International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 11 Nov. 2025, pp: 235-244 www.ijaem.net ISSN: 2395-5252

Effect of plantain peels on the yield of Tomato (Solanum lycopersicum L)

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Date of Submission: 10-11-2025 Date of Acceptance: 20-11-2025

ABSTRACT
The effect of dried plantain peels as natural fertilizer on the growth and yield of tomato (Solanum lycopersicum L.) was studied under field conditions in Bayelsa State, Nigeria. The experiment was laid out in a Randomized Complete Block Design (RCBD) with five treatments i.e 0 g, 100 g, 200 g, 300 g, and 400 g of plantain peel powder per plant, replicated three times. The measurements were taken for growth parameters (plant height, number of leaves) and yield components (fruit number, fruit weight, and yield per hectare) while soil nutrient composition analysis was done before and after planting. It was found that the plantain peel application had a significant effect ($p < 0.05$) on the growth and yield of tomatoes. The 300 g treatment produced the highest mean yield (45.6 t/ha), which is a 92% increase over the control, but the higher application (400 g) did not show any significant improvement. The soil nutrient levels especially potassium, phosphorus, and organic carbon increased after harvest thereby confirming the soil fertility improvement. The results suggest that plantain peels not only are a good source of nutrients but also improve soil and at the same time support sustainable tomato production. It is therefore concluded that application of 300 g of plantain peel per plant is the best practice for high tomato yield and at the same time promoting recycling of waste and environmentally friendly agricultural practices.
Keywords: Plantain peel; Tomato yield; Organic fertilizer; Soil fertility; Biofertilizer; Waste recycling

I. INTRODUCTION

1.1 Background of the Study

Tomato (Solanum lycopersicum L.), one of the most widely cultivated and consumed vegetable crops, is a major source of vitamins, minerals, and antioxidants to the diet. Its market value lies not only in its nutritional importance but also in its role as a cash crop in some tropical and subtropical regions [1]. The total production of tomatoes worldwide is more than 180 million tons per year, and among the major producers are China, India, the USA, and Turkey [2]. In Nigeria, tomato is the second most important vegetable after pepper, with an annual production of around 2.3 million tons [3]. The crop is a significant source of income for smallholder farmers and a key player in the local food industry. Nonetheless, the average yield per hectare of tomatoes in Nigeria is still very low, compared to the global average, which is mainly caused by the poor soil fertility conditions, pest attacks, and limited access to quality inputs [4]. The over-reliance on synthetic fertilizers has been a double-edged sword, yielding higher tomato production at the expense of the environment and sustainable agronomy practices. Although inorganic fertilizers do provide nutrients that are easily available for uptake resulting in quick plant growth, their high pricing and long-run use have rendered the soil unproductive with little microbial activity, and it has also resulted in the occurrence of nutrient imbalance [5]. Moreover, throughout the process of improper fertilizer use, leaching and runoff are promoted, thereby leading to the contamination of groundwater and eutrophication of the water bodies around [6]. The above-discussed issues serve as a reminder of the necessity for going back to the drawing board and looking for sustainable practices that will not only maintain soil fertility but also cause little environmental damage and save on farmers' production costs.

The method of utilizing organic waste has now become a trendy and eco-friendly way to manage soil fertility. The organic residues, including crop wastes, livestock manure, and fruit peels, are reported to improve the characteristics of the soil, making it more capable of retaining water and attracting and holding positively charged ions [7]. Additionally, the presence of organic matter in the soil encourages the growth of the good soil microorganisms that are involved in the process of

