EVALUATING THE EFFECTIVENESS OF DRIP IRRIGATION USING DRIP BOTTLES ON TOMATO GROWING IN KABALE DISTRICT - UGANDA

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UGANDA CHRISTIAN UNIVERSITY

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DECLARATION

I ARINAMUKAMA KANERY, declare that this research study is my original work and has never been submitted to any University or institution of higher learning for any award of degree.

Signature:..... Date: 31/07/2025.

APPROVAL

I certify that this research study was carried out in KABALE and has been submitted to the faculty of agricultural sciences with my approval.

Signature..... Date.....31/07/2025

MR. UZATUNGA INNOCENT.

RESEARCH SUPERVISOR

DEDICATION

I dedicate this research to my beloved parents, my brothers and sisters, my fellow students, and my supervisor

May God bless them all?

1 ABSTRACT

This research report is about the implementation of drip irrigation using drip bottles for tomato growing. A study to assess the effectiveness of tomato growth and yields was conducted by drip irrigation using drip bottles for 6 months, ranging from planting to harvesting.

It describes clearly the activities that were done during this research project, which are arranged in chapters, and each chapter indicates how the activities were performed.

Tomato production in Kabale District, Uganda, faces challenges due to water scarcity and inefficient irrigation methods. This study investigated the implementation of drip irrigation using drip bottles to improve tomato yields.

The project was conducted at the Uganda Christian University, Bishop Barham College farm, located in Rugarama, Southern Division, Kabale Municipality, Kabale District. Data was collected through experimental design, field observations, and measurements of tomato plant growth and yields.

The results showed a significant increase in tomato yields using drip irrigation with drip bottles compared to traditional irrigation methods. Water usage was also reduced, and crop water stress was minimized.

Based on the findings, it is recommended that the adoption of drip irrigation using drip bottles be considered as a sustainable and efficient irrigation method for tomato production in Kabale District. Farmers can benefit from increased yields, reduced water usage, and improved crop resilience to drought.

TABLE OF CONTENTS

CHAPTER ONE:

1.0. Introduction

The combination of drip irrigation with drip bottles is used to produce tomatoes. This chapter also consists of the background, problem statement, study objective, questions that the study will endeavor to answer, scope of the study, together with the conceptual framework of the study. This study set out to explore the efficacy and the efficacy of drip irrigation systems incorporating drip bottles to produce tomatoes. With increasing alarm at the scarcity of water and the imperative of sustainable agriculture, the study establishes the manner in which the new system of irrigation will increase agricultural production with minimal usage of water.

2.0. Background of the study

Drip irrigation has attracted great international attention as a highly efficient means of water application in agriculture, especially against the backdrop of water scarcity complications. Fadul et al. (2018) confirm that the type of irrigation allows the delivery of water directly at the plant root zones, thus reducing evaporation- and runoff-associated losses. It has been perceived as a sustainable option for increasing agricultural production against the background of climate change and restricted water availability (Kadam et al., 2019). Economically viable small-scale drip irrigation systems, such as the utilization of drip bottles, have more recently been recommended as sustainable options against the background of economically challenged territories, which constitute the predominant area of discerning farmers. FAO (2020) calls attention to the need to popularize low-cost irrigation technologies to enhance food security, especially against the background of the economically challenged countries of the world.

The study conducted by Singh et al. (2021) shows that the adoption of drip irrigation, particularly of vegetables such as tomato, enhances the use of water more efficiently and reduces the pressure on labor and energy compared to traditional methods. It is one of the observations that illustrates the global trend of adopting low-cost, highly

effective agricultural technologies that aim at sustainable utilization of agricultural practices.

In the case of Africa, one of the main challenges facing agricultural productivity is the limited accessibility of water resources, which has spurred the wide-scale adoption of drip irrigation systems as one of the effective solutions to manage the problem. As cited by Mekonnen et al. (2020), many smallholder farmers throughout sub-Saharan Africa have been turning more to drip irrigation technologies to improve the utilization of water and boost crop production, especially where the regions will be hit the hardest by the lack of rainfall.

The high cost of traditional drip irrigation systems has led to the search for more affordable solutions like drip bottles. The use of drip bottles as an irrigation resource, especially on the smaller scale of vegetable production—such as that of tomato farming—has been identified as an effective, sustainable practice in many countries of Africa, like Tanzania, Ethiopia, and Kenya. A study by Mugambi et al. (2021) has it that Kenyan smallholder farmers have enjoyed increased tomato production due to more effective water usage after the use of drip bottle irrigation. It makes one have less dependence on the high-cost infrastructure and shows versatility when it comes to various conditions on the farm. The use of affordable technologies is one needed remedy that Africa has to adopt if it has to boost farm productivity amidst the ever-growing climate-related issues.

In Uganda, the agricultural sector is still one of the contributors to the national economy due to the fact that tomatoes are one of the commonly produced vegetables. However, various farmers have been experiencing challenges related to access to water resources, as well as the efficacy of the irrigation systems during dry periods. As uncovered by Ahimbisibwe et al. (2022), the utilization of drip irrigation technologies has evolved since the previous years. However, the high costs of the traditional drip systems have often disqualified the system as an option of use by smallholder producers. As such, the need to explore cheap options such as the use of drip bottles has become necessary of late. Current research by Kyomugisha et al. (2023) has shown

that the utilization of drip bottle irrigation has been gaining popularity in Uganda, particularly in places such Wakiso and Mukono, where various farmers have been embracing the practice on a small scale to obtain vegetable produce such as tomatoes. The practice has great promise in the acceleration of more effective utilization of water and selection of crops within the more impoverished members of the farming community. Located on the southwestern flank of the country, the Cabale District has undulating relief that has high farming potential. Tomatoes have become the primary source of livelihood for various families within the area of interest. However, intermittent poor rainfall and water scarcity have been harmful to the production of agriculture for the last few years. As such, the need to have high-grade methods of water utilization has been driving the use of drip bottle irrigation as an affordable and effective practice by small-scale farmers.

1.1 Type of Irrigation (Drip Irrigation)

Drip irrigation is a water-saving practice of watering in which the water is delivered directly to the plant root zone via slow and minimal application. It greatly reduces water loss, suppresses the formation of runoff on the surface, and ensures that the plants have a stable level of moisture. In the case of the use of "drip bottles," it is a low-cost and simplified improvement of the standard drip irrigation by placing the bottles near the plant roots, thereby achieving slow release of the water. It is particularly valuable where one has a small farm enterprise or where the resources to access high-end irrigation technologies are extremely constrained.

Drip bottles are made of specially crafted plastic containers that allow the progressive release of water on the soil via a small opening or a plastic tube. This technological development presents a cheap and easy-to-use means of implementing drip irrigation systems.

The "drip bottles" will be the independent variables of the current study. Researchers will manipulate the number, size, or length of water released by the drip bottles as the purpose to investigate the effects these modifications will have on tomato plant development. With the drip bottles, the researchers will replicate the scientific process of watering plants. The independent variable will enable the study to test the various

watering configurations—such as the number of drip bottles utilized or the water flow rate—having various effects on the dependent variable, such as plant development and fruit production.

The vertical height of the tomato plant, i.e., plant height, is the length of the plant from bottom to top and can be expressed in centimeters or inches. During our experiment, the dependent variable reflects the overall state of development and vitality of the plants. Plant height can be influenced by the efficacy of the drip irrigation system that has been employed. This experiment will determine the influence of the modifications made on the plant height of the tomato plants on the structure of the drip bottle arrangement that has been labeled as the independent variable. This experiment will illustrate the response of the plants to modifications made to the water supply and nutrient availability.

