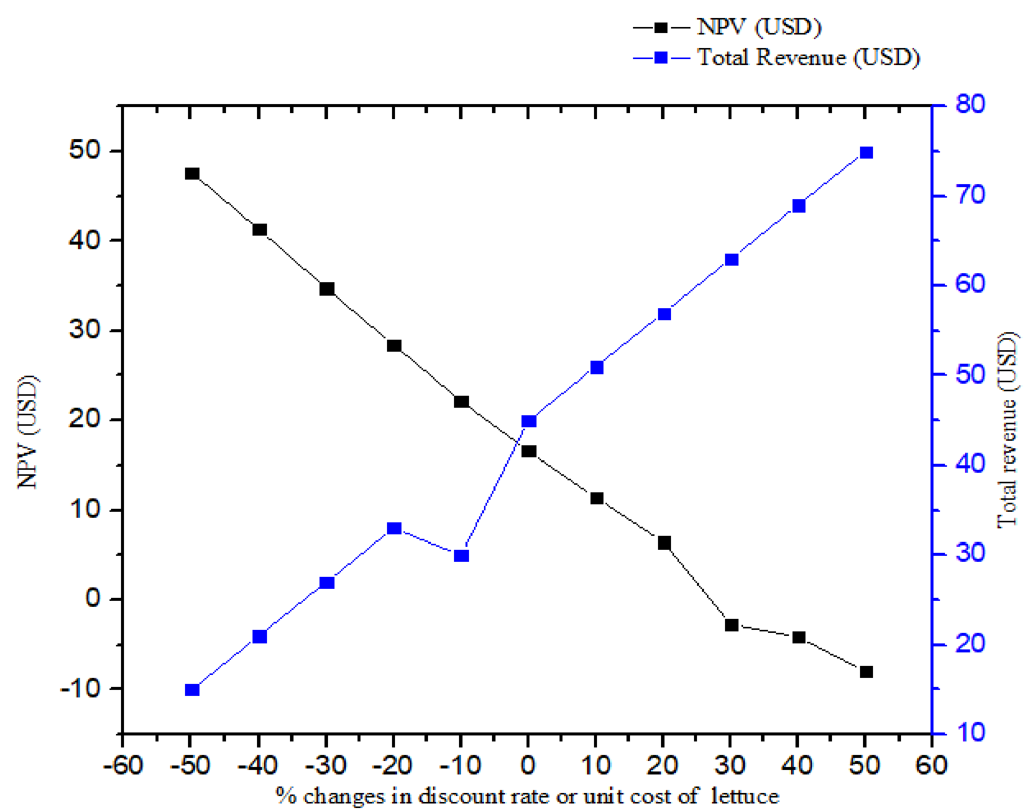

Figure 14: Effects of a change in discount rate on the NPV and change in unit cost of lettuce on the total revenue earned from sale of 60 heads of hydroponic lettuce

(ii) Scenario Analysis

Regarding the scenario analysis, the impact of a change in unit cost for sale of different quantities of lettuce on revenue earned was evaluated to predict risks and maximize opportunities. Results showed that a change in unit cost of the lettuce had a significant influence on the total revenue generated from the sale of different quantities of the lettuce as anticipated.

A 50% reduction in the projected unit price of a lettuce head (0.75$) will result into earnings of 7.5$ for 30 heads of lettuce sold (Fig. 19). Alternatively, selling 10 heads at the assumed unit price of 0.75$ will earn 7.5$. Table 16 shows a forecast of the effect of a change in unit cost of lettuce and in the number of lettuce heads sold on the total revenue earned. Small scale urban hydroponic farmers can thus make more profit by opting to borrow money from low interest firms, farmers groups or SACCOs to offset the impact of cost of borrowing on the NPV or revenue generated.

