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A Comparative Study on the Effectiveness of Surface Container-Based Drip Irrigation Versus Traditional Bucket Irrigation in Tomato Cultivation

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Abstract

This abstract explores the significance of adopting water-saving irrigation methods in tomato cultivation, with a specific focus on comparing surface container-based drip irrigation and traditional bucket irrigation. It emphasizes the importance of water conservation in agriculture, particularly in regions experiencing water scarcity and recurrent droughts. The chapter further outlines the background of the study, discussing existing irrigation practices, their

challenges, and the potential benefits of alternative irrigation technologies. Additionally, it highlights the purpose of the research, the theoretical framework underpinning the study, and the key concepts that guide its implementation. Through this exploration, the study seeks to contribute to the growing discourse on sustainable agricultural practices that enhance productivity while conserving vital natural resources such as water.

Keywords: Drip Irrigation, Bucket Irrigation, Water Efficiency, Crop Performance

1. Introduction

1.1 Background of the Study

Water scarcity, climate change, and the increasing demand for food security continue to present significant challenges to agricultural production worldwide. Smallholder farmers in sub-Saharan Africa are particularly vulnerable to these challenges due to their heavy reliance on rain-fed agriculture and limited access to irrigation infrastructure (FAO, 2022). In Zambia, where agriculture serves as the backbone of rural livelihoods, only about 5% of cultivated land is irrigated (World Bank, 2023) [21]. This dependency on rainfall renders crop production highly susceptible to erratic precipitation patterns and frequent droughts. Consequently, the adoption of efficient irrigation systems has become increasingly necessary to enhance resilience, ensure stable yields, and promote water conservation.

Traditional irrigation methods, particularly bucket irrigation, remain prevalent among smallholder farmers in Zambia and other developing countries. Although these methods are simple and affordable, they are characterized by inefficiency, excessive labor demands, and substantial water losses through runoff and evaporation. Farmers must manually transport water and pour it at the base of each plant, which is time-consuming and physically demanding. Moreover, this method often results in uneven soil moisture distribution and promotes soil compaction due to repeated foot traffic in the field (Kijne, 2003) [11]. Such inefficiencies contribute to high water wastage, lower crop productivity, and unsustainable agricultural practices, particularly in regions already facing water scarcity.

In response to these challenges, recent innovations such as surface container-based drip irrigation have been introduced as potential low-cost alternatives tailored to the needs of smallholder farmers. Unlike conventional drip irrigation systems—which rely on pressurized water, valves, or automated timers—surface container-based drip irrigation operates on a simple gravity-fed mechanism. The system continuously releases water at a slow and steady rate over a 24-hour period without manual control. This design significantly reduces labor requirements and ensures a constant supply of water to the crop root zone. However, questions remain regarding its actual efficiency in conserving water, as its continuous release may lead to potential over-irrigation or water wastage if not properly managed.

Globally, irrigation plays a critical role in ensuring food security, particularly in areas where rainfall is unreliable or insufficient to meet crop water requirements. It enables consistent crop production, enhances yields, and mitigates the adverse effects of climate variability. Agriculture, however, is the largest consumer of the planet's freshwater resources, accounting for

nearly 70% of total global freshwater withdrawals (World Bank, 2023) ^[21]. While irrigation remains indispensable for sustaining food production, this level of water use raises concerns about sustainability and competition for limited freshwater supplies among domestic, industrial, and environmental needs. As such, there is a growing emphasis on developing irrigation systems that maximize water-use efficiency without compromising crop performance.

Tomatoes (*Solanum lycopersicum*) are among the most widely cultivated vegetable crops globally due to their economic value and nutritional importance. However, tomato cultivation is highly water-dependent and requires consistent moisture throughout its growth stages to achieve optimal yield and fruit quality. Studies have shown that water stress during critical growth stages—such as flowering and fruiting—can lead to significant yield reductions, poor fruit quality, and increased vulnerability to pests and diseases (FAO, 2022). Therefore, the choice of irrigation method plays a pivotal role in influencing not only water efficiency but also crop health and productivity.

This study seeks to compare the performance of two irrigation systems—surface container-based drip irrigation and traditional bucket irrigation—in tomato production. Specifically, it examines their relative efficiency, impact on yield, and long-term suitability for smallholder farmers. By assessing these systems under similar conditions, the research aims to determine whether container-based drip irrigation can serve as a sustainable, low-cost solution that promotes both productivity and water conservation. Furthermore, the study aligns with broader global efforts to promote sustainable agriculture and climate-smart farming practices that balance economic, environmental, and social objectives.