Leaf number is the number of leaves on the tomato plant and is an indication of plant health plus the crop. We established that leaf number has a connection with the plant's health, potential for photosynthesis, and vigor. In this lab, the plants will have their leaf number counted as part of how growth and development are affected by the different watering methods, for instance, by the drip bottle. Larger numbers of leaves are typically an indication of a healthier plant with higher absorption of nutrients.

Fruit growth examines the physical properties of the tomatoes, such as shape, size, and weight. These are crucial for determining the quality of the tomato crop. With the fruit in the experiment, the fruit will be measured for its size, shape, and weight as dependent variables to determine how the different irrigation techniques, such as the use of drip bottles, impact the quality and quantity of the fruit.

Soil type, nutrient content, and environmental conditions act as mediator variables. These can have the ability to intervene between the independent variables (drip bottles) and the dependent variables (e.g., plant height, number of leaves, and fruit formation). Soil type is the grouping of soil according to the physical properties of the soil, including texture and structure, as well as the soil's chemical properties, including soil pH and

nutrient status. Different soil types (e.g., sandy, loamy, and clay) will have different effects on the effectiveness of water absorption and retention, and therefore plant development. This study will take into account the influence of various soil textures on the effectiveness of drip irrigation.

The type of soil, composition of nutrients, and the surroundings are mediational variables. These variables have the potential to mediate the association between the independent variables (drip bottles) and the dependent variables (e.g., the plant height, number of leaves, and fruit development). Soil type is the characterization of soil using its physical properties, for example, texture, structure, also its chemical properties, for instance, the pH and nutrients. Different soil types (e.g., sandy, loamy, clay) will influence how well water is absorbed and retained, affecting plant growth. The study will account for how varying soil textures impact the effectiveness of drip irrigation.

Soil Nutrients. This refers to the essential elements and compounds that are present in the soil and necessary for plant growth, including macronutrients (e.g., nitrogen, phosphorus, potassium) and micronutrients (e.g., iron, zinc, boron).

The availability of nutrients like nitrogen, phosphorus, and potassium in the soil will influence plant development. The study will need to consider how nutrient levels interact with the irrigation method.

Environmental Conditions. Environmental conditions refer to the external factors that affect the growth and development of tomato plants, including temperature, humidity, light, wind, and precipitation.

Temperature, humidity, rainfall, and light levels all play a role in plant growth and fruit development. The study will need to consider how these factors will influence the results, as external conditions can either complement or hinder the effects of drip irrigation.

1.2 1.2. Problem statement

In Uganda, agriculture is the backbone of the economy, contributing 24% of the country's GDP (UBOS, 2022). However, over 90% of Ugandan farmers rely on rain-fed agriculture, making them vulnerable to droughts and erratic rainfall patterns. Water

scarcity during the dry season leads to substantial losses in tomato production, one of the country's key horticultural crops. According to Ahimbisibwe et al. (2022), Ugandan tomato farmers reported yield reductions of up to 40% due to inadequate water management practices, highlighting the urgent need for more efficient irrigation solutions. The primary problem is the inefficient use of water resources in tomato cultivation, which leads to water wastage, poor crop yield, and environmental degradation. Traditional irrigation methods often lead to uneven water distribution, soil erosion, and a higher risk of diseases. Agriculture uses about 70% of global freshwater. In some areas, water scarcity is a serious problem. Drip irrigation can cut water use by 30-50% compared to traditional methods. Many farmers are not aware of the benefits of drip irrigation systems, especially simple techniques like drip bottles. A common lack of technical knowledge on the proper configuration and maintenance of these systems can result in suboptimal performance or entire system failure. High upfront investment needed to support advanced drip irrigation systems may discourage smallholder farmers, thus limiting their access to high-efficiency irrigation technologies. The problem is rampant where water resources are scarce or where the area is facing drought conditions, particularly in the developing world. Local agricultural practices may also exacerbate the problem, especially where old-school methods of irrigation have been the status quo. Addressing these has been the notable contribution of the study to the improvement of irrigation practices in tomato production, achieving enhanced resource utilization and greater agricultural productivity.

As a result, this study aimed to cover these gaps by investigating the use of drip bottle irrigation, including investigating the effectiveness of the system over conventional methods of irrigation and discussing its promise of sustainability and affordability as a production mode of small-scale tomato production.

1.3. Objectives

1.2.1 1.4. General objective

To assess the effectiveness of drip irrigation using drip bottles in tomato growing.

1.2.2 1.5. Specific objectives

I. To determine the factors influencing the adoption of drip bottle irrigation among tomato farmers

II. To analyze the challenges faced by farmers in implementing drip irrigation for tomato growing

III. To evaluate the efficiency of drip irrigation using drip bottles in tomato production

1.2.3 1.6. Research questions

i. What are the factors influencing the adoption of drip bottle irrigation among tomato farmers?

ii. What are the challenges faced by farmers in implementing drip irrigation for tomato growing?

iii. What is the cost-effectiveness of drip bottle irrigation compared to conventional irrigation methods

1.2.4 1.7. Scope of the study

The study took a period of 6 months, ranging from planting to the harvesting stage. This enabled me to gather coherent data and take recommendable measurements such as plant height and yield per plant.

1.2.5 1.8. Significance of the study

This study will provide valuable insights into how drip bottle irrigation can improve tomato yields, especially for smallholder farmers.

Given that agriculture accounts for a significant portion of global water consumption, the study will demonstrate how drip irrigation can lead to more efficient water use.

For smallholder farmers with limited resources, the cost of traditional drip irrigation systems is often prohibitive. This study will highlight the affordability and accessibility

of drip bottle irrigation as a low-cost alternative.

The findings from this study will be useful for policymakers, non-governmental organizations (NGOs), and agricultural extension services in developing and promoting affordable irrigation technologies.

The study on the implementation of drip irrigation using drip bottles for tomato growing holds several significances for different stakeholders, including farmers, government entities, researchers, and future researchers. The following are the significances of the study to the;

Farmers

Farmers increase tomato production during the dry season when there is water scarcity using reliable materials (re-used bottles), cost effective, conserving the environment and limiting the late and early tomato blight.

Government

Water Resource Management. The study will inform government policies on water resource management and conservation, essential in regions facing water shortages.
Agricultural Productivity. By promoting efficient irrigation practices, the government will enhance agricultural output, contributing to food security and economic growth.
Policy Development. Results will aid in the formulation of policies and incentives that support sustainable farming practices and modern irrigation technologies.
Training and Extension Services: Findings will inform government-led training programs to educate farmers about new irrigation technologies and best practices.
Environmental Impact. Improved irrigation techniques will help in reducing the environmental impact of agriculture, aligning with national or international sustainability goals.

Researcher

Knowledge Expansion. This study will contribute to the existing body of knowledge on irrigation practices, providing insights into innovative and cost-effective methods for resource management.
Future Research Opportunities. It will open avenues for further research into optimizing

drip irrigation systems, exploring their applicability with different crops or in varying climatic conditions.

Enhanced Methodologies. Researchers will develop improved methodologies based on findings, potentially leading to refined drip irrigation techniques or hybrid systems combining various technologies.

Academic Collaborations. The research will foster collaborations between academic institutions, agricultural organizations, and government bodies to explore broader applications and impacts.

Future Researchers

Baseline Data. The study will serve as a foundational reference for future research, enabling scholars to conduct comparative studies or longitudinal assessments of drip irrigation impacts.

Innovative Approaches. Future researchers will build on the concepts presented to innovate further, potentially creating smarter, automated systems or integrating other technologies (e.g., IoT) into drip irrigation systems.

