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# Can soilless farming feed urban East Africa? An assessment of the benefits and challenges of hydroponics in Uganda and Tanzania

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A R T I C L E I N F O

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A B S T R A C T

East Africa has the potential to boost its urban food production through adoption of soilless farming techniques. The case study assessed the benefits and drawbacks allied with hydroponic vegetable farming among urban and peri-urban farms in Northern Tanzania and Central Uganda. Snowball sampling was used to identify 150 vegetable farms/farmers through urban farmers' groups and recommendations from the agricultural organizations from Uganda and Tanzania. Based on the complexity and distinctiveness of this farming system, only 51 individuals engaging in hydroponic vegetable production took part in responding to the semi-structured Google form questionnaire that was issued through social media platforms, face to face interviews and farm visits. Results from the study showed that hydroponics is a climate smart farming system ($n = 13$, 26%), produces high yields within limited space ($n = 24$, 48%), has no soil borne pests and diseases ($n = 10$, 20%) and gives the farmer the ability to control environmental conditions ($n = 2$, 4%). On the contrary, over 50% of the respondents reported high investment costs ($n = 16$, 31%) and lack of adequate knowledge on hydroponics ($n = 11$, 22%) as the main limitations of the technology. Based on farmers' recommendations, hydroponics has potential to increase food security within urban areas if more efforts are put in sensitization about the farming system and research into ways to reduce the high costs associated with the technology.

## 1. Introduction

### 1.1. Background

The world population is expected to increase to 9.5 billion people in the next 40 years. This calls for an increase of over 60% in food production worldwide at least by 2050 to combat the crisis faced by the continuously increasing population (Saiz-Rubio and Rovira-Más, 2020). Unfortunately, natural resources such as: land meant to sustain food production and meet the demands of such an expected population increase are diminishing coupled with the high cost of the limited existing land (Angotti, 2015). The high rates of urbanization and environmental degradation caused in the last decade have negatively impacted on the quality (nutrient composition and physical characteristics) and quantity of food production (Manos and Xydis, 2019). Besides the above challenges, there is a problem of nutrient depleted soils and water scarcity across the globe and these are expected to exacerbate in the face of the increasing population especially in urban areas (Magwaza et al., 2019). Traditional farming is generally faced with problems of weather changes, water pollution, soil degradation and soil infertility (Bationo and Waswa, 2011).

Africa alone continues to fight the problem of food insecurity where improved yield and sustainability in the agriculture sector can best be achieved through climate smart agriculture (CSA) (Anastasios et al., 2020). CSA has been defined as an intervention vital for maintainace of global food security and nutrition through changing and readjusting agricultural practices within the new era of climate change (Reinhard and Verburg, 2020). In order to conserve sustainable crop production systems, there is need to utilize spaces like: non-arable

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**Table 1**
Descriptive analysis of socio-economic factors linked with soilless farming.

| Factor | 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 |

Source: Field data.

fields that do not support crop cultivation and develop alternative cultivation methods (Angotti, 2015; Manos and Xydis, 2019). This justifies the increasing use of various smart agricultural technologies to meet these rising levels of food insecurity. Emami et al. (2018) described smart agriculture as the use of technology that has the capability to increase food security if well streamlined to the domestic levels. On other hand, CSA synchronizes actions by researchers, policy maker, private institutions, societies and farmers to promote climate resilient systems, practices and technologies (Lipper et al., 2014).

## 1.2. What is soilless farming?

Soilless culture is one of the growing smart agriculture technologies in East Africa which encompasses growing crops with or without a media or using a static/flowing nutrient solution (Qiansheng et al., 2018). Media refers to an organic or inorganic solid material that is used in the place of soil either in single or mixed form to provide support to the plant, for example: perlite, vermiculite, rice hulls, saw dust, coco-peat (Gruda et al., 2018; Gumisiriza et al., 2020). Soilless farming is largely used under controlled environment mainly for horticultural crops and gives the opportunity to cultivate in areas with un favorable agriculture conditions such as: poor soils and limited space among other benefits (Lu et al., 2017; Zhigang and Qinchao, 2018). Soilless farming has the capacity of solving some of prior challenges such as: limited water availability and soil degradation, reduced pests and diseases, while promoting sustainable agriculture (Sambo et al., 2019). Soilless farming is divided into 3 main categories which are: hydroponics, aeroponics and aquaponics (Bruce Campbell et al., 2014).