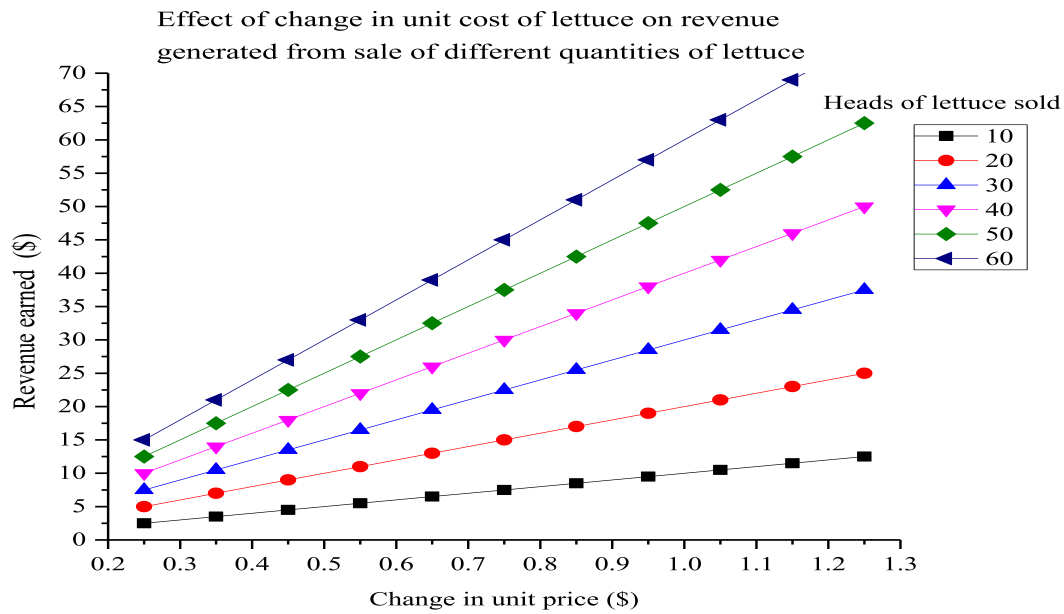

Figure 19: Graph illustrating scenario analysis based on variation in unit price as per heads of lettuce sold and revenue

A scenario analysis is generally a method of forecasting the possibility of an incidence of an intervention following its continuity based on changing two or more variables at the same time (Kishita *et al.,* 2016). Berkhout *et al.* (2002) described scenarios as "learning machines" which assist in explaining future concepts and support communication among stakeholders. The study results showed that a change in unit cost of the lettuce has an impact on the total revenue generated from the sale of different quantities of the lettuce as expected. This implies that revenue generated from an intervention depends on the unit price of a product which is also determined by demand and supply factors.

If the position of an investor is to provide quick precise revenue tax returns, setting a low price for the commodities is the proper approach to employ (Staliūnienė, 2014). A study by Duinker and Greig (2007) encouraged environmental impact assessment (EIA) specialists to consider and adopt scenario-based studies and approaches in order for EIA to effectively achieve sustainable growth. This justifies the role of the above scenario based model in the achievement of sustainability with in cities.

Table 16: **Effect of variations in unit cost of lettuce and quantity sold on revenue earned**

Change in Quantity ↓	10 % Change in unit cost of lettuce ($) ↓										
	-50	**-40**	**-30**	**-20**	**-10**	**0**	**10**	**20**	**30**	**40**	**50**
				↓	**Revenue earned**						
10	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5
20	5.0	7.0	9.0	11.0	13.0	15.0	17.0	19.0	21.0	23.0	25.0
30	7.5	10.5	13.5	16.5	19.5	22.5	25.5	28.5	31.5	34.5	37.5
40	10.0	14.0	12.0	22.0	26.0	30.0	34.0	38.0	42.0	46.0	50.0
50	12.5	17.5	22.5	27.5	32.5	37.5	42.5	47.5	52.5	57.5	62.5
60	15.0	21.0	27.0	33.0	39.0	45.0	51.0	57.0	63.0	69.0	75.0

(iii) Linear Regression

A linear regression analysis was perfomed to approximate a model that can predict and estimate the revenue earned or quantity that can be sold as a result of a change in the unit price of lettuce. The analysis also aimed at identifyig the direction of the relation ship between the variables. Results (Table 17) revealed a significant relationship exists between revenue earned ($\rho = 0.04$), quantity sold ($\rho = 0.01$) and price of the lettuce at $\rho < 0.05$. This shows that the unit price of lettuce has a statistical significant influence on revenue earned and quantity sold.

