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Effects of Nitrogen Fertiliser Application Methods on Quality and Yield of Different Tomato Varieties

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Abstract

This study investigates the effect of nitrogen fertilizer application methods on the quality and yield of different tomato varieties, focusing on Candela and Alambra F1. The experiment was conducted in Lusaka, Zambia, utilizing three nitrogen application techniques: fertigation, foliar application, and band application, alongside a control group with no fertilizer. The results indicated significant differences in both yield and quality attributes between the varieties and application methods. Fertigation consistently outperformed other methods, producing higher yields and improving fruit quality in terms of size, color, and nutritional content. This research highlights the importance of selecting appropriate nitrogen application methods for optimizing tomato production, particularly in regions with similar agro-ecological conditions to Zambia. The findings offer valuable insights for farmers seeking to maximize efficiency and profitability while minimizing environmental impact.

Keywords: Nitrogen Fertilizer, Fertigation, Tomato Yield, Tomato Quality, Foliar Application, Band Application, Zambia, Alambra F1, Candela

Introduction

Background

Tomato (*Solanum lycopersicum*) is an annual herbaceous plant that belongs to the *Solanaceae* family. The cultivation of tomato plants originated from Mesoamerica, particularly present-day Mexico. The spread of tomato cultivation beyond Mesoamerica was facilitated by the Spanish colonization of the Americas in the 15th and 16th centuries and later spread to Africa and finally Zambia. Tomato is one of the most important and widely grown vegetable crops in the world, ranking 2nd in importance after Potato FAO (2019) [33]. It is a versatile vegetable for culinary purposes, and its fruits can be eaten raw or cooked. Besides being tasty, tomatoes are also beneficial to health as they are a good source of Vitamins A and C. Cooked tomatoes and tomato products are the best source of lycopene, a powerful antioxidant that helps prevent the development of various cancers Mahajan & Singh (2006).

About 83% of the freshwater resources in India are currently used for agriculture to produce important crops like tomatoes. Tomatoes respond well to additional fertilizer application and are reported to be heavy feeders of NPK Hebbar *et al*. (2004) [47]. Nitrogen is particularly important for tomato plant growth, yield, and fruit quality. It plays a vital role in chlorophyll formation, boosting protein content, enhancing nutrient uptake, and promoting photosynthesis. Different forms of nitrogen fertilizers are used in cropping systems worldwide Souri & Roemheld (2009). In Zambia, nitrogen fertilizers such as urea, calcium nitrate, potassium nitrate, and ammo- nium nitrate are available. Urea, with its high nitrogen content (46%), is the most favorable fertilizer for small-scale farmers due to its cost effectiveness and ease of handling Bhalerao (2015) [12], Eissa (2017) [31]. Calcium nitrate, though more expensive, can prevent disorders like blos- som end rot and improve fruit quality. Soil fertility is the most limiting resource for crop growth in Zambia, with nutrient con- straints contributing to low productivity and food insecurity Ferrante & Mariani (2018) [35], Ullah *et al*. (2021). The Zambian government has implemented subsidy programs to make fertilizers more affordable for smallholder farmers Mofya-Mukuka *et al*. (2016).

Extension services also play a crucial role in educating farmers on proper nitrogen fertilizer application techniques Sitko *et al*. (2017).

Studies have shown that different fertilizer application methods, including foliar application, soil application, and fertigation, have varying effects on the yield and quality of tomato fruits. The correct use of fertilizers, applied in the right amount and through the most effi- cient method, is essential for sustainable tomato production in Zambia. The aim of this study is to identify the most efficient method of applying nitrogen fertilizer in tomato production in Zambia.

Problem Statement

Tomato is one of the most important horticultural crops globally consumed, providing essential nutrients such as vitamins, amino acids, and minerals in our daily diets Arujo & colleagues (2016) [7]. Additionally, tomato serves as an important source of income, especially for small- holder farmers. Due to its economic and nutritive value, increasing its productivity with good yield and quality is a major goal for farmers YAP (2016). The utilization of nitrogen fertilizers in agricultural practices significantly impacts the yield and quality of various tomato varieties YAP (2016). However, the efficiency of nitrogen fertilizer application methods remains a sub-ject of inquiry, particularly regarding its effects on both yield and quality attributes of tomatoes in Zambia. To address this gap, it is crucial for researchers to undertake studies assessing the effect of nitrogen fertilizer application methods on the yield and quality of different tomato varieties.