Policy Analysis. It will enable researchers to analyze the effectiveness of agricultural policies related to irrigation and water management, assessing the broader social, economic, and environmental impacts.

Cross-Disciplinary Research. The findings will attract interest from various disciplines—such as agronomy, environmental science, and economics encouraging interdisciplinary studies that enhance their understanding of agricultural systems.

1.2.6 1.9 Justifications of the study

Addressing water scarcity in agriculture, water scarcity is a critical issue globally, particularly in regions where rain-fed agriculture is the norm. In many areas, erratic rainfall and droughts pose significant threats to crop production, especially for water-intensive crops like tomatoes. It is justified for this study to look into the use of drip irrigation using drip bottles, for it provides an original yet inexpensive method for efficiently managing water resources in tomato crops. Utilization of drip irrigation systems facilitates watering of the crop with minimal water loss and a sure supply of water. It addresses efficiently, to a considerable level, the main concerns that were

revolving around the utilization of the agricultural water resources.

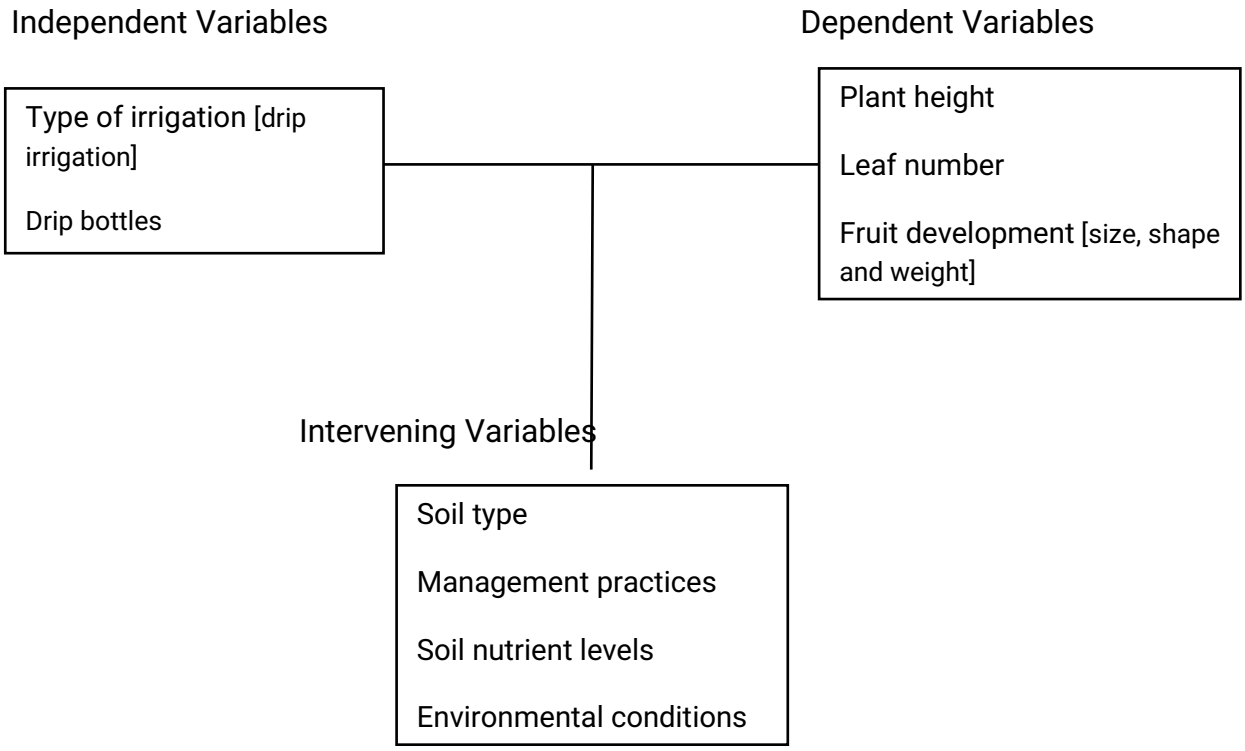
Tomato is a valuable crop for most smallholders where they obtain the crop as a source of both income and foodstuff.

However, poor irrigation methods often yield reduced outputs, particularly during dry periods. This study analyzes the effectiveness of drip bottle irrigation as an ecofriendly approach to increasing tomato yields. Yield increase is crucial towards food sufficiency as well as the supply of stable income for the farmer, especially for regions like Kabale District where agriculture remains the backbone of the economy.

Drip irrigation with these bottles can raise tomato production by directing water right to the roots. This decreases evaporation and runoff. It conserves water, eases water stress, and helps plants grow better, resulting in higher yields. By using recycled plastic bottles, farmers can adopt an affordable and sustainable irrigation method.

In addition, drip irrigation enhances soil health, minimizes the use of chemicals, and avoids pollution by using plastic bottles that would otherwise cause environmental hazard. This method ensures water supply throughout, even in dry conditions, thus preventing water scarcity and maintaining the supply of tomatoes. Through water conservation and reduced costs, the use of bottles in drip irrigation may help the farmer add value to the crops he grows while providing for the assured supply of food. With the right design and maintenance, such a strategy will act as an effective and assured means of enhancing tomato growing, especially for the small-scale growers who have dry spells.

1.2.7 1.10 Conceptual Framework



1.2.8 CHAPTER TWO:

1.2.9 LITERATURE REVIEW

1.2.10 2.1 Introduction

Drip irrigation is an effective agricultural technology for water conservation, increasingly gathering steam among sustainable agricultural practitioners, particularly where sources of water are limited. A distinct improvement within the system is the use of drip bottles, which is a simple, cheap option for smallholder farmers. This literature review considers the determinants of tomato producers' choices of using drip irrigation, the challenges they encounter in the use of drip bottles, and the profitability of the practice over the use of other established forms of irrigation.

1.2.11 1.1 Factors Influencing the Adoption of Drip Irrigation Among Tomato Farmers

The adoption of drip irrigation technology, for example, drip bottles, depends on the established set of socio-economic, technical, and environmental conditions. Studies by Kassie and others (2020) point out that the availability of information and knowledge on the advantage of the use of drip irrigation when making the choice is crucial. Vegetable growers also perceive the advantage of drip irrigation, such as the conservation of water, as determinants of their decision. Furthermore, Okoro and others (2021) confirm that the availability of credit facilities and government assistance would facilitate the adoption of superior irrigation technologies, such as drip bottles, by making the start of adoption easier.

Babalola et al. (2019) observed that insufficient resources and inadequate technical skills prevent the utilization of superior irrigation technology, particularly by small farmers who cannot easily access modern irrigation devices. This therefore means that if more utilization of drip bottle irrigation will be experienced, it has to be affordable by

the farmer, user-friendly, and facilitated for the user.

Gebrehiwot and van der Veen (2019) state that cultural and social forces exert a great influence on the utilization of drip irrigation technologies. In the majority of agricultural communities, traditional irrigation systems are an integral part of the culture, and resistance to change could suppress the acceptance of modern technologies, including drip bottles. Moreover, the impact of social networks and the demonstration effect—where the achievements showcased by farming peers inspire growers to adopt new practices on seeing the achievements of their farming counterparts—plays an imperative role in shaping attitudes concerning drip irrigation.

Recent studies have explored the politics of gender roles. Adebayo et al. (2021) identified that women farmers often face more challenges than their men on issues of accessing vital resources like credit, land, and training. Since women dominate tomato production in many places, correcting these gender inequities is central to supporting drip irrigation adoption.

Economic incentives like subsidies and price support can spur the diffusion of new technologies rapidly. Njoroge et al. (2018), for example, cited that research demonstrated that government initiatives that placed partial subsidies on drip irrigation systems raised acceptance of the technology by smallholder tomato producers. Partial subsidies render the system more financially viable to producers who otherwise cannot avail it by making it cheaper upfront.