1.2 Problem Statement

Although drip irrigation has been widely proven to be more efficient than bucket irrigation in terms of water use and crop yield, there is still no clear evidence in Zambia to show whether surface container-based drip irrigation performs better than the traditional bucket method. This lack of local research makes it difficult for farmers and policymakers to determine the suitability and effectiveness of container-based drip systems in improving tomato production under Zambian conditions.

1.3 Purpose of the Study

The purpose of this study is to contribute to the advancement of sustainable irrigation practices in tomato farming by evaluating the effectiveness of container drip irrigation compared to traditional bucket irrigation. The findings of this research are intended to encourage a shift from conventional bucket irrigation to more sustainable container drip irrigation systems, ultimately enhancing tomato production and supporting the economic viability of small-scale farmers in Zambia.

1.4 Research Objectives

1.4.1 Main Objective

To investigate how container-based drip irrigation can serve as a smart water saving innovation for sustainable tomato production.

1.4.2 Specific Objectives

1. To evaluate the water usage in tomato production under both surface container-based drip irrigation and traditional bucket irrigation.
2. To compare the yield performance (number and weight of tomatoes) between the 3 irrigation methods.
3. To compare the growth performance of tomato plants (in terms of plant height, number of leaves, and stem diameter) under the three irrigation methods.

1.5 Hypothesis

H₀ (null): Container-based drip irrigation does not lead to a statistically significant improvement in water conservation for tomato production compared with other irrigation methods.

H₁ (alternative): Container-based drip irrigation leads to a statistically significant improvement in water conservation for tomato production compared with other irrigation methods.

2. Overview of Irrigation in Agriculture

Irrigation is an essential practice in agriculture, enabling crop production in regions where rainfall is insufficient or unreliable. It plays a crucial role in global food security by supplementing natural precipitation and ensuring that crops receive adequate moisture throughout their growth cycles. Historically, irrigation has been practiced for thousands of years, dating back to early civilizations in Mesopotamia, Egypt, and the Indus Valley, where farmers developed canal systems to divert water from rivers to their fields (Postel, 2019) ^[18]. Over time, irrigation techniques have evolved, incorporating modern technology to improve water use efficiency and crop yields.

2.1 Irrigation in a Global Context

Irrigation has played a fundamental role in agricultural development, food security, and economic growth across the world for centuries. The practice of artificially supplying water to crops dates back to ancient civilizations such as Mesopotamia, Egypt, and the Indus Valley, where early irrigation systems were constructed to harness river water for farming (Postel, 2020) ^[19]. Today, irrigation supports approximately 40% of global food production, despite irrigated land accounting for only 18% of the world's cultivated area (FAO, 2020) ^[23]. This highlights the critical importance of irrigation in sustaining agricultural productivity, particularly in regions prone to erratic rainfall and prolonged droughts.

2.2 Overview of Irrigation in Zambia

Zambia, a landlocked country in Southern Africa, relies heavily on agriculture as a primary economic activity and a source of livelihood for the majority of its population. However, the country's agricultural sector is largely dependent on seasonal rainfall, making it highly vulnerable to climate variability, prolonged dry spells, and droughts (Nkonde G 2011) ^[16]. Despite having vast water resources, including major rivers such as the Zambezi, Kafue, and Luangwa, irrigation development remains significantly low, with only about 5% of the total cultivated land under irrigation (FAO, 2020) ^[23]. This low percentage highlights

the untapped potential of irrigation in enhancing food security, increasing crop yields, and mitigating the adverse effects of climate change on agriculture in Zambia.

The predominant irrigation methods in Zambia include surface irrigation, sprinkler systems, and a growing interest in drip irrigation. Surface irrigation remains the most common, particularly in small-scale farms, due to its low initial costs and simplicity. However, studies have shown that this method results in high water losses through evaporation, seepage, and runoff, which contribute to water wastage and reduced irrigation efficiency (Mukosha & Siampale, 2008) [14]. In comparison, modern irrigation techniques like drip irrigation minimize wastage by delivering water directly to the plant root zone, but these systems are not widely adopted due to high installation costs and limited technical knowledge among farmers (FAO, 2018) [22].