***Aquaponics*** is a soilless farming system where plants and fish are raised in an associated relationship as the water is recycled through the system and plants uptake nutrients acquired from recycled fish waste water (Juarez, 2018). ***Aeroponics*** on the other hand is a technique where devices like foggers are used to supply plant roots with nutrients inform of a mist (Tessema and Dagne, 2018; Lakhiar et al., 2018).

**Table 2**
Agricultural factors related to hydroponic vegetable production.

| Factor | 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 irrigation | 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-$\frac{1}{4}$ acre | 30 | 58.8 |
| | $\frac{1}{4}$- $\frac{1}{2}$ acre | 10 | 19.6 |
| | $\frac{1}{2}$ - 1 acre | 6 | 11.8 |
| | More than 1 acre | 5 | 9.8 |

Source: Field data.

## 1.3. Hydroponics

Arshad Mahmood et al. (2018) described ***hydroponics*** as an agriculture system for growing crops in water composed of mineral nutrients supported by medium. This system which uses less water as compared to soil faming has successfully been used for cultivation of different vegetables like: lettuce, spinach, cucumbers, tomatoes among other crops as these respond well to hydroponics due to low nutrient demands and short growth period (Cifuentes-Torres et al., 2020). New drifts in agriculture have shown hydroponics as one of the new innovative soilless farming systems to realize satisfactory outcomes and has the potential to produce more yields in minimal space and promote food security through production of food vertically (Rattan, 2016; Joshitha et al., 2021; Dionysios et al., 2016) thus should be considered as a better farming option for East Africa facing a quandary of challenges as earlier discussed. Hydroponic farming has different types which include: Nutrient Film Technique (NFT), Wick system, Drip system, Ebb and Flow and Deep water culture (DWC). Wick system is the simplest hydroponic method which uses wicks to draw nutrients from the reservoir without use of pumps or timer while NFT hydroponics is a method where shallow channels are used to supply the nutrient solution to the bare plant roots through re-circulation process (Nisha et al., 2019). DWC is a method of hydroponics in which plant roots are suspended directly into the nutrient rich water solution while drip system uses micro emitters to drip the nutrient and water directly to the plant roots with the help of a pump (Verdoliva et al., 2021). Ebb and Flow involves flooding the plant tray with the nutrient solution using a pump that is connected to the solution tank at given time intervals with the use of a timer. The solution is later drained back to the nutrient tank.

Adoption of hydroponics in East African countries like: Uganda and Tanzania, where this technology might offer a profitable agri-business and food security solution for urban dwellers by tapping into the growing demand for local produce, is still very low (Nicole et al., 2021). The potential of hydroponic farming in these developing countries hasn't yet been fully established (Croft et al., 2017). It is likely to be more complicated to provide sufficient food for the fast-growing population using traditional agriculture in future, therefore soil-less cultivation is the right substitute technology to adapt effectively (Lakhiar et al., 2018). There has also been a lot of attention given to urban agriculture among researchers, scientists and the general public (Buscaroli et al., 2021) which calls for more attention into hydroponics as it is considered an urban farming technology. Based on the impasse of challenges presented by conventional farming practices, urbanization and the increasing urban population as well as the ability of hydroponics to tackle these challenges, this study focused on examining the status and perception of soilless farming (hydroponics) in Central Uganda and Northern Tanzania as an alternative sustainable cropping system to increasing food security and agdribusiness opportunities around urbanand peri-urban areas.

Focus was specifically put on a couple of influential factors majorly socio-economic and agricultural factors surrounding the urban and semi-urban farmers and farms practicing hydroponics in these countries. The study assessed and categorized the benefits, challenges and recommendations for enhancing the implementation of this technology. It focused specifically on vegetable production because research has shown vegetables to be one of the most easy-to-cultivate crops under hydroponics as earlier mentioned.

## 2. Materials and methods

### 2.1. Study site and sample size

The study was carried out in the months of April-July 2021 in the urban and peri-urban areas of Meru district located in Northern Tanzania and Wakiso district located in Central Uganda. Tanzania and Uganda are both located in East Africa and experience tropical climate conditions. Tanzania has an estimated population of 58 million while Uganda has approximately 44 million people. Northern Tanzania was selected as study site because it is one of the vegetable growing hot spots in the country and also has a couple of large hydroponic farms in the country while the Central Uganda was selected because it has majority of the urban and peri-urban farmers engaging in soilless farming. A total of 150 farmers/firms/farms were identified using snowball sampling (Espinosa et al., 2012) through farmers groups and recommendations from expert farmers and agricultural bodies. 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 both 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.