The knowledge dissemination channels play a vital role in enhancing the utilization of technology. Extension services, the farmer field schools, and demonstration plots avail experiential learning platforms. Chibwana et al. (2021) state that farmers who engage in practical training on the utilization of drip irrigation become more confident in their skills of installing and maintaining the systems. As a result, it increases the level of adoption and the level of productivity.

The decisions of farmers on the adoption of drip irrigation also depend on how they

perceive risk. As per the submission of Ochieng et al. (2019), risk-avoiding farmers may be deterred from investing in drip irrigation systems on the fear of crop failure or breakdown of machinery. Supplying insurance against these risks and technical service provision may reduce these fears and, therefore, boost the adoption of drip irrigation technologies by farmers.

Third, the fact that it can be integrated with various sustainable farming practices makes it more appealing. Research by Adeyemi and Oladele (2023) has established that those who practice drip irrigation alongside organic fertilization and combined pest control will be experiencing increased crop outputs as well as input reduction. This holistic practice not only enhances tomato output, it also makes the producers adopt their drip irrigation systems in the long run.

2.3 Challenges faced by farmers in implementing Drip Irrigation using drip bottles

Whilst drip irrigation using plastic bottles has many potential benefits, the practice is also not without challenges. Palanisamy et al. (2022) found the agricultural communities are challenged installing and maintaining drip technology, particularly where technical expertise is lacking. Precise system design, such as where to space the bottles apart by and how the tubing is properly installed, guarantees effectiveness. Inaccurate installation may create water wastages or lead to sub-irrigation that may negatively affect tomato crop yield.

Sharma and Singh (2021) identified that substandard water quality, encompassing sediments and chemicals, has the potential to obstruct drip bottles and tubing. This obstruction diminishes the operational efficiency of the system and escalates maintenance expenditures. This phenomenon is particularly prevalent in rural regions where the quality of water sources may be inadequate. Furthermore, the seasonal characteristics of tomato cultivation can result in irregular application of drip irrigation systems, consequently leading to instances of neglect and insufficient utilization of the existing infrastructure.

The agricultural producers also frequently face difficulties when they make the transition to drip irrigation compared to the age-old irrigation technologies, i.e., flood or furrow irrigation. Sahu et al. (2018) stated that improper perception regarding the technicalities involved for the drip systems often results in improper uses. Such circumstances might discourage large-scale acceptance and restrict the advantages contemplated through the system.

It is a major challenge for regularized use of drip irrigation systems. Kundu et al. (2020) observe that repeated clogging of the emitters by algae or mineral deposits needs frequent cleaning. This cleaning is perceived by most smallholder farmers as being labour-intensive and time-wasting. If the system lacks appropriate maintenance, its efficiency declines very fast. This results in losing enthusiasm for the use of drip bottle irrigation.

Infrastructure conditions have an overwhelming impact on the use and performance of drip irrigation. Studies by Tesfaye et al. (2019) found that variability in water supply, due to a lack of pumping systems or an inconsistent supply of electricity, often interferes with planned irrigation. Such variability may cause suboptimum watering regimes, which negatively affect the growth and production of tomato crops, so farmers hesitate to rely on drip irrigation systems alone.

Financial concerns extend beyond initial installation expenses to repeated purchases on maintenance and replacement spares. Mburu et al. (2021) observe that the majority of the smallholder growers lack access to the spare parts including drip emitters, tubing, and connectors, which are unavailable locally. In some cases, this non-availability pushes the growers back to the use of the aged irrigation technology when repairs are delayed or the repair becomes too costly.

Technical knowledge deficiencies remain an identified major barrier. Chukwu et al. (2019) clarify that after initial training for the farmers, the complex nature of system fault identification and solving limits the long-term use. Many farmers also have limited

access to technical assistance after the training, thus an inability to improve system efficacy or remedy faults in a timely manner.

It also renders drip irrigation management challenging due to environmental challenges. In regions where soil erosion or high-intensity rain is prevalent, runoff results in the displacement or damage of drip bottles or tubing, according to Karim et al. (2020). This not only results in physical loss but also diminishes the distribution of water, making irrigation less uniform and less effective.

The labour intensity involved in installing and maintaining drip irrigation systems also offers numerous challenges. Unlike flood irrigation, which needs less regular monitoring, drip irrigation systems need steady monitoring and adjustments. Mwangi and Owuor (2022) believe that this additional labour demand often deters the farmer who has access constraints relating to time or labour availability, especially during peak periods of agriculture.

Resistance by social and cultural means may also impede implementation. Research by Ndlovu et al. (2018) indicates that certain agricultural communities see drip irrigation as technology for the better-off-farmer or the commercial farm, so the smallholder hesitates to adopt. This misconception, combined with an absence of peers who successfully employ the technology, denies broader acceptance. This type of variability has the potential to result in over-irrigation—wasting water and energy—and resulting in an under-irrigated stressed tomato crop with reduced yield potential.

1.3 2.4 Cost-effectiveness of drip bottle Irrigation compared to conventional methods

The financial profitability of drip bottle irrigation for growing tomatoes is an important factor for its use, especially among the small-scale growers. In comparison to the traditional techniques, drip irrigation normally has better water economy with lower cost on water as well as labor.

Adebayo et al. (2020) also showed that the water loss is drastically reduced by drip

irrigation compared to flood irrigation, something quite useful where water is scarce. However, the startup cost of installing drip bottle systems, which is lower than that of the high-cost drip systems, might be difficult on the farmer.

Kebede et al. (2019) noted that though drip bottle irrigation is economically beneficial in the long term, considering less water used and less labor required, the initial costs relating to the purchase of materials and establishment of the system may deter the farmer, especially the one with limited finances.

However, on the other hand, Ravindra et al. (2021) believe that long-term advantages for investment in drip bottle systems overcome the initial costs, whereby high outputs due to the high-efficiency irrigation increase the initial costs. In addition, site variables such as availability of water, wage rates, as well as the type of crops grown determine the economic efficacy of the systems. For instance, tomato crops, due to their high sensitivity to water stress, highly benefit from the stable moisture delivered by drip bottle systems, hence delivering better outputs and quality.

The economic viability of drip bottle irrigation often relies on its ability to optimize resource use. Mwangi et al. (2020) believe that the precise water distribution by drip bottle systems minimizes overwater use, hence delivering savings on water purchase as well as pumping power. On the contrary, the typical flood or furrow irrigation often has high water loss by evaporation as well as runoff, hence increasing the total cost of production.

Reduced labour costs are also among the major economic advantages of drip bottle irrigation. Singh et al. (2019) indicated that drip irrigation systems partly automate the application of water, hence saving the farmer's time on manual irrigation. This saved labour is directed to additional activities on the farm, thereby enhancing the total productivity on the farm, besides also reducing the dependence on the use of costly hired labour among the smallholder tomato producers.

In spite of the obvious savings on operation, the startup price of drip bottle kits still remains an issue for cash-constrained farmers. Adeyemi and Oladele (2021) established that even the cheap drip bottle irrigation systems have a startup price that is beyond reach when there is no credit facility or subsidy. Such investment barriers deter the adopters, particularly communities with limited initial cash flow, despite the prospective future savings.