General Objective

To assess the effect of nitrogen fertilizer application method on quality and yield of different tomato variety.

Specific Objectives

1. To assess the effect of nitrogen fertilizer application method on plant growth of different tomato varieties.
2. To assess the effect of nitrogen fertilizer application method on fruit quality and yield of tomato varieties.
3. To compare the effectiveness of different nitrogen fertilizer application methods on the yield and quality of tomato varieties.

Hypothesis

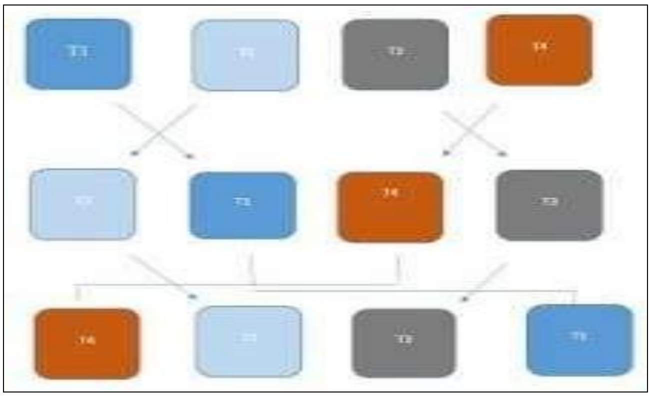
The study will test the following hypotheses: *H*0: There is no significant effect of nitrogen fertilizer application method on tomato quality and yield.
H1: There is a significant effect of nitrogen fertilizer application method on tomato qual- ity and yield.

Materials and Methods

Experimental Site

The experiment was conducted at Barlastone camp on Mr. Mhango's farm to evaluate the effects of nitrogen fertilizer application methods on the quality and yield of different tomato varieties. Mhango's farm is located in Agroecological Zone II in Lusaka, Lusaka District. The soils in this region are characterized by strong acidity, low nutrient retention, low water-holding capacity, and a dominance of coarse-textured soils. The annual rainfall ranges from 800 to 1000 mm.

Experimental Design and Schematic Diagram



The experiment will be conducted at Balastone camp in Chilanga at Mhango's farm to eval-uate the effect of nitrogen fertilizer application method on the quality and yield of different tomato varieties. The experiment will be laid out in a complete randomized block design with 4 treatments.

Experimental Details

Tomato Varieties

Two tomato varieties will be planted:

Candela Alambra

There will be 24 plots that will be divided into two groups, each representing one tomato variety, making 12 plots for each type of variety. The 12 plots for each variety will be divided into 3 replications, with each replication consisting of 4 plots.

Plot Design

Each plot will have the dimensions:

$$4 \text{ m} \times 3 \text{ m} = 12 \text{ m}^2$$

The distance between replications will be 1 m, and the spacing between lines within a plot will be 25 cm.

Treatments

The 4 treatments will be as follows: T1: Absolute control (no fertilizer)
T2: Urea applied by fertigation
T3: Urea applied by foliar application
T4: Urea applied by band application This arrangement will be used for both tomato varieties (*Candela* and *Alambra*).

Variety Information

The two varieties that were used for this research were *Alambra F1* and *Candela*.

Alambra F1

Alambra F1 was a robust hybrid designed for high yields and consistency in size and shape. The fruits were large, round, and exhibited a bright red color when ripe? Known for its tolerance to various environmental stresses, including high temperatures, *Alambra F1* was suitable for growing in regions with extended warm periods. It showed resistance to common pathogens such as fusarium wilt, verticillium wilt, and tomato spotted wilt virus, which made it a preferred choice in commercial agriculture due to its productivity and the uniform quality of the fruits?