### 2.2. Data collection and analysis

A pre-tested semi-structured questionnaire using both closed and open-ended questions was designed to capture socio-economic and agricultural factors related to hydroponic farming as well as the benefits and challenges faced by the farmers and farms at large. 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.

Based on the COVID-19 challenges and restrictions, the questionnaire was designed and answered using Google forms and face-face interviews with key informants especially with companies that were engaging in seed production using soilless farming. Due to the limited sample size, data collected was coded and summarized into frequencies using the Statistical Package for Social Sciences (SPSS) version 26.0 and presented using tables and graphs.

## 3. Results and discussion

### 3.1. Descriptive analysis of socio-economic and agronomic factors associated with hydroponic vegetable farmers in Tanzania and Uganda

This analysis looked into and summarized the factors that describe 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. 9.8% ($n = 5$) of the respondents were from Meru district while 90.2% ($n = 46$) were from Wakiso district. Soilless farming in Meru is mainly practiced for large scale vegetable seed production thus the respondents were majorly operators/farm managers from large scale commercial hydroponic companies thus representing large scale hydroponic farming. About 33% ($n = 17$) of the respondents were female while about 66.7% ($n = 34$) were male. Majority of the respondents, (41.2%, $n = 21$) as were aged 26–35 years and the least age group were those aged above 56 years (9.8%, $n = 5$) for each group. A contrary 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).The study revealed that the largest number of hydroponic farmers 64.7% (33) were university degree holders and only 2% ($n = 1$) did not have any education background. This shows the educated individuals are more willing to take on this complex technology which as compared to traditional farming systems that don't have a lot of technicalities. Few participants engaged in hydroponics as their main economic activity (21.6%, $n = 11$) while selling produce and also carrying out hydroponic trainings 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 that use soilless farming for production of vegetable seeds for export ($n = 3$, 5.9%) (Table 1). Regarding the agronomic factors (Table 2), 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. Drip irrigation was reported as the most used hydroponic system because it does not require full automation for growing the vegetables and is cheap compared to other hydroponic systems (54.9%,$n = 28$). 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. This is because majority were producing lettuce which can easily be grown using PVC pipes. Only 5.9% ($n = 3$) reported using hydroponic grow pots to grow their vegetables. Hydroponic grow pots which are not readily available in Uganda and Tanzania 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 because it is readily available and less expensive as compared to other media such as: peat moss, vermiculite and rock wool as reported by 9.8% ($n = 5$) of farmers. Approximately 58.8% ($n = 30$) of the participants grew hydroponic vegetables on land size of 0–1/4 an acre mainly within their home backyards. Tables 1 and 2 below summarize the different socio-economic and agronomic factors associated with hydroponic vegetable farming in Uganda and Tanzania.

Fig. 1 (a and b) shows hydroponic lettuce production outside the greenhouse while Fig. 2 shows cucumber production in a greenhouse.


**Fig. 1.** a and b. Hydroponic lettuce production outside the green house using PVC pipes and plastic buckets as grow containers. Source; Field data

**Fig. 2.** Cucumber production inside a locally made non automated greenhouse using normal grow bags and drip irrigation system. Source; Feild data

Figs. 3 and 4 show the socio-economic and agricultural factors related to hydroponic farming of vegetables in Uganda and Tanzania, respectively.

### *3.2. Benefits of hydroponic farming in Uganda and Tanzania*

Previous research has pointed out hydroponic farming to have a number of benefits as compared to other traditional farming system. Hydroponic in general promotes environmentally friendly measures with the ability for improved commercial food production and perform better than traditional open field farms (Buehler and Junge, 2016; Daina et al., 2018). One of its advantage is the production of good quality crops (Nisha et al., 2019; Pace et al., 2018; José et al., 2020). Approximately 24% ($n = 12$) of the farmers recognized this advantage stating that hydroponic vegetables are clean with good color, taste, uniformity in texture and size, and pesticide residue free. Results from a study in Trinidad similarly reported a high willingness to pay greenhouse-“hydroponic tomatoes” compared to “open-field” tomatoes based on being free of pesticides (Narine et al., 2014). Hydroponically grown crops have more mineral composition than soil grown plants (Sapkota et al., 2019). About