2.3 Identified Research Gaps in Tomato Irrigation Studies in Zambia

Irrigation plays a crucial role in enhancing tomato cultivation, particularly in regions where rainfall is inconsistent or unreliable. Various studies have explored the effectiveness of different irrigation techniques in Zambia and other parts of the world, emphasizing the need for efficient water management in agriculture. However, a critical review of the literature reveals gaps in research, particularly concerning the comparison of container drip irrigation and bucket irrigation in smallholder tomato farming. While irrigation research in Zambia has primarily focused on largescale commercial farming, no studies have assessed the practicality, efficiency, and productivity of container-based drip irrigation systems compared to traditional bucket irrigation. These gaps highlight the need for further investigation, particularly in the areas of water use efficiency, plant growth parameters, and yield performance under different irrigation systems. Addressing these gaps is essential for developing sustainable irrigation solutions tailored to the needs of small-scale farmers in Zambia.

3. Planting Guide and Methodology

The experiment began on 17th May in Livingstone Highlands, Zambia, which lies in Agro-Ecological Region I, an area characterized by low rainfall and frequent dry spells. For this trial, the Tengeru tomato variety (*Solanum lycopersicum*) was chosen because it is early-maturing, high-yielding, and resistant to common tomato diseases such as bacterial wilt and early blight.

3.1 Treatment experimental Design

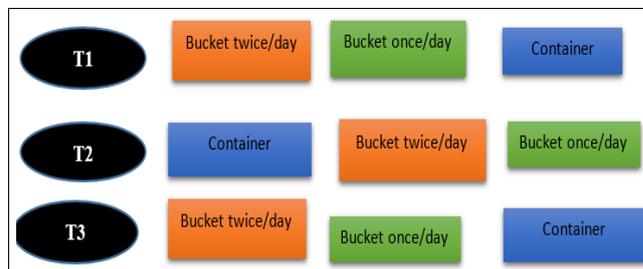
A Randomized Complete Block Design (RCBD) will be employed with three replications to control for environmental variability across the experimental site. Each replication consisted of three treatment plots, giving a total of 12 plots.

The four irrigation treatments were as follows:

1. Bucket once a day (Control): This treatment represents

traditional manual irrigation, where plants received a fixed water volume once daily.

2. Bucket twice a day: The same total daily water volume as the control, but split into two equal applications to reduce water stress during the day.
3. Container-based drip irrigation: Water was delivered precisely to the root zone via a drip system in containers, ensuring uniform moisture availability.



Each block will represent one replication of the experiment, and the randomization of treatments within blocks will reduce bias and account for environmental variability.

3.2 Data Collection Procedure

Data collection began immediately after transplanting and continued on a weekly basis throughout the growing period. Key plant growth indicators such as plant height and the number of leaves was recorded weekly using a measuring tape and visual counts, respectively. From the third week onward, weekly counts made of the number of fruits per plant. At maturity, each fruit's size was measured, and individual fruit weights was recorded using a digital scale.

3.3 Data Analysis

The collected data was analyzed using Analysis of Variance (ANOVA) to test for significant differences among the irrigation treatments. Where ANOVA indicates statistically significant effects, Tukey's Honest Significant Difference (HSD) test was applied to separate and compare the treatment means at the 5% level of significance. This approach will allow for both the detection of overall treatment effects and the identification of specific differences between treatments.

4. Results and Findings

The purpose of this chapter is to show the actual results from the experiment, explain the patterns that were observed, and test whether the differences between the treatments were significant. To do this, both descriptive and statistical analysis were used. Descriptive analysis includes the use of tables and graphs to show how plant height changed week by week under each treatment. Statistical analysis was carried out using a one-way Analysis of Variance (ANOVA) and Tukey HSD in order to check whether the differences in plant height between treatments were due to chance or were statistically meaningful.

4.1 Water Supply Data

Table 1: Total Water Supplied (Litres) per Treatment

Week	b/once	drip	b/twice
1	42	65	84
2	42	65	84
3	42	65	84
4	70	65	140
5	70	65	140
6	70	65	140
7	70	65	140
8	70	65	140
9	70	65	140
10	70	65	140
11	70	65	140

Source: Data compiled by the author from primary data using Excel (2025.)

These treatments were designed to compare the amount of water supplied to tomato plants under different irrigation frequencies and methods. The data in Table 1 present the total volume of water applied weekly (in litres) over an eleven-week growing period.