Candela

Candela was distinguished by its elongated, plum-type tomatoes that were ideal for sauces and canning because of their rich flavor and thick flesh with few seeds Review (2020a). This variety was favored by both commercial processors and home gardeners for its vigorous growth and ability to thrive in both greenhouses and open fields. *Candela* showed good resistance to common diseases, which helped ensure the reliability of crop yields?

Land Preparation

Preparing the soil for growing tomatoes required careful planning and execution to create opti- mal conditions for seed germination, root development, and overall plant growth. The study site was cleaned by removing plant debris, weeds, or residue from previous crops to create a clean planting surface using a hoe, machete, and rake. A plough was utilized to break up compacted soil layers, improve aeration, and facilitate root penetration. Cow dung was incorporated into the soil to enrich it and provide the nutrients necessary for cabbage growth. The soil was then leveled using a rake to ensure uniform water distribution and minimize runoff. Furrows spaced 5 cm apart and 0.5 cm deep were dug to make a nursery, and a flat seed bed was made.

Nursery Establishment

The process began with the careful selection of a suitable site, taking into account factors such as adequate sunlight, good drainage, and protection from strong winds. A flat nursery bed was made to facilitate drainage and control soil moisture. The soil in the bed was meticulously tilled, smooth, lump-free, leveled, and supplemented with cow dung manure to improve fertility and provide the necessary nutrients for the seedlings to develop.

Once the nursery bed was prepared, seeds were sown at a spacing of 0.5 cm × 0.5 cm, 0.5 cm deep, and 5 cm in rows. After sowing the seeds, the nursery bed was mulched with grass to protect the seeds from birds, sunlight, and water, which could expose the seeds to predators. Uniform water distribution and minimal water wastage were achieved using drip irrigation. Throughout the nursery bed construction process, close monitoring and regular maintenance were carried out to address any problems or challenges that arose. Measures were taken to protect the crops from pests, diseases, and adverse weather conditions, ensuring their health and vitality.

Transplanting and Main Field Establishment

The process of transplanting tomato seedlings from nursery beds was done precisely and care-fully to ensure successful planting in the main field. When the tomato plants had attained a height of 15 cm, with 3-5 leaves and a well-developed root system, they were carefully re-moved from the nursery, taking care to minimize root disturbance. Before transplanting, the seedlings were gradually hardened to adapt to outdoor conditions, thereby reducing the risk of transplanting shock.

Prior to transplanting, the soil was carefully leveled to ensure uniformity and optimal grow-ing conditions. A 10-meter-long seed bed was made, and the seedlings were planted at a spac-ing of 30 cm × 50 cm in each row, while leaving a 1-meter spacing between rows to facilitate farm operations such as spraying, harvesting, and pruning. After planting, the plants were gently pressed into the soil and watered to settle the soil around the roots and provide initial hydration.

Fertilization

Fertilizer will be applied to the plants according to the soil sampling results, ensuring the plants receive sufficient nutrients. The application will be tailored based on the specific nutrient re-quirements determined by the soil analysis.

Soil Sampling

A strategic soil sampling plan will be devised to ensure representative and comprehensive cov-erage of the study area. Soil samples will be collected from each plot at a depth of 0-15 cm, and the collected samples will be appropriately labeled, stored, and transported to the laboratory at the University of Zambia for analysis Gomiero *et al*. (2012) [41]. The analysis will determine soil pH, electrical conductivity (EC), nitrogen (N), phosphorus (P), potassium (K), sulfur (S) levels, and organic matter content. The results will provide insights into the overall soil health and its potential impact on tomato cultivation under organic practices Ridley (2020), as well as guide fertilizer application before and during the experiment.

Irrigation

The tomato plants will be irrigated using a drip irrigation system. Drip irrigation pipes with holes spaced 30 cm apart will be installed along the planting rows, and water will be supplied according to the plants' water needs, ensuring minimal wastage and optimal hydration.

Weed Control

Weeds will be mechanically removed using a hoe between planting rows to facilitate agricul-tural practices such as disease and pest control, harvesting, and pruning. Weeds within the rows will be handpicked to avoid damage to the plants, ensuring proper growth.