Table 17: **Linear regression analysis results**

Variables	Regression analysis			t-stat
	R^2	**P-value**	**Multiple R**	
	Unit price			
Revenue	0.71	0.04*	0.84	3.09
Quantity sold	0.80	0.01*	0.91	-4.27

"*" indicate a significant difference at $P < 0.05$

Nonetheless, based on the regression co-efficients, the impact of a change in the unit price of lettuce was slightly stronger and negatively affected the quantity sold ($R = 0.91$) as expected than the influence of the same independent variable on revenue earned ($R = 0.84$). The linear model on revenue earned (Equation 8) and quantity of lettuce sold (Equation 9) as a function of unit price indicated that for every change in the unit price per head of lettuce, there is a corresponding 22.53 increase in unit price towards the revenue earned and a 38.67 unit decline in price towards the quantity of lettuce sold respectively (Fig. 20).

$$(\gamma = 22.533x + 25.367)$$

Equation 6

$$(\gamma = -38.673x + 85.063)$$

Equation 7

For example: a unit price of 0.9$ for lettuce will lead into a sale of a lower quantity lettuce), approximately 50 heads of lettuce (Equation 10) and concurrently earn more revenue of nearly 45$ (Equation 11).

$$(\gamma = -38.673 * 0.9 + 85.063) = 50$$

Equation 8

$$(\gamma = 22.533 * 0.9 + 25.367) = 45.6\$$$

Equation 9

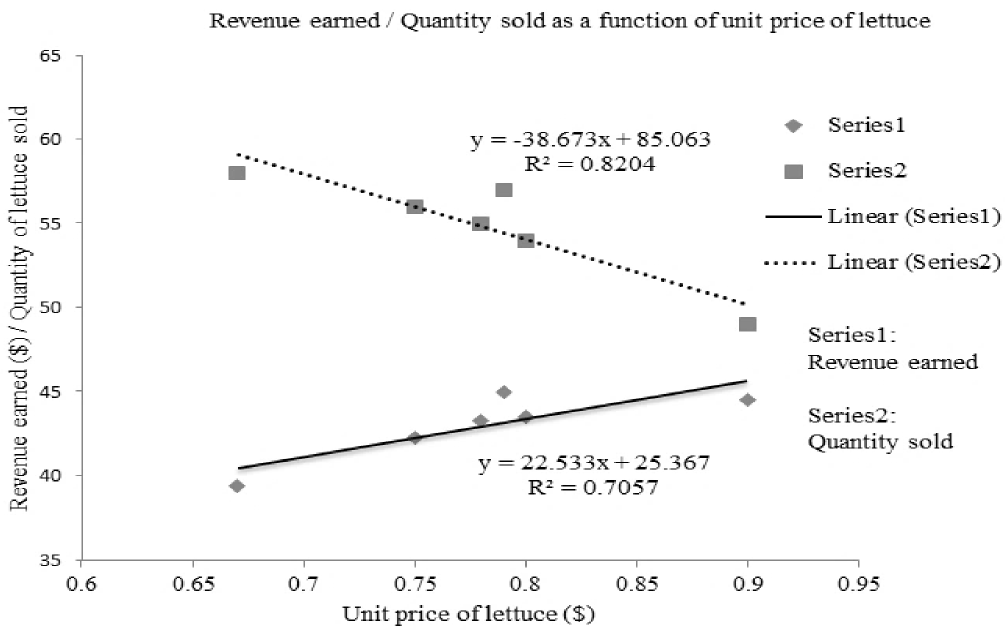

Figure 20: Graph illustrating the linear regression lines and models of revenue earned and quantity sold as a function of unit price of lettuce