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Volume 7, Issue 11 Nov. 2025, pp: 235-244 www.ijaem.net ISSN: 2395-5252

nutrient cycling and the development of the plants. Citing [8], the mixing of organic waste with the soil used for agriculture raises the level of soil organic carbon and, at the same time, increases the supply of primary nutrients macronutrients, which are N, P, and K, that plant development and health rely on the most. Out of all organic wastes, plantain peels have been recognized as an effective bio-fertilizer amongst others. Plantain (Musa paradisiaca) is a major crop in Nigeria and other tropical regions where it is grown extensively and thus, there is a continuous increase in the amount of peel waste which is sometimes improperly disposed of, and that leads to environmental issues. The research has confirmed that the plantain skin is the source of essential nutrients, especially potassium, phosphorus, and calcium which are the main elements in the flowering and overall metabolism of plants [9], [10]. Potassium is responsible for enlarging the fruit and making it more colorful in tomatoes, phosphorus is dedicated to the strengthening of roots and the blossoming of flowers, and calcium plays a vital role in rendering the fruit resistant to cracking and imparting it with firmness by becoming part of the cell wall [11]. When the plantain peels are composted, they release these nutrients gradually, which enables the crops to absorb them over a long period of time hence the soil fertility being improved sustainably. In this scenario, plantain peel as an organic fertilizer can be considered as the best option when it comes to increasing tomato yield, mainly for the small-scale farmers in Nigeria. Garbage of agriculture being turned into a valuable input is one of the main reasons that this practice is in alignment with the principles of the circular economy and sustainable agriculture. It can also prevent the use of costly synthetic fertilizers, lessen the pollution caused by the environment, and help to secure food supply.

1.1.1 Tomato Growth and Nutrient Requirements

Tomato (Solanum lycopersicum L.) is a vegetable crop that is in great demand and has specific and relatively high nutrient requirements for its optimal growth and fruiting. Nitrogen (N), phosphorus (P), and potassium (K), the key macronutrients, are essential and perform different functions: nitrogen helps in the growth of plants and development of their leaves; phosphorus is necessary for the development of roots, flowering, and setting of fruits; and potassium controls the size, quality, and stress tolerance of the fruit [1], [11]. Other nutrients like calcium (Ca) are also considered secondary ones but they are still quite important for the strengthening of cell walls and for the prevention of some physiological disorders like blossom-end rot [11]. In case of lack or the wrong amounts of these nutrients, the yield and quality of the fruit get reduced, while in case of too much [(mainly of the readily soluble N)] the flowering gets suppressed through the promotion of vigorous vegetative growth [5]. In the tropical smallholder systems, nutrient availability that is often limited due to low soil organic matter and poor nutrient-holding capacity is a frequent reason for the low productivity of tomatoes [3], [4].

1.1.2 Organic Fertilizers and Soil Improvement

Organic amendments like composts, manures, and crop residues provide multiple benefits besides just supplying macronutrients. They enhance the whole soil profile i.e. the physical properties (aggregation, porosity, and water-holding capacity), chemical properties (cation exchange capacity and buffering), and biological activity (microbial diversity and nutrient cycling) [7], [8]. Organic fertilizers are generally slower to release their nutrients and more effective in minimizing leaching losses than inorganic fertilizers; thus, they can sustain the nutrient supply over the entire growing season [8]. In tropical regions, a series of scientific investigations have verified the effectiveness of organic and inorganic fertilizers in improving soil health and through giving similar or better yields of crops as compared to synthetic fertilizers used exclusively [5], [7]. Besides, the practice of applying locally generated organic wastes not only slashes input cost but also contributes to the circular economy by making soil organic matter from biomass-derived nutrients returned [6].

1.1.3 Plantain Peel as a Biofertilizer

Plantain peels are considered as a huge agro-waste in several tropical countries and they have gained the interest of the scientific community as a possible source of biofertilizer. Chemical analyses of residues and composts of plantain peels have shown that they contain high levels of potassium, intermediate levels of phosphorus, and high levels of calcium, all three of which are the nutrients that are directly important for yielding and quality of tomatoes [9], [10]. Among the three, the very high level of potassium is the most significant EPA because potassium is a vital component in the simultaneous process of fruit formation, translocation of sugar and stomatal control which are respectively linked to the yield and quality of tomatoes [11]. The alkaloids of the peels enrich the soil with organic matter when they

are broken down, thus enhancing the soil structure and facilitating the microbial activities that mobilize the nutrients bound [7].