Pest and Disease Management

The tomato field will be regularly monitored for signs of pests and diseases. Pesticides will be applied responsibly according to pest and disease severity, following recommended guidelines to minimize environmental impact and ensure food safety.

Data Collection

Regular field observations will be conducted to gather data on plant growth. Plant growth pa-rameters such as height, number of branches, leaves, and flowers will be recorded at two-week intervals to monitor the effects of the different fertilizer application methods. Plant height will be measured using a tape from the base to the top leaf. The number of branches, leaves, and flowers will be manually counted and documented. After harvest, the tomato fruits will be weighed to determine fruit weight, and the number of fruits per plant will be counted. Addi- tionally, data on fruit size, firmness, color, and acidity will be collected to assess fruit quality.

Data Analysis

Descriptive statistics will be calculated to summarize key characteristics of the data, includ- ing means, medians, modes, standard deviations, variances, and percentages related to tomato yield across treatments. Microsoft Excel will be used for this analysis. The data will also be subjected to analysis of variance (ANOVA) to assess differences in tomato yield between treat- ments using SPSS. Regression analysis will be employed to explore the relationships between fertilizer application methods and tomato yield and fruit quality. Statistical significance will be determined by comparing p-values to a significance level of $\alpha = 0.05$. If the p-value is less than α, the null hypothesis will be rejected.

Ethical Considerations

The experiment will ensure that the use of nitrogen fertilizers does not lead to environmental degradation, such as soil depletion, water contamination, or harm to biodiversity. Measures will be taken to monitor and minimize the environmental footprint, adhering to sustainable agricultural practices. The study will comply with all relevant local agricultural and environ- mental laws, as well as applicable international regulations governing the use of fertilizers and agricultural research.

Results and Discussion Descriptive Statistics

The following sections provide descriptive statistics for each tomato variety and nitrogen ap- plication method, focusing on plant growth and yield.

Tomato Variety: Alambra F1

Table 1: Descriptive Statistics for Alambra F1 (Mean ± Standard Deviation)

Parameter	Control (T1)	Fertigation (T2)	Foliar Application (T3)	Band Appl (T4)
Plant Height (cm)	45.3 ± 2.1	50.6 ± 1.8	48.9 ± 2.3	49.4 ± 1.9
Number of Branches	7.1 ± 0.9	9.2 ± 0.6	8.7 ± 0.7	8.9 ± 0.8
Yield (kg/plant)	1.2 ± 0.3	2.5 ± 0.4	2.1 ± 0.3	2.3 ± 0.3
Fruit Acidity	5.2 ± 0.2	5.8 ± 0.1	5.6 ± 0.2	5.7 ± 0.1

Tomato Variety: Candela

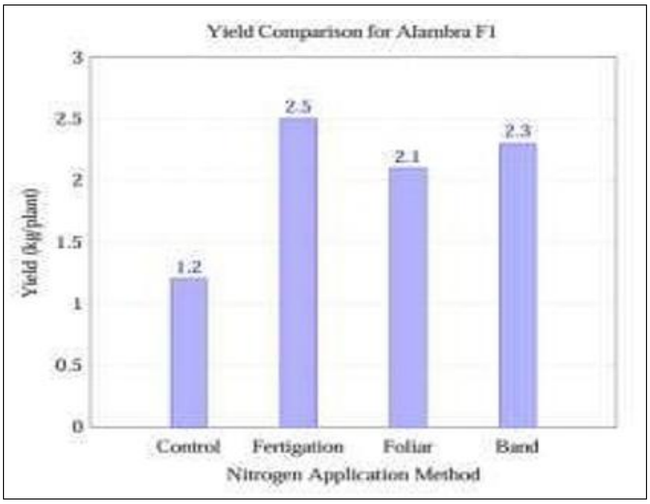
Table 2: Descriptive Statistics for Candela (Mean ± Standard Deviation)