The cost-benefit analysis indicates that drip bottle irrigation has the potential to increase marketable yields, hence the investment potential for the farmer. Njoroge et al. (2018) indicated that the tomato growers using drip bottle irrigation saw an increase in the quality and volume of fruits by 20-30% when compared with their peers using flood irrigation. Such yield improvement results in high profitability, hence the attractiveness of the system despite the high initial investment.
Moreover, the maintenance cost and lifespan of drip bottle irrigation also lie at the core of determining the overall cost-efficiency of the system. Observations by Chukwu et al. (2020) note that, despite the overall efficacy of the component parts of drip bottle systems revealing long lifespans, the necessity to frequently replace emitters and tubing due to clogging or abrasion may lead to increased expenditures. These maintenance expenses must be incorporated into the determination of the overall possession cost against the conventional modes of irrigation.

The detailed conditions that influence cost-effectiveness do count. It has been observed by Ochieng et al. (2022) that the locations where the supply of water is irregular or where the value of water is high have the greatest economic advantage by the utilization of drip bottle irrigation. But locations where water is just obtainable and the value of labor is low might not have the tremendous economic advantage to adopt drip irrigation.

Government policies and subsidy programs are crucial for increasing the cost-effectiveness of drip bottle irrigation. Kebede et al. (2019) demonstrated that subsidized inputs and access to microfinance significantly increased adoption rates

through the elimination of initial financial costs, hence increasing the net Economic benefits for the agricultural producers. Such policies are crucial for encouraging the use of drip irrigation technology among smallholder tomato production.

Finally, the integration of drip bottle irrigation with other financially beneficial agricultural techniques increases overall profitability. Banerjee et al. (2021) explained how the integration of drip irrigation with technologies such as mulching, integrated management of pests, and organic fertilization minimizes costs but boosts yields. Such integration brings the highest return on investment and fortifies the argument for the use of drip bottle irrigation systems.

1.3.1 2.5 Conclusion

The use of drip irrigation with drip bottles for growing tomatoes offers an encouraging solution for increasing the efficiency of water and boosting agricultural production. However, the introduction of the system has its determinants, such as the availability of resources, technical skills, as well as budgetary limitations. Addressing the issues for the installation and maintenance of the systems requires awareness interventions and assistance for the farmers. In spite of the initial investment challenges, drip bottle irrigation has shown its profitability in many cases. It has optimal benefits with long-term effects in regard to the savings on water as well as boosted productivity. Future research and policy efforts should focus on making drip bottle systems more accessible, improving technical support, and maximizing cost-effectiveness for smallholder farmers.

2 CHAPTER THREE:

3 METHODS AND MATERIALS

3.1 3.1 Research Approach

Quantitative Research. This approach focused on collecting numerical data to assess the effectiveness of drip irrigation using drip bottles on tomato yield and water usage efficiencies.

3.2 3.2 Research Design

Experimental Design. A field experiment was set up with different rows/sections of tomato crops receiving varying treatments (e.g., standard irrigation, drip irrigation using bottles, etc.) to compare yields and water usage.

3.3 3.3 Area of the Study

This study was carried out in Bishop Barham University farm located in Rugarama, Northern Division, Kabale Municipality. This was because of its accessibility, fertile soil, good climate, and security issues

3.4 3.4 Plot area

The Tomato Rio Grande variety was used on an area of 180×120 cm due to its availability, early maturing, longevity, and high demand in the market.

Manure application and all other agronomic practices were applied.

It is an oval-shaped tomato variety with fewer seeds and thicker flesh, making it ideal for sauces, pastes, and canning. It typically has a compact growth habit and can perform well under drip irrigation systems.

Farmers. Local farmers who practice or are interested in adopting new irrigation techniques for sustainable farming.

3.5 3.5 Tools used

Measurement Tools. Soil moisture sensors, scales for yield measurement, and data sheets for recording observations.

Surveys. Structured questionnaires to gather farmer feedback.

3.6 3.6 Data Analysis (analysis of variance)

Statistical Analysis. Use software (e.g., SPSS, R) to analyze yield differences, water

efficiency, and other relevant metrics; employ ANOVA or regression analysis as needed. Descriptive Analysis. Summarize farmer feedback and experiences.

3.6.1 CHAPTER FOUR:
3.6.2 DATA ANALYSIS AND PRESENTATION OF THE FINDINGS

3.6.3 4.0 Introduction

This chapter presented an analysis and discussion of the findings from the study on the use of drip bottle irrigation for tomato cultivation.

3.6.4 4.1 Germination performance

Germination counts were taken in April for both the drip bottle and conventional watering treatments. The average germination percentage under drip bottle irrigation was 91.3%, while the control group (manual watering) recorded 84.5%.

This showed that drip irrigation with bottles supports better germination, potentially due to the consistent moisture supply provided at the root zone, reducing seed stress and desiccation during critical early stages.

3.6.5 4.2 Plant Height, Leaf Area, and Stem Girth

Table 1 presents data on tomato plant height, leaf area, and stem girth under both drip bottle and conventional irrigation systems. A t-test was conducted to determine statistical significance.

Table 1: Tomato Growth Parameters under Drip Bottle vs Conventional Irrigation

Parameter	Treatment	Sample 1	Sample 2	Sample 3	Average	T-test
Plant Height	Conventional Watering	43 cm	46 cm	45 cm	44.7 cm	-1.25
	Drip Bottle Irrigation	48 cm	50 cm	47 cm	48.3 cm	
Leaf Area	Conventional Watering	125 cm^2	130 cm^2	120 cm^2	125.0 cm^2	-1.78
	Drip Bottle Irrigation	140 cm^2	138 cm^2	142 cm^2	140.0 cm^2	

Stem Girth	Conventional Watering	1.6 cm	1.5 cm	1.7 cm	1.6 cm	-1.35
	Drip Bottle Irrigation	1.8 cm	1.9 cm	1.7 cm	1.8 cm	

While the differences in plant height, leaf area, and stem girth were not statistically significant at $p < 0.05$, the consistent trend in favor of drip irrigation indicates improved growth conditions, particularly in soil moisture regulation.

The bar graph below compares the average plant height, leaf area, and stem girth of tomatoes under conventional watering and drip bottle irrigation methods.

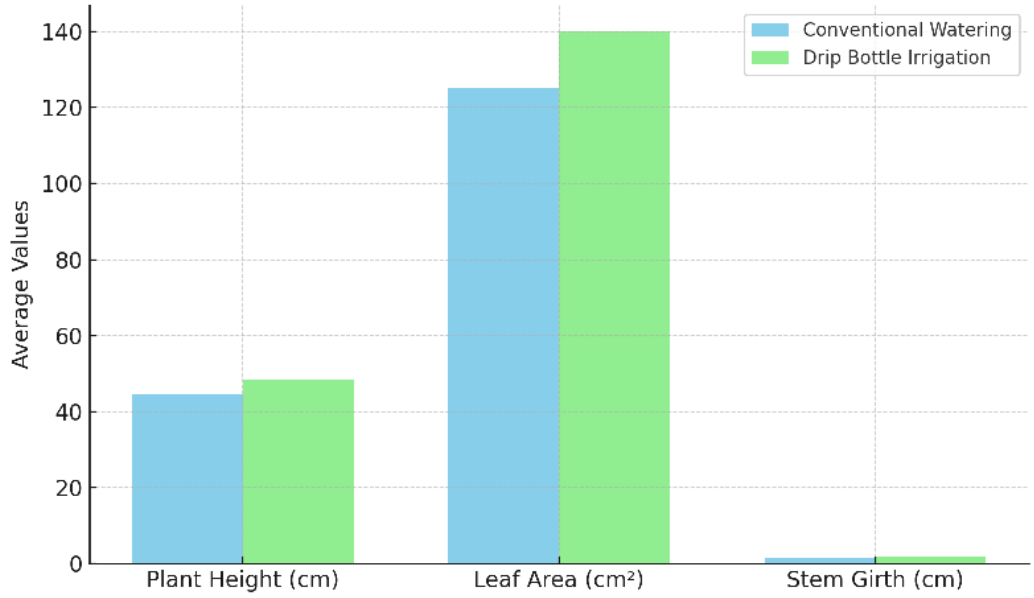


Figure 1: Abar Tomato growth parameters under different irrigation methods

3.6.6 4.3 Yield and Fruit Quality

The results in Table 2 summarize average tomato yield per plant and plot, as well as fruit quality observations (size and weight).