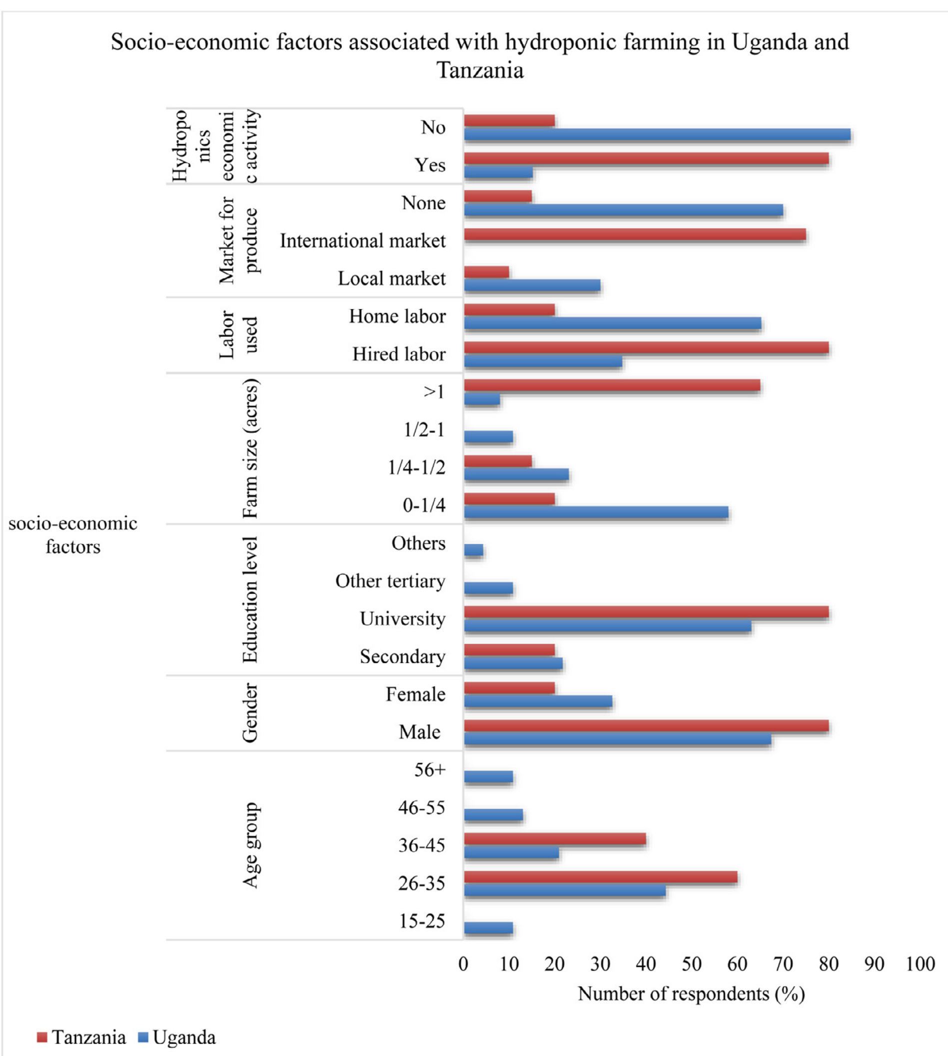


**Fig. 3.** Socio-economic factors related to hydroponic farming of vegetables in Uganda and Tanzania.

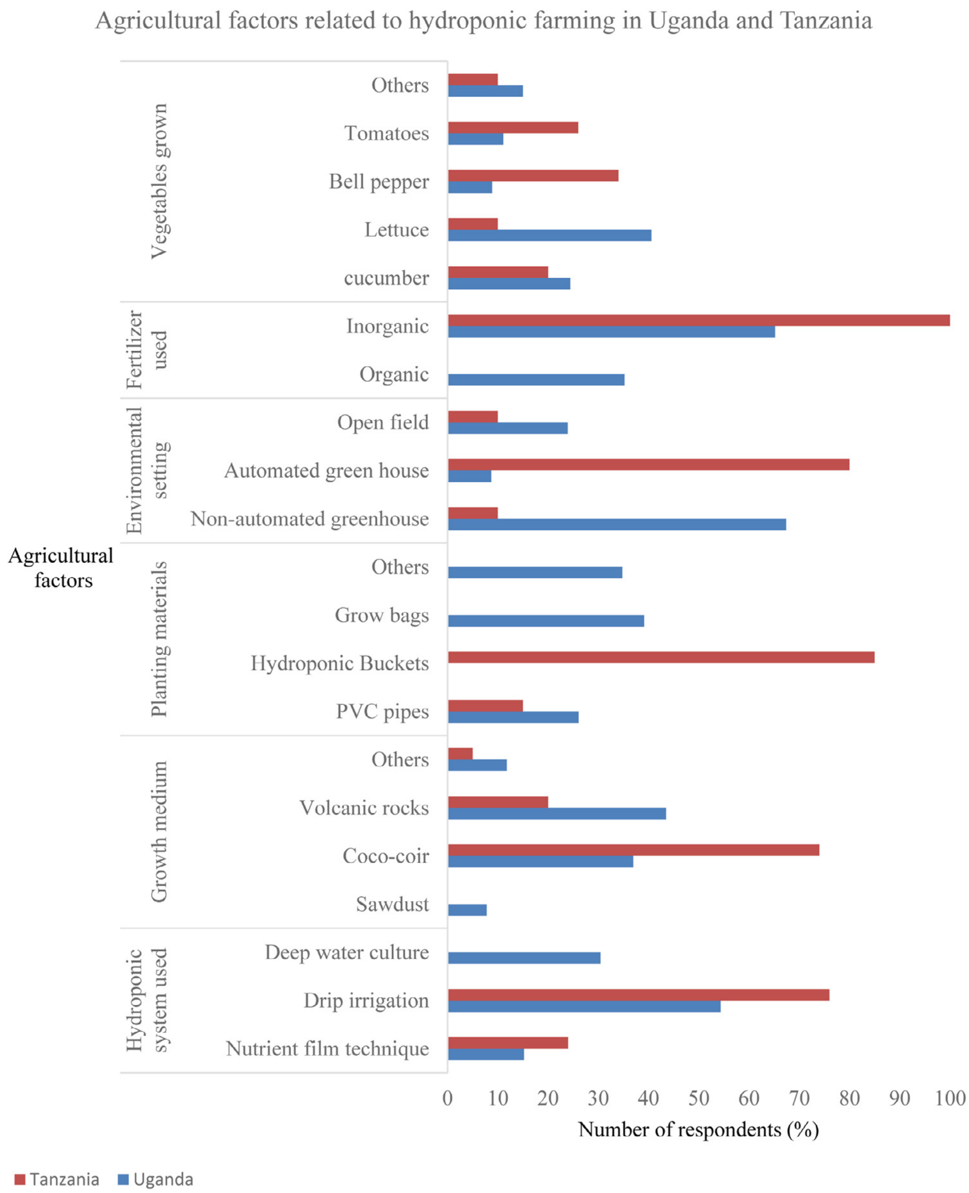


**Fig. 4.** Agricultural factors related to hydroponic farming of vegetables in Uganda and Tanzania.

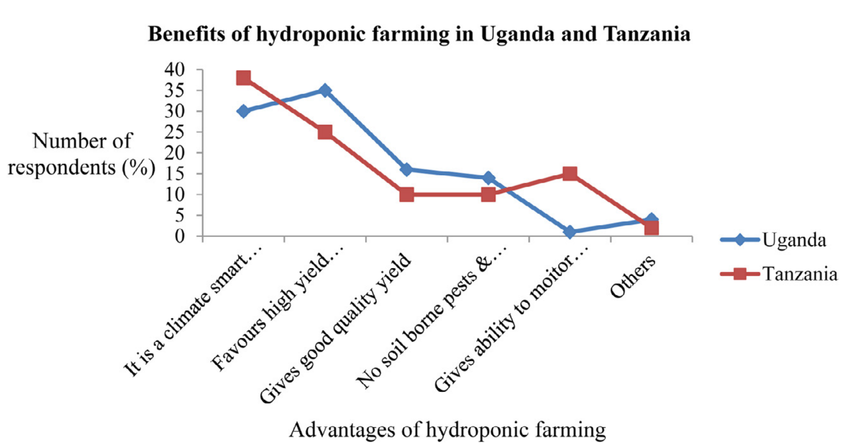


**Fig. 5.** Advantages of hydroponic farming.

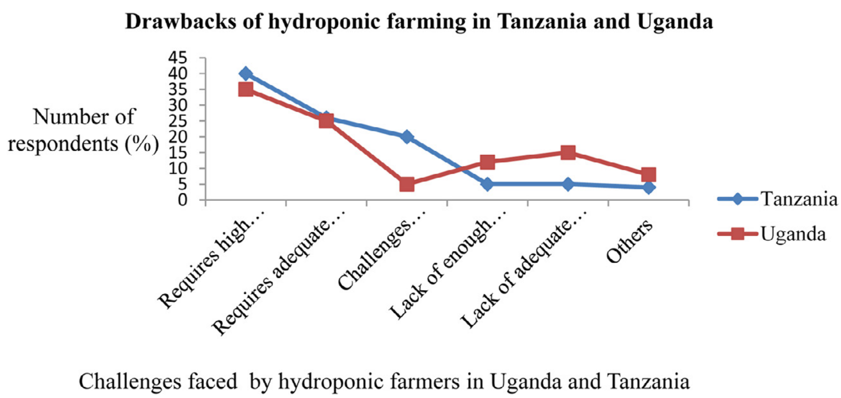


**Fig. 6.** Draw backs of hydroponic farming.

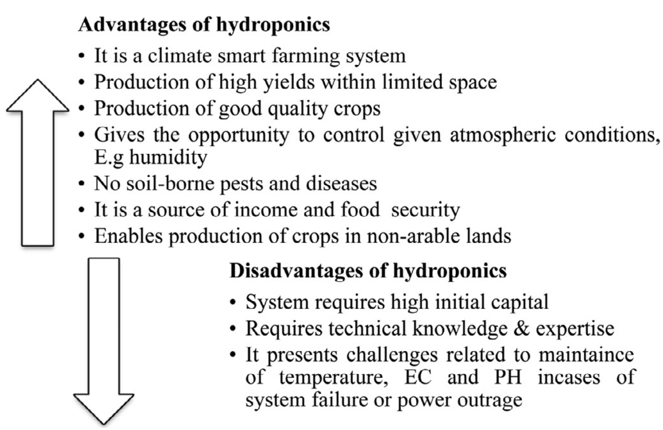


**Fig. 7.** Advantages and disadvantages of hydroponic farming.

26% ($n$ = 13) of respondents also reported hydroponics to be a CSA system that 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.

24% ($n$ = 12) of the respondents noted that hydroponics allows production of high harvests within a small space or areas with unfertile soils through vertical farming as compared to the ancient farming system where farmers need huge chunks of fertile land to get big harvests. This makes it a