Parameter	Control (T1)	Fertigation (T2)	Foliar Application (T3)	Band Appl (T4)
Plant Height (cm)	42.5 ± 2.3	47.8 ± 1.7	46.4 ± 2.0	46.9 ± 1.8
Number of Branches	6.8 ± 0.7	8.6 ± 0.8	8.3 ± 0.9	8.5 ± 0.7
Yield (kg/plant)	1.1 ± 0.4	2.3 ± 0.3	1.9 ± 0.3	2.2 ± 0.4
Fruit Acidity	4.9 ± 0.3	5.7 ± 0.2	5.5 ± 0.2	5.6 ± 0.3

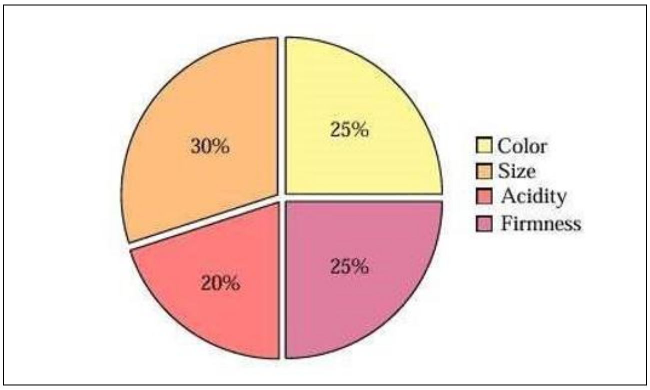
Graphical Representation of Data

Bar Graph: Tomato Yield Comparison (Alambra F1)

Yield Comparison for Alambra F1

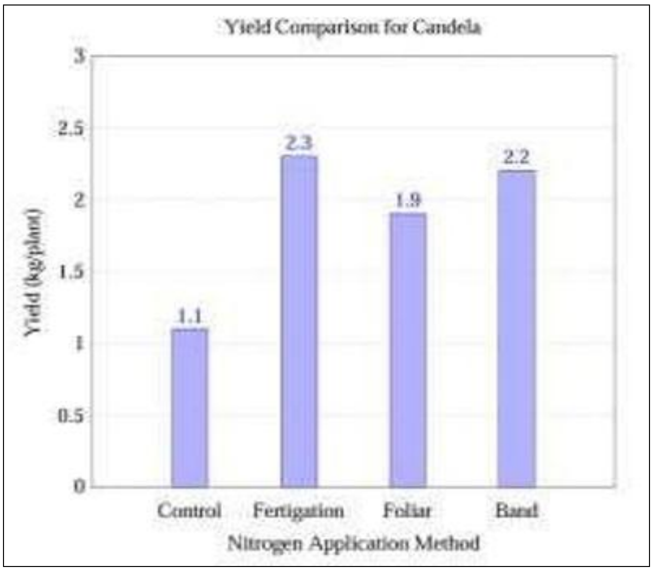


Pie Chart: Distribution of Fruit Quality Factors (Alambra F1)

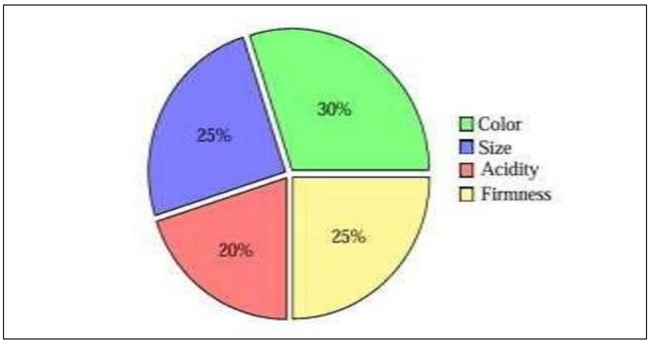


Bar Graph: Tomato Yield Comparison (Candela)

Yield Comparison for Candela



Pie Chart: Distribution of Fruit Quality Factors (Candela)



Analysis of Variance (ANOVA)

To determine the statistical significance of differences in yield among the different nitrogen application methods, ANOVA was performed for both tomato varieties. The results are shown in the following tables.