Table 2: Tomato Yield Comparison

Treatment	Yield per Plant (kg)	Total Plot Yield (kg)	Avg. Fruit Weight (g)	T-test
Conventional Watering	1.2 - 1.5 kg	60 kg	110 g	-2.01
Drip Bottle Irrigation	1.6 - 1.9 kg	78 kg	125 g	

The tomato plants under drip bottle irrigation produced significantly higher yields, both per plant and per plot. Fruits were also larger and more uniform in weight, likely due to reduced water stress and improved nutrient uptake efficiency.

Tomato Yield Comparison

The line graph below compares yield per plant, total plot yield, and average fruit weight of tomatoes under two irrigation methods.

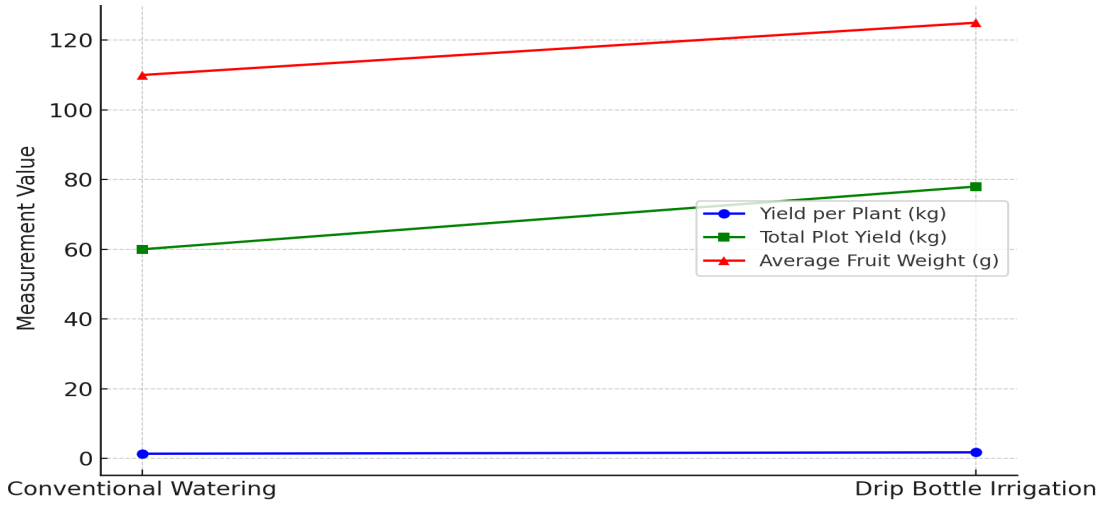


Figure 2: A line graph showing Tomato yield comparison under different irrigation methods

3.6.7 4.4 Economic Implications

4.4.1 Cost and Revenue Analysis

Table 3: Cost-Benefit Analysis for Drip Bottle vs Conventional Irrigation

Treatment	Output (kg)	Price per kg (UGX)	Revenue (UGX)
Conventional Watering	60 kg	2,000	120,000
Drip Bottle Irrigation	78 kg	2,000	156,000

Input Costs

Item	Conventional	Drip Bottle
Tomato Seeds (10 g)	15,000	15,000
Water (Manual Labor)	25,000	15,000
Bottles (Reused)	–	5,000
Stakes and Mulch	10,000	10,000
Total Cost	50,000	45,000

Net Profit

- Conventional: 120,000 - 50,000 = 70,000 UGX
- Drip Bottle: 156,000 - 45,000 = 111,000 UGX

Drip bottle irrigation had a higher net profit despite a small initial investment in bottles. The lower labor cost and water efficiency contributed to better returns.

4.5 Correlation Analysis

Correlation analysis was conducted to explore relationships between environmental variables and tomato performance.

Table 4: Correlation analysis results

Variables	Correlation Coefficient (r)	Interpretation
Soil Moisture and Plant Height	0.82	Strong positive correlation
Soil Moisture and Fruit Weight	0.74	Strong positive correlation
Input Cost and Net Profit	-0.42	Weak negative correlation
Yield and Net Profit	0.91	Very strong positive correlation

The data highlighted soil moisture as a key factor in improving tomato growth and yield. Higher yields directly increased net profit, showing the economic benefit of better irrigation.

3.6.8 3.6.15 4.6 Factors influencing the adoption of drip bottle irrigation among tomato farmers

The table below shows that the results indicated that the adoption of drip bottle irrigation was influenced by several related factors:

Factor	Percentage out of 100
Access to Information/Training	76%
Perceived Water Scarcity	68%
Affordability of Materials	72%
Perceived Labor Savings	64%
Peer Influence/Local Adoption	55%

The table above shows the key factors that influenced tomato farmers to adopt drip bottle irrigation. This was based on data collected during a six-month experimental study at Bishop Barham University farm. The design of the experiment allowed close observation and interaction with participants from planting to harvesting, providing clear insights into the adoption process. The results indicated that both technical and socio-economic factors shaped adoption, pointing out where farmer engagement and support could have the most significant effect.

The most important factor, mentioned by 76% of farmers, was access to information and training. During the experiment, farmers who received demonstrations and guidance on how to set up and maintain the drip bottle system were much more likely to adopt it. The practical orientation of the study being carried out on the university farm allowed the researcher to conduct hands-on training sessions. These sessions demystified the irrigation process for some fellow farmers, increasing their confidence in using the technology. Some of the farmers without access to such knowledge were hesitant or unwilling to adopt the system, indicating a strong need for extension services and capacity building in rural areas.

Affordability of materials, cited by 72% of respondents, was another major influence. Since the drip bottle system primarily used recycled plastic bottles, the setup cost was significantly lower compared to conventional drip irrigation systems that require expensive pipes and emitters. The researcher appreciated that they could locally source the bottles and make simple modifications to them without needing external support. This made the system especially appealing to smallholder farmers with limited capital. Throughout the six-month experiment, it was evident that once farmers realized they could implement the system with minimal financial input, their willingness to adopt increased significantly.

Perceived water scarcity was reported as a motivator by 68% of the farmers. During dry spells in the experimental period, conventional watering methods proved inefficient and

labor-intensive.

4.7 Challenges faced by farmers in implementing drip irrigation. In contrast, the drip irrigation system delivered a consistent and localized water source, thereby alleviating plant stress and enhancing growth. Agricultural practitioners acknowledged the system's capability to conserve water while ensuring sufficient soil moisture levels. This perspective on efficiency was particularly pronounced during the mid-growth and flowering phases, periods characterized by elevated water requirements. It underscored the significance of the system in conditions where water availability is restricted.

The labour savings perceived were also instrumental, cited by 64% of the respondents. Even though the initial setup of the drip bottles involved elbow grease, watering repeatedly needed much less daily labour when compared with buckets or other conventional methods. This was highly appreciated during peak periods such as harvesting or weddings. Across the six-month pilot, the majority of the farmers stated that the system saved time for other activities on the farm, increasing efficiency. Women and old farmers, who are the actual ones who would water by hand in the majority of the smallholder farms, most appreciated the benefit.