very suitable urban farming system in areas faced with scarcity of arable land. Gholamreza et al. (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 (Dionysios et al., 2016; Buehler and Junge, 2016; Daina et al., 2018). Another advantage noted by approximately 20% ($n$ = 10) of the participants was the absence of soil borne pests and diseases with the farming system as compared to soil farming. 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, Charles (Faber 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 and Dagne, 2018). Approximately 4% ($n$ = 2) reported having control over the environment of the vegetables through monitoring climatic and environmental conditions such as: temperature, Electrical Conductivity (EC), pH (Potential of Hydrogen) and humidity, majorly those who were cultivating under fully automated green houses. With hydroponic farming, there is control over the climatic conditions within the greenhouse environment (Nkcukankcuka et al., 2021).

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, provides supply of fresh vegetables, require little attention during growth and production of surplus food for home consumption. Fig. 5att link="no" categorizes the advantages of hydroponic farming within Tanzania and Uganda.

### 3.3. *Drawbacks of hydroponic farming*

The biggest challenge reported was the high investment costs required to set up this high end technology especially for the fully automated greenhouse farms ($n$ = 16, 31%). This was also noted by Nicole et al. (2021) who identified high startup costs as a challenge for adoption of hydroponic farming technology. These costs include: greenhouse construction, costs of fertilizers, electricity for system installation, hydroponic equipment such as: PVC pipes, hydroponic net cups, climate monitoring systems among others. Artificial lighting, for instance through use of Light Emitting Diodes (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 and 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).