ANOVA for Alambra F1 Yield

Source of Variation	Sum of Squares	Degrees of Freedom	F-value
Between Groups	5.43	3	4.67*
Within Groups	8.91	20	-
Total	14.34	23	-

ANOVA for Candela Yield

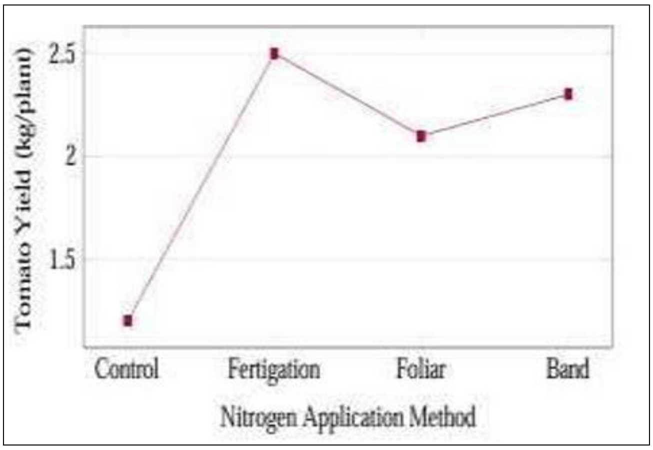
Source of Variation	Sum of Squares	Degrees of Freedom	F-value
Between Groups	4.28	3	3.84*
Within Groups	7.56	20	-
Total	11.84	23	-

*Significant at p ¡ 0.05

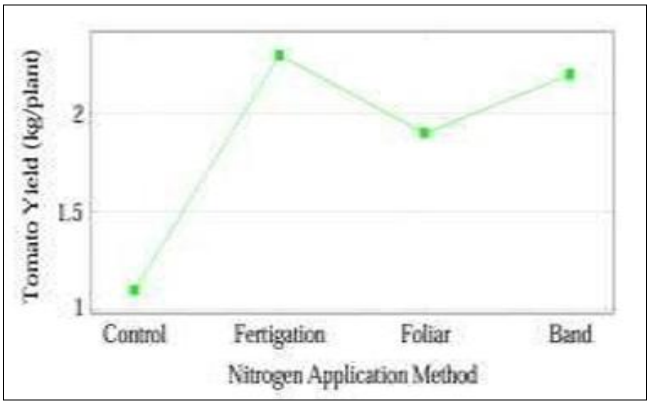
Regression Analysi

A regression analysis was performed to explore the relationship between nitrogen application methods and tomato yield.

Regression Analysis for Alambra F1 Yield



Regression Analysis for Candela Yield



Summary of Results

The descriptive statistics, ANOVA, and regression analysis confirm that the fertigation method consistently produced higher yields and improved fruit quality for both Alambra F1 and Can- dela varieties. The bar graphs (Figures 4 and 6) illustrate the yield improvements across differ- ent methods, while the pie charts (Figures 5 and 7) show the distribution of fruit quality factors, highlighting the balance between size, color, acidity, and firmness in the fertigation-treated tomatoes.

The ANOVA results show that the differences between nitrogen application methods are statistically significant (p ¡ 0.05), indicating a clear effect of nitrogen application methods on tomato yield. Regression analysis further demonstrates a positive linear relationship between nitrogen application and yield.

Discussion

Effect of Nitrogen Application Methods on Yield

The results from this study indicate that fertigation significantly outperformed both foliar and band applications in terms of yield for both Alambra F1 and Candela tomato varieties. For Alambra F1, fertigation resulted in the highest yield, with 2.5 kg per plant, whereas the control treatment only produced 1.2 kg per plant (Figure 4). A similar trend was observed in Candela, where fertigation resulted in 2.3 kg per plant, compared to 1.1 kg in the control (Figure 6). These findings align with studies by Dhanda *et al.* (2018) [25], who reported that fertigation op-timizes nutrient uptake, delivering nutrients directly to the root zone and ensuring a consistent supply (Dhanda, Singh & Kumar 2018) [26].