Finally, the impact of peer influence and local implementation proved to be considerable. Some 55% of farmers identified the factor as one of the motivating forces to adopt the system. Farmers who saw the advantage experienced by neighbors or fellow adopters were more disposed to investigate the system further themselves. This system of social endorsement helped considerably to dispel the uncertainty. In the trial period, several of those who were initially ambivalent were persuaded otherwise by seeing better tomato development and produce on adjoining fields. The collaborative atmosphere of the university farm facilitated the informal dissemination of knowledge and results among participants, thereby enhancing adoption through observed success.

Lastly, the Bishop Barham University farm study revealed that the acceptance of drip bottle irrigation is influenced by different factors such as technical knowledge, cost consideration, availability of water, labour intensity, and social influence.

3.6.9 4.7 Challenges faced by farmers in implementing drip bottle irrigation

Despite the method's benefits, several challenges were reported by farmers using drip bottles for tomato cultivation.

Challenges	Percentage out of 100
Early blight	44%
Uneven Water Distribution	39%
Difficulty in Bottle Installation	33%
Lack of Technical Knowledge	39%
Wilting in non-irrigated areas	28%
Pest Nesting Around Bottles	16%

Challenges in Drip Bottle Irrigation System

The bar graph below shows the percentage of respondents who experienced different challenges with the drip bottle irrigation system.

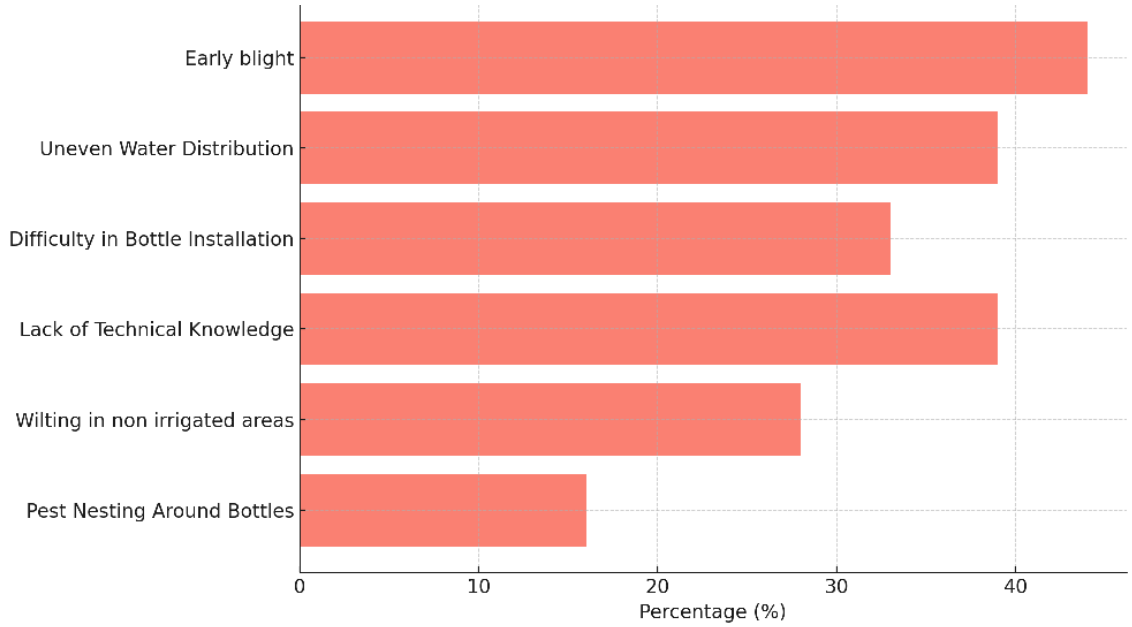


Figure 3: Challenges in the drip bottle irrigation system

These challenges highlight the importance of addressing both technical and agronomic issues when promoting low-cost irrigation systems in smallholder farming environments.

The most commonly reported challenge was the outbreak of early blight, affecting 44% of farmers. This fungal disease thrives in humid environments, and the use of drip bottles, especially when combined with mulch, creates localized microclimates conducive to its development. Although drip irrigation typically reduces leaf wetness and disease spread compared to overhead irrigation, poor sanitation, bottle positioning near the base of the plants, and insufficient crop rotation practices may have contributed to disease incidence. This finding emphasizes the need for integrating proper disease management strategies when introducing new irrigation methods.

Uneven water distribution, cited by 39% of the farmers, was another major obstacle. In the early stages of the experiment, some farmers struggled to maintain uniform bottle spacing and control the rate of water release. Bottles with inconsistent hole sizes or blockages in the cap led to either excessive water in some spots or inadequate supply

in others. This variability resulted in irregular plant growth and, in some cases, wilting. While the system is low-cost, its effectiveness depends heavily on proper setup and maintenance, something that many farmers were not initially well-equipped to manage without hands-on guidance.

Closely related to this was the difficulty in bottle installation, reported by 33% of participants. While the idea of reusing plastic bottles was widely accepted, the process of modifying and setting up dozens of bottles across a field proved to be laborious and time-consuming for some farmers. Properly piercing the caps to control flow, positioning the bottles near the root zones, and securing them in place required more effort than anticipated, especially for older farmers or those with limited labor. This challenge was most evident during the transplanting and early vegetative stages of the tomato crop.

Another significant issue was the lack of technical knowledge, which affected 39% of the farmers. While training was provided during the experimental phase, it became clear that a one-time demonstration was insufficient for some participants to fully grasp the method. For instance, many did not understand how to regulate water flow or adjust for soil type and crop stage. This knowledge gap often led to either under- or over-irrigation. The results suggest that continuous extension support or follow-up training is essential for successful long-term adoption of the system.

Lastly, wilting in non-irrigated areas (28%) and pest nesting around bottles (16%) were reported as minor but relevant concerns. Where bottles were incorrectly placed or omitted, tomato plants experienced wilting due to insufficient moisture. Additionally, a few farmers observed that plastic bottles left on the ground attracted pests like ants and snails, especially during the rainy season. Although these issues were less common, they highlight the need for proper coverage and hygiene. Preventative practices, such as regular bottle cleaning and field monitoring, were not consistently followed. This reduced the system's effectiveness in certain plots.

In conclusion, while the experimental research at Bishop Barham University farm

confirmed the potential of drip bottle irrigation to support tomato cultivation under water-limited conditions, the findings also reveal key implementation challenges. These range from agronomic issues like early blight and wilting to technical barriers such as uneven water distribution and poor system setup. Addressing these challenges through farmer education, follow-up support, and system design improvements will be essential for scaling up the use of this low-cost irrigation method in Uganda and similar contexts.

3.6.10 4.10 Cost-effectiveness of drip bottle irrigation compared to conventional irrigation

A comparative economic analysis (see Section 4.4.1) demonstrated the clear cost advantage of using drip bottles over conventional watering methods.

Parameter	Conventional Watering	Drip Bottle Irrigation
Total Yield (kg)	60 kg	78 kg
Revenue (UGX)	120,000	156,000
Total Input Cost (UGX)	50,000	45,000
Net Profit (UGX)	70,000	111,000
Water Use (liters/plot/day)	~200 L	~100 L

The comparative economic analysis, carried out during a six-month experimental study at Bishop Barham University farm, clearly highlights the cost-effectiveness of drip bottle irrigation compared to conventional watering methods. As shown in the table, tomato farmers using the drip bottle system achieved a total yield of 78 kg per plot, which was significantly higher than the 60 kg obtained using traditional methods such as watering cans or hoses. This yield increase of 30% demonstrates that a more consistent and targeted supply of water at the root zone promotes better plant growth, fruit development, and ultimately, higher productivity.