22% ($n$ = 11) of the farmers still reported that hydroponic farming requires enough technical knowledge which also continues to deter farmers from adopting the technology. For example: knowledge on the right ammount of nutrients required for a particular crop, how to mix them, in what proportions and recycling. Majority of the respondents reported having learnt about hydroponic faming using internet which further corelates with the high number of educated participants of the study. Controlled environment hydroponics requires some knowledge on how to run the climate control system within the green house for factors such as: humidity, temperature etc.… The need for technical knowledge for hydroponics such as: maintainace of PH (potential of Hydrogen) and EC (electrical conductivity) maintainace is one of the challenges of hydroponics (Nisha et al., 2019; Aurosikha et al., 2021). 6% ($n$ = 3) of the farm operators who practiced hydroponics using high end technology such as: climate control systems accordingly reported a hitch related to maintainace of EC, PH and temperature of the nutrient solution and damage to crops in case of system failure. 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

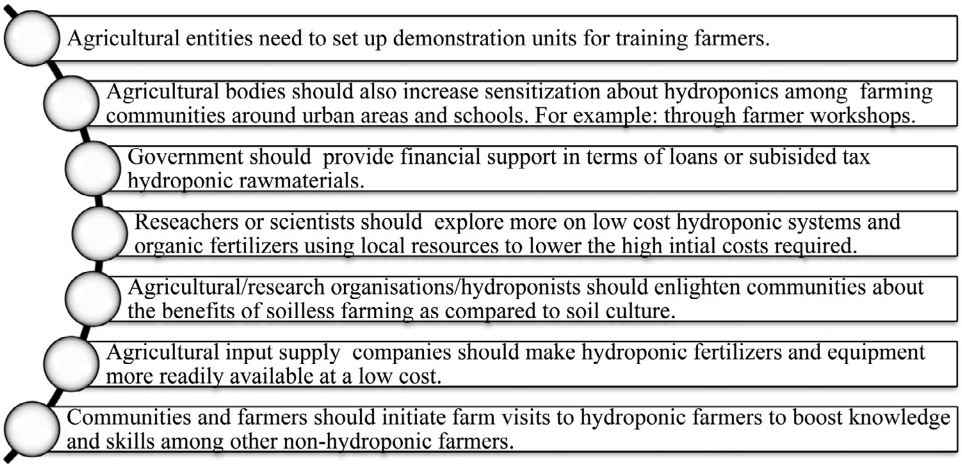


**Fig. 8.** Recommendations to improve adoption of hydroponics in Uganda and Tanzania.

well handled. 12% ($n = 6$) of the farmers stated that lack of adequate ideas or innovations on use of alternative locally available resources for hydroponic farming is a setback for the adoption of the farming system. 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 mentioned by approximately 20% ($n = 10$) of the respondents. Other challenges reported by 9% ($n = 5$) were: bias from the community for hydroponic produce who consider them to be non-organic products, lack of variety of organic fertilizer alternatives and the timeliness needed by the system to avoid crop or system failure.

Fig. 6 shows the drawbacks of hydroponic farming in Tanzania and Uganda.

Fig. 7 reviews the advantages and disadvantages of hydroponic farming among urban and semi-urban farmers in Uganda and Tanzania while Fig. 8 further summarizes the recommendations made by the respondents which can assist increase the adoption of the technology among the two countries and Africa at large.

## 4. Conclusions

The main objective of the study was to identify benefits and challenges faced by hydroponic farmers/farm operators in Tanzania and Uganda in order to enhance adoption of the technology in East Africa and Africa at large. The major benefits identifed were: hydroponics is CSA system, produces high yield and quality crops, has no soil borne pests and diseases among other benefits. These justify why the technology should be considered in the face on increasing population challenges. However, lack of adequate technical knowledge about the technology and the high initial costs associated with it remain the major hindrance to the vast implementation of the technology. The highlighted infleuntial factors, benefits and limitations can be used by governments, research organisations or agricultural bodies to boost the adoption of the technology within urbanities and farming communties at large. Based on recommendation from the participants, there is need to provide financial support to farmers though subsized loans or hydroponic input and increase sensitization and training about soilless farming in general to increase adoption of the technology. More research needs to be done to identify means of reducing the high costs associated with the technology, for instance: with regard to use of organic fertilisers, non-automated green houses and local materials that can used for hydroponic farming.

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## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## CRediT authorship contribution statement

**Margaret S. Gumisiriza:** Visualization, Data curation, Formal analysis, Writing – original draft. **Jolly M.L. Kabirizi:** Visualization, Data curation, Formal analysis, Writing – original draft. **Micheal Mugerwa:** Visualization, Data curation, Formal analysis, Writing – original draft. **Patrick. A Ndakidemi:** Visualization, Data curation, Formal analysis, Writing – original draft. **Ernest R. Mbega:** Visualization, Data curation, Formal analysis, Writing – original draft.

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