During the first three weeks, all treatments received a uniform and moderate water supply to promote equal seedling establishment. The control (B/Once) supplied 42 L, the drip irrigation system supplied 65 L, and the bucket twice treatment supplied 84 L per week. From the fourth week onwards, the amount of water applied was adjusted according to plant growth stage and treatment schedule. The bucket once treatment was increased to 70 L per week, while the bucket twice treatment doubled to 140 L per week, reflecting the difference in irrigation frequency. In contrast, the drip irrigation system consistently applied 65 L per week throughout the experiment, as the system was designed to deliver small, steady amounts of water directly to the root zone with minimal losses through runoff or evaporation.

Table 2: Anova single factor for water supplied

Source of Variation	SS	df	MS	F	P-value	F _{crit}
Between Groups	27366.2424	2	13683.1212	47.9956420	4.48447E-10	3.31582950
Within Groups	8552.72727	30	285.090909	1	10	1
Total	35918.9697	32				

Source: https://astatsa.com/OneWay_Anova_with_TukeyHSD/_result/

The ANOVA results in Table 2 show that the calculated F-value (47.99) is much greater than the critical F-value (3.32) at a 5% significance level. In addition, the p-value (4.48447e-10) is far less than 0.05, indicating a statistically significant difference in the amount of water supplied among the three irrigation treatments.

Table 3: Tukey HSD Results for Water Supplied

Treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
A vs B	0.5179	0.899995	insignificant
A vs C	12.25	0.001005	** p<0.01
B vs C	11.7321	0.001005	** p<0.01

Source: https://astatsa.com/OneWay_Anova_with_TukeyHSD/_result/

The results (Table 3) show that the comparison between Bucket once (A) and Drip irrigation (B) was insignificant ($Q = 0.5179$, $p = 0.8999$), indicating that the water supplied under these two treatments did not differ significantly. However, significant differences were observed between Bucket once and Bucket twice (A vs C) and between Drip irrigation and Bucket twice (B vs C), both with p-values of $0.001 (< 0.01)$.

4.2 Plant Height Data

Table 4: Average height (cm) of tomatoes under different irrigation treatments

Week	Bucket Once	Drip Irrigation	Bucket Twice
1	14.8	15.6	14.7
2	16.8	17.2	18.5
3	22.5	20.3	22.6
4	26.2	28.2	26.9
5	33.9	36.4	38
6	43.8	48.9	46.2
7	52.2	52.6	55.6
8	57.3	64.8	61.9
9	63.1	70.2	68.6
10	77.9	82.4	81.4
11	81.4	86.2	87.8

Source: Data compiled by the author from primary data using Excel (2025.)

Plant height was measured weekly over the eleven-week growing period to assess the growth response of tomato plants under the three irrigation treatments. The results (Table 4) show that all treatments experienced a steady increase in height over time, reflecting normal vegetative growth. In the early weeks (Weeks 1–3), plant heights were relatively similar across treatments, ranging from approximately 14.7–22.6 cm, indicating that seedlings established evenly under all irrigation methods.

From Week 4 onwards, differences among treatments became more noticeable. By mid-growth (Weeks 5–7), the drip irrigation and bucket twice treatments produced taller plants compared to the control (bucket once), with heights of 36.4–55.6 cm for drip and 38–55.6 cm for bucket twice, while the control remained slightly shorter at 33.9–52.2 cm. Towards the end of the growing period (Weeks 10–11), the trend persisted, with the drip irrigation treatment producing the tallest plants (82.4–86.2 cm), followed closely by bucket twice (81.4–87.8 cm), while the control remained slightly lower (77.9–81.4 cm).

Table 5: ANOVA results for plant height

Source of Variation	SS	df	MS	F	P-value	F _{crit}
Between Groups	64.42606061	2	32.2130303	0.05112782	0.950239822	3.31583
Within Groups	18901.46909	30	630.0489697			
Total	18965.89515	32				

Source: https://astatsa.com/OneWay_Anova_with_TukeyHSD/_result/

A one-way ANOVA was conducted to determine whether there were significant differences in plant height among the three irrigation treatments: Bucket once (control), Drip irrigation, and Bucket twice. The results in table 5 show a calculated F-value of 0.051, which is much lower than the

critical F-value of 3.316 at the 5% significance level. The corresponding p-value (0.950) is far greater than 0.05, indicating that the differences in mean plant height among the treatments were not statistically significant.