(iv) Comparison on lettuce Production under Hydroponics and Conventional Farming

An economic assessment was done on a co-current comparative study in which lettuce was grown in black potting bags on a wooden stand using soil as a medium (Plate 5- left) in the same urban home stead using a space of 16 m^2. This depicted the total capital required for the 6 CPPs at roughly 129$ which was higher than that of hydroponic crop production by 42$. Results (Table 15) showed that the unit cost of lettuce production under conventional farming was 0.36$ with an NPV of 58.09$ at a 10% discount rate. The profitability index was 1.45 which was also slightly close to that of non-greenhouse hydroponic lettuce production thus making hydroponic vegetable production as economically feasible as the conventional urban vegetable crop production systems. The non-discounted payback period was however shorter with a break-even point of approximately 6 months of production (3CPPs) less than that of hydroponic lettuce production. This is likely caused by the low inputs required hence low capital input. It is however worth noting, that traditional crop cultivation system requires; high labor in-put, weeding, consistent irrigation leading to high water consumption.

Previous literature shows limited studies exploring capital budgeting in less developed countries yet this is one of the most vital pillars of investment decisions for projects or innovation (Wnuk-Pel, 2014). In order to evaluate the performance or success of an innovation, there is need to subject it to measures that will help understand whether the innovation or investment will generate profits or losses. The NPV is one of the main economic measures used in economic evaluation and it works on 2 major principles, which are:

(i) An assured dollar of today is better than a less valued dollar of tomorrow.

(ii) Consideration of all expected future net cash flows connected to the investment (Ondřej, 2014).

This implies that the method considers the projected risk of the innovation by discounting all projected future cash flows where the discount rate used in discounting reveals the opportunity cost of the initial investment. While the second principle indicates that the method considers all future net cash flows as compared to other methods that only consider initial investment. The importance and consistency of a measure in terms of economics depends on its compatibility with NPV. A measure is said to be reliable with NPV if it signals value creation (Andrea & Carlo, 2014). Results on NPV from the study depicted lettuce hydroponic farming as a measure that signals value creation and thus profitable. Similar studies have also shown lettuce production in soilless outdoor systems as an economically feasible venture (Maestre-Valero *et al.*, 2018).

Besides the above, Sulma *et al.* (2019), noted that hydroponic farming allows crop production of at least 30 plants/m^2. Considering the vertical crop production system, the amount of space used for the experiment can as well be used to produce over 180 vertically crops which is more than 30 plants/m^2. Malek (2015) also stated that vertical farming has the ability to offer food supply to cities in a sustainable way. Lettuce production using vertical hydroponic farming in particular offers a distinctive opportunity for producing high yields per unit area of land cultivated through extension of crop production into vertical magnitudes (Dionysios *et al.,* 2016). This further validates the profitability of the small-scale urban hydroponic unit. The unit cost of production for growing hydroponic lettuce was calculated at 0.46$ which is slightly lower than that of hydroponic lettuce (0.49$) produced using floating system under a greenhouse in a study carried out by Rosa and Gonzabay (2020) with sale price of 0.70$/unit. This indicates that the extra costs incurred under greenhouse hydroponic farming don't significantly affect the unit cost of production thus non-greenhouse hydroponic vegetable production can still be as profitable as greenhouse hydroponic production.