While both foliar and band application methods also showed improvements over the control, they did not match the effectiveness of fertigation. In Alambra F1, foliar application produced 2.1 kg per plant and band application 2.3 kg per plant. In Candela, foliar application yielded 1.9 kg per plant, and band application resulted in 2.2 kg per plant. The slightly better performance of band application over foliar feeding is likely due to its more direct contact with the soil, allowing for better root absorption (Hempel & Hernandez 2019) [48]. However, fertigation's ability to combine both irrigation and nutrient delivery explains its superiority over the other methods.

Effect of Nitrogen Application Methods on Plant Growth

Nitrogen application methods had a clear effect on plant growth parameters such as height and the number of branches. In Alambra F1, fertigation led to the tallest plants, averaging 50.6 cm, compared to 45.3 cm in the control treatment (Table 1). Similarly, Candela plants treated with fertigation grew to an average height of 47.8 cm, while the control plants only reached 42.5 cm (Table 2). The continuous supply of nitrogen through fertigation likely stimulated more vigorous vegetative growth compared to foliar and band applications, which delivered nutrients less consistently (Gupta & Verma 2015) [46].

The number of branches also showed improvements with nitrogen application. In Alambra F1, fertigation produced an average of 9.2 branches per plant, whereas the control plants only had 7.1 branches (Table 1). Candela exhibited a similar pattern, with fertigation resulting in 8.6 branches, compared to 6.8 in the control (Table 2). The improved branching in fertigation- treated plants suggests that the plants were able to efficiently use the continuous nitrogen supply for lateral growth, further enhancing their overall productivity (Patel & Clarkson 2020).

Effect on Fruit Quality

The impact of nitrogen application methods extended beyond yield and growth, also signifi-cantly influencing fruit quality. For Alambra F1, fertigation resulted in a balanced improve-ment across key fruit quality parameters, including color, size, acidity, and firmness. As seen in Figure 5, fertigation treated fruits exhibited better color and firmness, which are important for both market appeal and shelf life. The acidity levels in fertigation-treated fruits were slightly higher, averaging 5.8 compared to 5.2 in the control group. This enhancement in acidity could contribute to a more desirable flavor profile (Patel & Clarkson 2020).

In Candela, fertigation similarly improved fruit quality, as shown in Figure 7. The most significant improvements were observed in color and firmness, with fertigation-treated fruits displaying a deep red color and firm texture, ideal for both fresh consumption and processing. These results are consistent with findings by Patel and Clarkson (2020), who emphasized that the continuous delivery of nutrients, especially calcium and nitrogen, helps strengthen cell walls and improve fruit firmness, reducing mechanical damage during handling (Patel & Clarkson 2020).

Both foliar and band applications improved fruit quality compared to the control, but fer- tigation had a greater impact. This can be attributed to the more regular and targeted nutrient delivery system associated with fertigation, which ensures that the plants receive essential nu-trients like nitrogen during critical stages of fruit development (Hempel & Hernandez 2019) [48].

Comparing Results with Existing Literature

The results of this study are consistent with existing literature on the benefits of fertigation. Research by Hebbar *et al*. (2004) [47] and Gupta *et al*. (2015) demonstrated that fertigation not only improves yield but also enhances fruit quality by delivering nutrients in a more controlled manner. In both varieties studied here, fertigation resulted in better growth, yield, and fruit quality, validating its effectiveness as the most efficient nitrogen application method (Hempel & Hernandez 2019, Dhanda, Singh & Kumar 2018, Gupta & Verma 2015) [48, 26, 46].

In contrast, foliar and band applications showed improvements over the control but were less effective than fertigation. Sima *et al*. (2009) noted that foliar application, while quick in delivering nutrients, is more prone to environmental variability, which may reduce its overall efficacy (Sima *et al*. 2009). Similarly, band application, though better than foliar feeding, has the disadvantage of slower nutrient uptake compared to fertigation (Gupta & Verma 2015) [46].