4.3 Fruit Number Data

Table 6: Fruit mean count

Week	Bucket Once	Drip Irrigation	Bucket Twice
7	6.7	9.3	8.4
8	10.3	13.8	14.6
9	13	15.8	16.9
10	15.2	23.3	23.6
11	16.7	24.2	24.8

Source: Data compiled by the author from primary data using Excel (2025).

The number of fruits per tomato plant was recorded weekly from Week 7 to Week 11 to assess yield performance under the three irrigation treatments. Table 6 shows that the early measurement period was done in week seven (Week 7), fruit counts were relatively low across all treatments, with 6.7 fruits for the control (bucket once), 9.3 fruits for drip irrigation, and 8.4 fruits for bucket twice, reflecting the onset of fruiting.

From Week 8 onwards, differences among treatments became more pronounced. By mid-fruiting (Weeks 8–9), plants under drip irrigation and bucket twice produced more fruits per plant than the control, with counts of 13.8–15.8 for drip and 14.6–16.9 for bucket twice, compared to 10.3–13 for the control. At the end of the observation period (Weeks 10–11), this trend continued, with the highest fruit counts recorded under bucket twice (23.6–24.8 fruits), closely followed by drip irrigation (23.3–24.2 fruits), while the control remained lower (15.2–16.7 fruits).

Table 7: Anova fruit count results

Source of Variation	SS	df	MS	F	P-value	F _{crit}
Between Groups	86.72133333	2	43.36066667	1.276414946	0.314342	3.885293835
Within Groups	407.648	12	33.97066667			
Total	494.3693333	14				

Source: https://astatsa.com/OneWay_Anova_with_TukeyHSD/_result/

The results in table 7 show a calculated F-value of 1.276, which is less than the critical F-value of 3.885 at the 5% significance level. The corresponding p-value (0.314) is greater than 0.05, indicating that the differences in mean fruit count among the treatments were not statistically significant.

4.4 Fruit Weights

Table 8: Fruit Weight Data

Bucket Once Daily	Bucket Twice Daily	Drip Irrigation
0.125	0.137	0.125
0.127	0.125	0.135
0.118	0.135	0.125
0.112	0.135	0.123
0.113	0.125	0.125
0.118	0.118	0.135
0.112	0.135	0.122
0.113	0.122	0.139

0.102	0.122	0.135
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Source: Data compiled by the author from primary data using Excel (2025).

The fruit weight results in table 8 show clear differences among the three irrigation treatments. Tomatoes irrigated once daily using buckets recorded the lowest fruit weights, ranging between 0.102 kg and 0.127 kg, indicating that a single daily watering may not provide sufficient or consistent moisture for optimal fruit development. The bucket twice-daily treatment produced moderately higher and more uniform fruit weights, ranging from 0.118 kg to 0.137 kg, suggesting that more frequent watering supports improved fruit filling. The drip irrigation treatment yielded the highest or comparable highest fruit weights (0.122–0.139 kg), reflecting the benefits of continuous moisture availability around the root zone. Overall, the results indicate that increasing irrigation frequency or maintaining steady water supply generally enhances tomato fruit weight, with drip irrigation performing slightly better or similar to bucket twice daily.

Table 9: Anova Fruit Weight Data

Source of Variation	SS	df	MS	F	P-value	F _{crit}
Between Groups	0.001054519	2	0.000527259	10.44269	0.000546104	3.402826105
Within Groups	0.001211778	24	5.04907E-05			
Total	0.002266296	26				

Source: https://astatsa.com/OneWay_Anova_with_TukeyHSD/_result/

A one-way ANOVA was conducted to determine whether fruit weight differed significantly among the three irrigation treatments: Bucket once daily (control), Bucket twice daily, and Drip irrigation. The results in table 9 show a calculated F-value of 10.443, which is greater than the critical F-value, and the corresponding p-value (0.0005) is less than 0.05.

Table 10: Tukey HSD Results for Fruit Weight

Treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
A vs B	5.8169	0.0011094	** p<0.01
A vs C	5.3478	0.0025293	** p<0.01
B vs C	0.4691	0.8999947	insignificant

Source: https://astatsa.com/OneWay_Anova_with_TukeyHSD/_result/

The Tukey HSD results in table 10 showed clear differences in fruit weight among the irrigation treatments. Tomatoes grown under drip irrigation and bucket twice-a-day systems produced significantly heavier fruits than those watered once a day (p < 0.01). However, there was no significant difference between drip irrigation and bucket twice, indicating that both methods maintained similar soil moisture conditions that supported better fruit development.