Research studies have shown that the costs of producing hydroponic vegetables inside greenhouses is higher compared to traditional farming systems (Shady *et al.*, 2021). This is associated with the high initial costs required such as; electricity, water pumps, greenhouse construction etc… Due to the low initial costs required, the initial investment recovery period (NDPBP) as shown in Table 15 was fairly short (4 CPPs/ approximately 8 months) as compared to ordinary hydroponic vegetable cultivation inside a green house. This implies that the farmer would be able to pay back the loan as well as the interest rate before the loan period granted. The elimination of costly equipment such as: Timers, green house construction materials among others justifies the low loan recovery period. The high initial costs related to greenhouse crop production present a challenge in the adoption of this sustainable crop production system (Jadhav & Rosentrater, 2017) as they lengthen the investment recovery period.

Since the Internal Rate of Return (12.57%) was higher than the cost of borrowing (10%), the investment was considered cost-effective (Table 15). A high IRR signifies better rate of return on the investment excluding external factors. Furthermore, the analysis results showed a profitability index of 1.1 which also presented the investment as feasible. The P. I indicated that the projects present value is more than the initial investment. One of the features of price dertermination theories is the descending / sloping demand curve which tells an inverse relationship between price and out put levels (Kahn, 1984). A higher price attached to a commodity simultaneously causes low sales. Therefore, a low market demand for the commodity will attract a low price attachment to the commodity and thus higher quantity sold reflecting the linear relationship between unit price and quantity sold visa viz revenue earned as seen in Fig. 19. Zenghelis and Paul (2021) noted that it is crucial to recognize innovative procedures so as to prevent reliance on carbon and resource intensive technologies inorder to respond to detoriating natural environment settings.

Understanding economic methods such as; the regression modelling, sensitivity analysis for non resource intensive technologies such as; small scale urban hydroponic farming can assist in reducing the dependency on carbon intensive soil based crop cultivation methods in urbanities. This contributes to sustanability within cities through (climate action). Production of biomass mainly from agricultural activities contributes to nearly 90% of biodiversity loss comprising of ecosystem around urban areas. People are thus likely to experience water scarcity as a result of the increasing conflict for water between capitals and agriculture (Zenghelis & Paul, 2021). Proper climate smart technologies in urban areas can contribute to a reduction in this biodiversity loss and water scarcity. The economic theory suggests that societies that accept change with flexibility and expanded assets are in better position to manage organizational ammendments (Zenghelis, 2016).

A number of economic models have tried to include innovation. However, it is contingent on "research and advancement, implementation and adoption as well as economies of scale" for it to be effective (Mamta & Shraddha, 2013). The economics of smart agricultural technologies that favour urban food production is relevant in enhancing the adoption of such innovative technologies. This can be achieved through disseminating information about their costs and profits and over all science sorrounding their operation especially for technologies that are more implemented in developed countries than LDCs. Cities have a crucuial role in developing novel technologies that enhance adaptation and mitigation to the changing climate (Orejon-Sanchez *et al.,* 2022). This plays a key role in enhancing sustainable cities and socities in general.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

(i) The adoption of hydroponic farming in Uganda and Tanzania can be boosted by governments or policy makers providing more information to about the technology to farmers and also providing financial incentives or grants to farmers.

(ii) Producing lettuce using a vertical hydroponic system under a non-controlled environment can be an alternative cropping system for not only urban farmers but also farmers in areas that have limited or no arable land. This can boost vegetable production and accessibility. This is owed to the simplicity of the system in terms of technology and the yield.

(iii) The system is cost-effective with an adequate profitability index, returns on investment and presents an opportunity to re-cover capital invested within a short period of time.

In a nutshell, the research study designated a low-cost hydroponic system that can assist in improving vegetable production in low-income countries faced with the challenge of food insecurity around urban areas. Adoption of hydroponic farming can contribute to the sustainable development goal 3, good health and wellbeing 11, sustainable cities and communities.