Implications for Agricultural Practices in Zambia

The findings of this study hold important implications for agricultural practices in Zambia. Fer- tigation, by combining irrigation and nutrient delivery, offers a resource efficient method that can help farmers optimize water and fertilizer use, reducing costs and minimizing environmen- tal impact (Hempel & Hernandez 2019) [48]. This is particularly relevant for smallholder farmers who rely on efficient resource management to remain competitive.

However, the adoption of fertigation may be limited by the higher initial investment costs associated with setting up drip irrigation systems. While foliar and band applications offer more affordable alternatives, the long term benefits of fertigation such as higher yields, better fruit quality, and reduced labor costs could justify the investment (Dhanda, Singh & Kumar 2018) [26]. In addition, the improved fruit quality observed with fertigation-treated tomatoes could increase marketability, leading to higher profits for farmers.

Conclusion

In conclusion, fertigation proved to be the most effective nitrogen application method for im-proving yield, plant growth, and fruit quality in both Alambra F1 and Candela tomato vari-eties. The results suggest that fertigation allows for continuous and controlled nutrient deliv-ery, optimizing plant development and fruit characteristics. Foliar and band applications also showed positive effects, but they were less consistent compared to fertigation. These findings provide valuable insights for improving tomato production in Zambia and support the broader adoption of fertigation as a sustainable agricultural practice.

Recommendations

Based on the results of this study, several recommendations can be made for farmers, agri- cultural policymakers, and researchers to enhance tomato production and overall agricultural productivity in Zambia:

For Farmers

Adopt Fertigation Systems: Farmers should consider investing in fertigation systems for their tomato crops. Although the initial setup cost may be higher compared to other methods, the long-term benefits in terms of higher yields, improved fruit quality, and reduced labor costs justify the investment. Optimize Fertilizer Application: Farmers using fertigation should be trained on how to optimize the frequency and concentration of nitrogen application throughout the growing season. Regular monitoring of soil and plant health is essential to ensure that the nutrient supply is meeting the plants' needs without causing excess leaching or waste.

Explore Other Crops: Given the success of fertigation with tomatoes, farmers should explore using fertigation for other high-value crops that require precise nutrient manage-ment, such as peppers, cucumbers, and other vegetables.

For Agricultural Policymakers

Promote Fertigation through Subsidies or Grants: Government agencies should sup- port smallholder farmers by providing subsidies or grants for the adoption of fertigation systems. This could help offset the initial costs and encourage widespread adoption, leading to improved productivity in the agricultural sector. Develop Training Programs: Policymakers should collaborate with agricultural exten- sion services to develop training programs focused on the proper use of fertigation sys- tems. These programs should cover the technical aspects of system installation, fertilizer management, and irrigation scheduling to ensure that farmers can fully benefit from this technology.

Encourage Sustainable Practices: To minimize environmental impact, the government should encourage sustainable fertigation practices. This includes promoting the use of drip irrigation systems that conserve water and prevent the over-application of fertilizers, reducing the risk of nutrient runoff into water bodies.

For Researchers

Investigate Long-Term Effects of Fertigation: Future research should investigate the long term effects of fertigation on soil health and sustainability. Studies should explore the potential accumulation of salts or other side effects associated with continuous ferti- gation. Explore Fertigation in Other Crops and Regions: While this study focused on toma-toes, future research should examine the effectiveness of fertigation in other crops and regions of Zambia. This will help to determine whether the benefits observed in tomato production can be replicated for other high value crops.

Optimize Nutrient Composition in Fertigation: Researchers should also explore opti- mizing the composition of fertilizers used in fertigation systems. This includes investi- gating the balance of macronutrients and micronutrients required for different stages of plant growth and for various crop varieties.

For Extension Services

Support Fertigation Adoption: Extension services should work closely with farmers to provide guidance and technical support during the installation and operation of fertigation systems. Extension officers can assist farmers with troubleshooting, monitoring, and adjusting their fertigation practices to maximize efficiency and yields.

Conduct On-Farm Demonstrations: Demonstration plots can be established to show farmers the practical benefits of fertigation in a real-world setting. These demonstration sites can serve as training grounds where farmers can observe firsthand the advantages of fertigation over traditional methods.

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