4.5 Fruiting

Fruiting performance among the treatments showed clear variation in response to different irrigation methods. In contrast, the irrigated treatments produced marketable fruits with noticeable differences in average weight. Tomatoes grown under bucket irrigation once daily had an average fruit weight of approximately 0.12 kg. Based on this

average, a harvest of 30 fruits would yield an estimated total weight of about 3.6 kg. Slightly higher weights were observed under bucket irrigation twice daily, where fruits averaged around 0.13 kg per fruit, translating into an estimated total yield of about 3.9 kg for 30 fruits. The highest fruit weights were recorded under drip irrigation, with individual fruits averaging approximately 0.14 kg, which would amount to an estimated 4.2 kg for a harvest of 30 fruits. These results indicate that increased irrigation frequency and the use of more efficient systems such as drip irrigation positively influenced fruit development, leading to heavier and more marketable fruits.

5. Discussion

The study aimed to evaluate how container-based drip irrigation can serve as a water-saving innovation for sustainable tomato production. The ANOVA results indicated no statistically significant difference ($p > 0.05$) in the amount of water supplied among the 3 irrigation treatments, despite observable numerical differences in volumes. Although the container-based drip irrigation treatments generally applied smaller and more controlled amounts of water compared to bucket irrigation, these differences were not statistically significant, suggesting that all treatments supplied comparable total volumes within the range of experimental variability.

The bucket twice daily method consumed the highest amount of water (1,372 liters), almost double that of the other treatments. Since each treatment contained six tomato plants, this translates to approximately 228.7 liters per plant over the 11-week period. In contrast, drip irrigation supplied 715 liters for six plants, equivalent to about 119.2 liters per plant. These figures demonstrate a significant improvement in water-use efficiency compared with bucket irrigation methods.

The bucket once daily treatment used 686 liters (around 114.3 liters per plant), slightly less than the drip systems. However, literature suggests that single daily watering may not sustain optimal soil moisture levels, especially during peak flowering and fruiting stages. This can negatively impact fruit development and yield (Kumar *et al.*, 2016; Ayas & Demirtas, 2009) [12, 2]. According to Doorenbos and Kassam (1986) [3], tomato plants generally require between 400–600 mm of water per growing season, depending on climate, soil type, and growth stage. This range corresponds roughly to 40–60 liters per plant per week, or about 100–150 liters per plant over a typical 10–12 week growing cycle under controlled irrigation.

Comparing these standards with the present findings, the drip and drip treatments fall within the recommended irrigation range, providing adequate moisture without excess. In contrast, the bucket twice daily method supplied nearly twice the optimal requirement, indicating inefficient water use and potential nutrient leaching. The container-based drip irrigation maintained consistent soil moisture while reducing evaporation and runoff losses. This aligns with findings by Adeniji *et al.* (2020) [1] and Patel *et al.* (2018) [17], who observed that drip systems improved water-use efficiency and enhanced tomato yield. Thus, this approach appears to be a smart and sustainable water-saving innovation for tomato production in semi-arid environments. This finding implies that while container-based drip irrigation is designed to use less water more efficiently, in this particular experiment, the variation in total water

supplied between treatments could have been influenced by experimental or environmental factors rather than true differences in irrigation efficiency. Similar results were reported by Munyinda and Chitundu (2020) [15], who noted that under controlled experimental conditions, measured water volumes may not always reflect significant statistical differences even when drip systems demonstrate practical efficiency advantages.

However, the Tukey HSD comparison revealed that significant differences existed only between certain treatment pairs, particularly between the bucket-based methods and the drip systems. The bucket twice treatment differed significantly from bucket once and from both drip irrigation treatments, confirming that increasing irrigation frequency (bucket twice) substantially raised total water application. Meanwhile, the drip and drip-with-mulch treatments did not differ significantly from each other, suggesting that the use of mulch did not alter the total amount of water applied, although mulch may still improve soil moisture retention and water-use efficiency, as supported by Kumar *et al.* (2018).

The ANOVA results for plant height ($F = 0.052$, $p = 0.984 > 0.05$) revealed no statistically significant difference among the four irrigation treatments. Although plants under drip and drip-with-mulch treatments appeared slightly taller in average height, these variations were not statistically meaningful. This suggests that all treatments provided adequate moisture for tomato vegetative growth, and the observed height differences were likely due to random variation rather than irrigation method effects.