5.2 Recommendations

Farmers are encouraged to pay more farm visits to the already existing hydroponic farms to boost their knowledge about hydroponics. Adoption of low-cost hydroponic systems at a small scale is also recommended to farmers as a means of learning more about the technology and improving its adoption across the continent. Due to the limited uptake or implementation of the technology in the study areas, there is need for researchers to innovate more low-cost hydroponic solutions that can motivate farmers to adopt this farming system. Further research can also be carried out to study the nutrient composition of vegetables produced using this low-cost hydroponic system. Sectors such as; the government bodies or policy makers are encouraged to support farmers through small grants or providing hydroponic equipment at subsided prices to farmers to improve adoption of this farming system.

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APPENDICIES

Appendix 1: Questionnaire

Introduction

My name is Margaret .S. Gumisiriza, a PhD student at The Nelson Mandela African Institute of Science and Technology, Arusha, Tanzania. I am conducting a study with the title below as part of my study program.

Title: status, physiognomies & economic viability of hydroponic vegetable production in selected areas of Uganda and Tanzania.

This study aims identifying the factors connected to hydroponics in Uganda and Tanzania with the aim of enhancing the awareness and adoption of this technology in East Africa. In this questionnaire, you are requested to answer some questions about hydroponics. You have the liberty to skip the questions that you are not comfortable answering or have limited knowledge about and are welcome to expound on the any questions with further information. Information provided will be kept confidential only accessible by the research team. As a participant, you are not requested required to pay to take part in the study and no money will be offered for your participation.

Questionnaire

Factors related to the practice of hydroponic farming in Uganda and Tanzania

(a) <u>Respondent/Farmers' Bio-data</u>

(i) **Sex:** (a) Female (b) Male

(ii) **Country:** ……………………………………………………………………………...........

(iii) **City:** ……………………………………………………………………….................

(iv) **Village:** ………………………………………………………………………………..

(v) **Name of the farm:** ………………………………………………………………….

(vi) **Size of the farm:** 0 < ¼ an acre (b) ¼ < ½ an acre (c) ½ < 1 acre (d) Above an acre

(vii) **Education level:** (a) Primary (b) Secondary (c) Tertiary (d) University (e) None

(b) <u>Agricultural factors</u>

1) How did you learn about hydroponic farming?

(a) Through government bodies (b) Farmers

(b) Non-government bodies: ………………………………………………………

(c) Private organizations: ……………………………………………………....

(d) Others: ………………………………………………………………………

2) What crops do you grow with your hydroponics?

(a) Fruits …………………………………………………………………………………

(b) Vegetables: ……………………………………………………………………….

(c) Flowers: ………………………………………………………………………….

(d)Others, Specify: ………………...………………………………………………..

3) Why do you grow those specific crops mentioned in b (ii) above?

(a) They have high market demand

(b) They grow very fast

(c) They are easy to grow as they require less attention

(d) Others: ……………………………………………………………………………

4) What hydroponic farming method do you use for growing your crops?

(a) Flood & Drain (b) Aeroponics (d) Wick system (e) Deep Water culture (f) NFT

(g) Drip hydroponic system (h) Kratky

5) Why did your select that hydroponic farming system?

(a) It is cheap and affordable (b) Materials are easily available (c) Easy to maintain

(d) It supports the type of crop being grown

(e) Others: ……………………………………………………………………

6) What medium do you use to support your crops?

7) (a) Rock wool (b) Saw dust (c) Gravel (d) coco-coir (e) sand (f) Others………………………………

8) Why do you use the medium selected above?

(a) It is cheap (b) Readily available (c) Has good support for the crop grown

(b) Others: ……………………………………………...

9) What kind of materials do you use for planting your crops?

(a) Hydroponic materials (PVC pipes) (b) Locally available materials: ……………….. …………………… (c) Others: …………………………….

10) Where do you grow your hydroponic crops?

(a) Green house (b) Locally made shelter (c) Open environment

(d) Others; ………………………………………..

11) Why did you select the type of housing mentioned above?