In terms of revenue, farmers using drip bottle irrigation earned UGX 156,000, compared

to UGX 120,000 earned through conventional irrigation. This difference can be directly attributed to the improved yield. Since both groups sold their tomatoes at the same market price, the revenue variation stems solely from the quantity of harvest. The data indicate that drip bottle irrigation not only enhances agricultural output but also translates into increased income, making it an attractive option for smallholder farmers who aim to maximize their return on investment.

It is also notable that the total input cost for drip bottle irrigation was slightly lower (UGX 45,000) than for the ordinary watering practice (UGX 50,000). Financial savings are largely due to reduced labour needs and reduced water use. Unlike the traditional method, where steady efforts for manual irrigation were needed, with high volume water use, the drip bottle method used recycled plastic bottles, sometimes which were free or very cheap, with lower daily labour demand after installation. Lower operational costs, albeit with an initial low investment for the adaptation and installation of the bottles, accounted for the total cost-saving nature of this technique.

Owing to increased revenue and reduced input expenditures, the net profit derived from drip bottle irrigation significantly exceeded that of traditional watering, amounting to UGX 111,000 in contrast to UGX 70,000.

This is a 58.5% increase in profit, reinforcing the economic viability of the system. For smallholder farmers with limited financial resources, this profit margin can make a meaningful difference in household income, school fees, or reinvestment into farming. It also demonstrates that sustainable farming techniques can be both environmentally friendly and financially rewarding.

Water use efficiency was another major benefit. The drip bottle method used approximately 100 liters per plot per day, while the conventional method consumed around 200 liters—a 50% reduction in water use. In regions like Uganda, where rainfall is seasonal and unpredictable, conserving water is crucial for maintaining agricultural output. The significant savings in water without sacrificing yield not only reduce production costs but also support environmental sustainability. In summary, the findings from Bishop Barham University farm confirm that drip bottle irrigation is a low-cost, high-impact innovation that can enhance both productivity and profitability for

smallholder tomato farmers.

3.6.11 4.11 In conclusion

The findings from this study clearly demonstrate that drip bottle irrigation significantly improves tomato productivity, enhances water use efficiency, and increases farmer profitability. Adoption is primarily driven by affordability, perceived benefits, and access to training. However, technical barriers such as clogging and poor setup highlight the need for capacity building. Therefore, when the issues are resolved, these challenges through community engagement, technical support, and low-cost innovations, drip bottle irrigation can be an effective, sustainable solution for smallholder tomato growers in Uganda and other water-scarce regions.

3.6.12 CHAPTER FIVE:
3.6.13 SUMMARY OF FINDINGS, DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

3.6.14 5.1 Summary of findings

This study aimed to assess the effectiveness of drip bottle irrigation on tomato growth and yield as compared to conventional irrigation methods. Conducted over six months at Bishop Barham University farm using an experimental design, the study revealed several key outcomes:

Germination Performance: Drip bottle irrigation yielded a higher germination rate (91.3%) compared to conventional watering (84.5%), attributed to consistent root zone moisture.

Growth Parameters: Tomatoes under drip irrigation recorded higher averages in plant height (48.3 cm), leaf area (140 cm^2), and stem girth (1.8 cm) than conventional methods, although differences were not statistically significant at $p < 0.05$.

Yield and Fruit Quality: Drip bottle irrigation led to significantly higher yields (78 kg per plot vs. 60 kg) and larger fruit sizes (125 g vs. 110 g average fruit weight).

Economic Impact: Drip irrigation was more cost-effective. It generated a higher net profit (UGX 120,000 vs. UGX 70,000) and used 50% less water each day (100L vs. 200L).

Adoption Factors: Key drivers included access to training (76%), affordability (72%), perceived water scarcity (68%), and labor savings (64%).

Implementation Challenges: Farmers faced challenges such as early blight (44%), uneven water distribution (39%), technical gaps (39%), and difficulty installing bottles (33%).

3.6.15 5.1 Discussions

The study reinforces the role of low-cost, resource-efficient technologies like drip bottle irrigation in transforming smallholder agriculture. The superior performance in germination, growth, and yield can be attributed to the method’s ability to deliver consistent water directly to the root zone. The improved fruit quality and uniformity further point to better nutrient uptake and reduced physiological stress in plants.

Environmental considerations are important. According to Singh and Kumar (2022), water scarcity and unpredictable rainfall in many tomato-growing areas push farmers to look for better irrigation methods. The water-saving benefit of drip irrigation is a strong incentive, particularly in drought-prone regions where traditional irrigation methods are ineffective and wasteful.

Economically, this method provides a practical and affordable solution for farmers with limited funds. Reusing plastic bottles significantly lowers setup costs compared to commercial drip systems. And water and labour savings contribute to profits. This reaffirms previous findings showing how the simplest drip irrigation systems could increase water productivity by 30 to 50% for smallholder horticulture.
Mwangi et al. (2020) have outlined that the localized compatibility of drip irrigation products highly matters. It is made clear that the affordability and accessibility of the machinery, along with localized weather conditions, significantly enhance the utilization of drip bottle irrigation. Also, the sustainability of the materials and the compatibility of the systems with local tomato varieties determine sustained usage.

Nevertheless, challenges like early blight and water distribution issues imply that simple solutions require careful thought. Proper training, regular maintenance, and proper disease control measures lead to the sustainability of benefits. Also, peer teaching and social acceptance remain imperative aspects of the development of adopters, highlighting the role of community-based extension services.

Environmental sustainability is one of the fields that has a great influence. It significantly lowers the use of water, which is very valuable to a country like Uganda, where water scarcity is the norm at times. It lowers the dependency on the hiring of labor hours, which has a high implication on the weaker sections of society who normally shoulder these responsibilities, particularly women and the elderly.

5.2 Conclusion

From the study research data, the following were the outcomes:
It also drastically enhances the tomato growth and production. It maintains the soil moisture steady at the root zone, allowing easy emergence of the seed as well as the development of the fruit.
It is also cheaper and water-friendly than the traditional methods of watering plants. It therefore enhances the earnings as well as the cost reduction. Adoption is also highly responsive to access to training, affordability, and perceived scarcity. Practical demonstrations as well as peer influence also highly influence farmer decision-making.
Despite the advantages, the challenges, such as the requirement for technical skills, disease incidence, and installation problems, discourage large-scale acceptance. This indicates the importance of sustained technical support and education among communities.

The drip bottle irrigation system provides an effective, low-cost solution for the smallholder growers. Through the integration of training and extension services, it can sustain climate-smart agriculture with the increase in the availability of food.

3.6.16 5.3 Recommendations

Based on the results of this research, the following are suggested:

1. Produce simplified technical pamphlets or handbooks in local languages on how to use and set up optimal bottle irrigation systems, and how to troubleshoot problems.
2. Promote community-led platforms for successful adopters to transfer their experiences and practical insights to others for facilitating peer-to-peer learning.
3. Incorporate drip bottle irrigation in agricultural extension and climate adaptation plans to support the use of water in sustainable ways and increase resilience to drought.
4. Promote the inter-university, NGO, and farmer association collaboration to finalize and customize the strategy for various crops, soils, and agro-ecological conditions.
5. Offer the startups supplies such as bottles or pre-pierced lids whenever practicable, particularly for the most vulnerable, such as women, the aged, or youth-headed families.

5.4 Areas for further research

Further study should investigate how continuous use of bottle-based drip irrigation affects soil moisture retention, nutrient leaching, and microbial activity over multiple growing seasons.

Another study is needed on how factors like gender, income level, education, and cultural beliefs affect the adoption of low-cost irrigation technologies.

3.6.17 References

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3.6.18 Appendices

Photos taken while carrying out the research in the field