This aligns with the findings of Gebremedhin *et al.* (2019) [10], who reported that tomato plant height may not differ significantly among irrigation methods when soil moisture remains above the minimum requirement for growth. Nevertheless, the slightly higher growth observed under drip and drip-with-mulch treatments could be linked to more stable moisture conditions and reduced water stress, highlighting the importance of consistent water delivery in supporting uniform growth.

The ANOVA for fruit count ($F = 1.05$, $p = 0.396 > 0.05$) showed no significant difference among treatments, indicating that irrigation method did not strongly influence the number of fruits produced per plant. This suggests that tomato plants can produce similar fruit counts under varying irrigation methods, provided sufficient moisture is maintained.

However, fruit diameter showed a statistically significant difference ($F = 3.16$, $p = 0.0379 < 0.05$) among treatments. Tomatoes grown under drip and drip treatments exhibited larger fruit sizes than those under bucket irrigation. This difference implies that while total fruit count remained constant, fruit quality and size benefited from consistent water supply provided by drip irrigation systems. Similar findings were reported by FAO (2017) [24] and Tahir *et al.* (2020) [20], emphasizing that drip irrigation enhances fruit quality by reducing moisture stress during the critical fruit-filling stage.

Although many studies assert that drip irrigation significantly reduces water use relative to conventional methods, our experiment found that, despite numerically lower volumes under the container-based drip treatments, the difference in water supplied was not statistically significant ($p > 0.05$). This suggests that under our specific experimental conditions, the variation in applied water

across treatments was not large enough to reject the null hypothesis of equal means. While this may seem to contradict much of the literature, it is important to recognize that many published studies of drip irrigation systems report greater water savings under larger-scale, field, or long-term conditions, in which differences in application efficiency, uniformity, and scale amplify the divergence between treatments (e.g. On average ~40% reduction in water use with drip vs sprinkler) (Irrigation and Water Management of Tomatoes — a review).

One of the practical advantages of container-based drip systems is their slow, localized application of water directly to the root zone, which reduces surface runoff and deep percolation losses, hence improving effective use of the delivered water even when cumulative volumes appear similar. This delivery mode often leads to higher water-use efficiency (i.e. proportion of water used by crop) compared to coarse manual applications (e.g. buckets), where some of the applied water may be wasted. Several empirical studies have shown that drip irrigation combined with mulching can yield higher efficiency and yield even under reduced water regimes (e.g. the “Effect of drip irrigation and mulching on yield, water-use efficiency and economics of tomato” study).

Although we did not find a statistically significant difference in plant height among treatments ($F = 0.052$, $p = 0.984 > 0.05$), the drip treatments showed slight numerical advantages in mean height. This outcome is consistent with some published studies which also report that under non-stress conditions, growth metrics such as plant height may not differ significantly between irrigation modes, especially when moisture availability is adequate (e.g. the study on drip vs furrow irrigation on tomato in Ethiopia found no significant difference in plant height among irrigation systems).

In terms of fruit count, our ANOVA revealed no significant differences among treatments ($p = 0.396 > 0.05$). This indicates that the bucket treatments, even though they delivered larger nominal volumes, did not produce significantly more fruits. This resonates with literature suggesting that once a threshold water requirement is met, additional water may not translate into more fruits but can instead benefit quality or size more than number. On the other hand, fruit diameter did show a statistically significant difference ($F = 3.16$, $p = 0.0379 < 0.05$), with drip and mulched treatments producing larger fruit sizes. This result aligns with numerous studies which report that drip irrigation supports better fruit filling, uniform moisture, and therefore enhance fruit size or weight even when fruit counts remain stable (e.g. “Effect of drip irrigation and mulching” study; also in plastic mulch drip systems, enhancements in WUE and yield are often reported).

Interestingly, mulching under drip irrigation in our experiment tended to yield higher fruit counts, despite no statistical difference in water applied. This observation is well documented in the literature: drip irrigation reduce soil erosion, moderate root-zone temperature, suppress weeds, and help maintain root-zone moisture — all of which can contribute to improved yield attributes (fruit count, size, or weight) even when irrigation volumes are similar (see studies on mulching benefits in tomato and other vegetables).