(a) It is cheap and affordable (b) Materials are easily available (c) Easy to maintain

(a) Other: ……………………………………………………………………………

12) What fertilizer do you use for growing your crops?

…………………………………………………………………………………………

13) What is the amount of water that you use to grow your crops per season?

(a) 10-20 litres (b) 21-30-litres (c) 31-40litres (d) More than 41 litres

14) Where do you acquire the hydroponic fertilizers from?

(a) Agricultural stores…………………………………………………………

(b) Imported: ….………………………………………………………………

(c) Retail shop

(d) Government

(e) Others: ………..……………………………………………………………….

Economic Factors

15) How much do they cost per kg/litre?

a) 0.1-10$ (b) 11-20$ (c) 21-30$ (d) above 30$

16) How often do you add fertilizers to the hydroponic system?

(a) At every stage of growth (b) after every month (c) I don't add till harvest

Other: ……………………………………………………………………..

30) Where do you sell your harvested hydroponic produce?

(a) Local market (b) International market (c) Both local & international market

(d) Others: ……………………………………………………………………

32 a) Do you receive any financial support for this farming technology?

(i) Yes (ii) No

b) If yes, where do you get the financial support from?

(a)Family (b) NGO (c) Government organizations (d) Private organizations

(e)Others: ………………………………………………………….

34 a) Is hydroponic farming your main economic activity?

(a) Yes: main activity (b) No

© Social factors

36) Where is the hydroponic farm located?

(a) Farmers' home stead (b) Away from the home (c) Others; ……………………………

37) How many workers do you have on your farm?

(a) 1-5 (b) 5-10 (c) 10-15 (d) above 15

38) What kind of labor is it?

(a) Home labor (b) Hired labor (c) Hydroponic specialists (d) Others:

39) What benefits have you achieved from hydroponic farming?

40) What challenges have you faced with this farming technology?

41) What can be done to enhance the adoption of hydroponic farming in the country?

Appendix 2: Nutrient composition in the Poly-feed fertilizer

Macro nutrients			Micro nutrients (PPM)				
N	**P**	**K**	**B**	**Fe**	**Mn**	**Zn**	**Cu**
19	19	19	100	500	250	75	55

N: Nitrogen, **P:** Phosphorus, **K:** Potassium, **B:** Boron, **Fe:** Iron, **Mn:** Manganese, **Zn:** Zinc, **Cu:** Copper

Appendix 3: Results on the performance of green and red lettuce at harvest between hydroponics and conventional farming

Parameters	P-values	
	H-R×S-R	**S-G×H-G**
PH (cm)	0.08	0.07
NL	0.59	0.52
LW (cm)	0.08	0.28
RL(cm)	**0.01***	**0.02***
FW (gm)	**0.03***	**0.02***
DM (%)	**0.02***	**0.01***

H-R: Red lettuce in hydroponics, **H-G:** Green lettuce in hydroponics, **S-G:** Green lettuce in soil, **S-R:** Red lettuce in soil.

PH: Plant height, **NL:** Number of leaves, **LW:** Leaf width, **RL:** Root length, **FW:** Fresh weight, **DM:** Dry matter

P-values show interaction of means of lettuce varities across the two farming systems (across rows) at 0.05 level. * and diffferent letters across rows indicate a significant difference at $p < 0.05$ under 2 sample T-test

RESEARCH OUTPUTS

(i) Publications

Gumisiriza, M., Ndakidemi, P., & Mbega, E. (2020). Memoir and Farming Structures under Soil-Less Culture (Hydroponic Farming) and the Applicability for Africa: A Review. *Agricultural Reviews, 41*(137), 139-145. https://doi.org/10.18805/ag.R-137

Gumisiriza, M., Kabirizi, J., Mugerwa, M., Ndakidemi, P., & Mbega, E. (2022). Can soilless farming feed urban East Africa? An assessment of the benefits and challenges of hydroponics in Uganda and Tanzania. *Environmental Challenges, 6*. https://doi.org/10.1016/j.envc.2021.100413.