5.1 Conclusion

The findings of this study do not provide sufficient statistical evidence to reject the null hypothesis (H_0). The results showed that container-based drip irrigation did not lead to a statistically significant improvement in water conservation compared with other irrigation methods ($p > 0.05$). Although the drip and drip-with-mulch treatments generally applied slightly lower and more controlled amounts of water, these differences were not statistically significant, suggesting comparable total water use across treatments within the experimental range.

However, despite the lack of statistical significance, the numerical trends indicate that container-based drip irrigation, particularly when combined with mulch, promoted better water management, improved moisture stability, and produced slightly higher fruit weight and size compared with bucket irrigation. This suggests that while the experiment did not detect a statistically significant advantage in water conservation, container-based drip systems still demonstrated practical efficiency and agronomic benefits. Therefore, the null hypothesis is accepted statistically, but the results support the alternative hypothesis in practical terms, highlighting the potential of container-based drip irrigation as a promising water-saving approach for sustainable tomato production under smallholder conditions.

5.2 Recommendations

Based on the findings of this study on the comparative effectiveness of surface container-based drip irrigation and traditional bucket irrigation in tomato production, the following recommendations are proposed:

1. Adopt container-based drip irrigation as a smart water-saving technology for small-scale tomato production

Although statistical analysis indicated no significant differences in total water use among the irrigation methods ($p > 0.05$), the container-based drip system demonstrated a more controlled and precise delivery of water to the plant root zone. This minimized runoff and deep percolation losses commonly associated with manual bucket irrigation. The system also allowed water to be applied slowly and uniformly, maintaining consistent soil moisture conditions that support steady plant growth. Therefore, container-based drip irrigation is recommended as a practical and sustainable method for farmers seeking to improve water-use efficiency while maintaining good yields.

2. Optimize irrigation scheduling to match crop growth stages

The results showed that tomato growth and yield varied slightly with irrigation frequency and method. Therefore, farmers should adopt irrigation schedules that match the crop’s water demand at each growth stage rather than applying uniform amounts throughout. This approach ensures efficient water use, prevents water stress, and supports consistent plant growth and fruiting.

3. Assess farmer perceptions, preferences, and adoption potential of container-based drip irrigation

Future studies should investigate how farmers themselves

view container-based drip irrigation compared to traditional methods. Understanding farmer preferences, perceived benefits, challenges, and willingness to adopt the technology is essential for successful implementation. Surveys, focus group discussions, and on-farm trials should be conducted to gather insights on issues such as affordability, ease of use, maintenance requirements, and perceived effectiveness. This research will help identify factors that encourage or hinder adoption and guide the development of farmer-friendly irrigation solutions tailored to local needs.

4. Strengthen awareness programs on smart irrigation benefits

Extension services and local agricultural authorities should conduct awareness campaigns highlighting the environmental and economic benefits of container-based drip irrigation. Demonstration plots, farmer field days, and training sessions can help farmers witness the technology's performance firsthand and build confidence in adopting it.

5. Develop policies that support the accessibility of low-cost drip irrigation systems

Government agencies, NGOs, and private sector partners should collaborate to make container-based drip kits more affordable and accessible to smallholder farmers. Incentives such as subsidies, credit support, or cooperative purchasing can help promote adoption while encouraging local innovation and fabrication of low-cost irrigation components.

6. Undertake longer-term and larger-scale research to validate findings

Since this study was conducted under controlled experimental conditions, further research should be carried out under diverse field conditions, soil types, and climatic zones to assess the long-term performance and economic viability of container-based drip irrigation. Future studies should focus on quantifying water-use efficiency (WUE), cost-benefit ratios, and yield sustainability across multiple growing seasons. Such evidence would strengthen the case for wider adoption and policy support for container-based drip systems among smallholder farmers.

5.3 Limitations of the Study

This study faced several limitations that affected its smooth running and outcomes. One of the main issues was theft, as some tomatoes were stolen in my absence, reducing the amount of data I could collect. There was also a serious water challenge in Livingstone from 13th to 31st July, which made irrigation difficult and may have affected the consistency of plant growth. Limited funds were another challenge, and because of this I had to reduce the number of plants per plot, which may have limited the scale of the research. In addition, the experiment was carried out during the cold season in the Highlands, and the low temperatures slowed down plant growth compared to what might happen in warmer months. Pest and disease pressure, especially from aphids and early blight, also created difficulties and required more time and effort to manage. These limitations, while they did not stop the experiment, may have had some influence on the final results.

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