Gumisiriza, M., Ndakidemi, P., Nalunga, A., & Mbega, E. (2022). Building food secure cities through vertical soilless farming: A cost-effectiveness analysis on a small-scale outdoor hydroponic system, *Sustainable cities and societies,* 103923 https://doi.org/10.1016/j.scs.2022.103923

Gumisiriza, M., Ndakidemi, P., & Mbega, E. (2022). A simplified non-greenhouse hydroponic system for small-scale soilless urban vegetable farming. *MethodsX.* 9 (101882) https://doi.org/10.1016/j.mex.2022.101882

Gumisiriza, M., Aloo, N. B., Makumba, B., Tumuhairwe, J. B., Ndakidemi, P., & Mbega, E. (2022). Prospects for soilless farming in Africa: A review on aids of plant growth-promoting rhizobacteria inoculants in hydroponics: *International Journal of Biosciences,* 21 (5), p. 273-282, http://dx.doi.org/10.12692/ijb/21.5.273-282

Gumisiriza, M., Ndakidemi, P., & Mbega, E. (2023). Soilless urban gardening as a post covid-19 food security salvage technology: A study on the physiognomic response of lettuce to hydroponics in Uganda. Scientific African, 20 (e01643). https://doi.org/10.1016/j.sciaf.2023.e01643

(ii) Poster Presentation

(iii) Workshops where research project work has been presented

(a) Sustainable Agriculture and Rural Transformation: Meeting Smallholders' Needs in Socio-Ecological Systems: 20th-24th, November 2021, *Rights Livelihood College,* Bonn, Germany.

(b) Contextualizing agricultural interventions and rural development strategies: Addressing smallholders' livelihoods vis-à-vis market changes, land tenure and soil fertility: 5th-10th, October, 2021, *Pride Inn Azure hotel,* Nairobi, Kenya.

(c) Poster presentation at the DAAD summer school programme on "project development for knowledge transfer"; *Leipzig University,* Leipzig, Germany, 3rd-30th September 2018.

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Development of a solar-powered-organic hydroponic system for vegetable farmers in Tanzania

Water-gro
Do it differently

The dilema of Climate change & variability in E.A!

Impact of climate change on food security
- Drought → Water scarcity → Low crop yields
- Heavy rainfall → Floods → Inadequacy of arable land
- Heavy rainfall → Over production → Wastage of yields

Problem over view

Majority of farmers in E.A rely on soil-based cultivation which is affected by **climate change** coupled with the **increasing population** resulting into food insecurity. There is need to adopt **climate-resilient agro-technologies** like **hydroponic farming (HF)** especially in urban centres which are faced with these challenges.

Farmer demands

Low cost climate-smart agro-technologies → Increased food production → Income generating urban farming practices

Main objective of the project

To develop a **cost-effective solar powered hydroponic farming system** that utilizes **organic components** for vegetable production among small-scale urban farmers in East Africa.

System name & its components

Water gro ← Grow channels, Plant medium, Organic fertilizer, Solar panels

Expected outputs

- Increased **all-year round food production** &
- **Income generation** among urban farmers.
- Promotion of **disease & pest free farming**.
- Increased adoption of **climate-smart agro-technologies**.

Key requirements for system development

Hydroponic system: Financial capital, Human resource, Raw materials, Laboratory supplies

Activities and time frame (2019-2020)

No.	Activities	Time (Months)
1.	Identification of collaborators & Resource mobilization	1
2.	Baseline survey	2
3.	Development & testing of prototype	10
4.	Field trial of prototype	8
5.	System patenting	3
6.	Dissemination of knowledge	6
	Total	30

Transforming to low cost urban agriculture in E.A

DAAD Deutscher Akademischer Austauschdienst German Academic Exchange Service

Nelson Mandela African Institution of Science and Technology, Tanzania