1.1.4 Previous Studies — Effects on Soil Nutrients and Crops

The nutrient supply and agronomic effects of plantain peel-based amendments have been the subjects of some experimental studies. In small-scale trials, laboratory and field trials have noted increased soil organic carbon and avail K after the application of plantain peel composts, along with the enhancing of crop performance for vegetable and root crops [9], [10]. Trials comparing plantain peel composts with conventional organic manures (e.g., poultry manure, compost) indicate that plantain peel amendments may supply lower total N than the latter, but they still supply comparable or even higher levels of K and Ca, which are especially beneficial for fruit crops such as tomato [5], [8]. The addition of plantain peels in mixed amendment systems has been shown to increase soil microbial activity, which in turn can lead to better nutrient mineralization rates and crop nutrient uptake [7]. Nonetheless, the variation of methods (composting duration, degree of decomposition, rates applied) among the different studies makes it difficult to conduct direct comparisons.

1.1.5 Gaps in Existing Research

Preliminary results were favorable, but there are still considerable gaps in research that hinder the incorporation of plantain peels into standard agronomic inputs:

1. Optimal Application Rates: The majority of the studies favored the use of application rates that were a very wide range (measured per pot, per plant, or per hectare) without proper scaling. Tomato application rates under smallholder field conditions are still a matter of debate as no clear and economically feasible rates have been [9], [10].

2. Standardized Preparation Methods: Pre-treatment differences (e.g., fresh peel incorporation versus composted peel, drying, and milling, or fermentation) all play a role in determining the nutrient release dynamics. Very few studies exist that have systematically compared these preparation methods from the perspectives of availability of nutrients, risk of pathogens, and labor requirements [8].

3. Field-Level Response in Local Conditions: A good deal of the evidence that is available comes from pot experiments or very short field trials in specific agroecological zones. Nigerian soils and climatic conditions variability has been reflected in multi-season, multi-location data limited [3], [4].

4. Long-term Soil Health Impacts: Studies assessing long-term effects on soil organic matter accumulation, cation exchange capacity, and potential build-up of deleterious compounds are scarce even though short-term nutrient and yield responses are encouraging [7].

5. Economic and Adoption Studies: There are very few studies that look into the cost–benefit trade-offs, labor implications, or farmer perceptions associated with the large-scale collection, processing, and application of plantain peels [6].

1.2 Problem Statement

The persistent challenge of low yield dominates the tomato production in Nigeria and other developing countries and has mainly been linked to the declining fertility of soils and the high price of inorganic fertilizers [4]. Advent of problems related to the economy and nutrition of tomatoes has not increased the average yield in Nigeria, which remains at a very low level compared to the global range of 40–60 t ha^{-1} with a large number of farmers producing less than 10–15 t ha^{-1} [2], [3]. The situation of such a large gap in yield would result in negative implications for food security, income, and the overall sustainable development of the rural population. One of the decisive factors which cause the low yield is the draining of nutrients from the soil through the constant practice of intensive farming and no corresponding replenishment of nutrients. The soils for many areas of Nigeria, especially in the humid and derived savanna regions, are found to be low in organic matter and poor in nutrient availability [5]. The result is that the productivity of crops goes down and eventually the farmers have to depend on chemical fertilizers more and more as the only way to get the yield up. It is true that the rising cost of chemical fertilizers, along with the lack of steady supply and adulteration, has made them so expensive that even small-scale farmers cannot afford them [6]. In the same way, the case of the synthetic fertilizers being either excessive or improper can result in the same problems as acidification of the soil, imbalance of nutrients and environmental degradation through leaching, and runoff, which in turn contaminates the water bodies nearby [7]. The problems that arise are indicative of the urgent need for a shift in the approach to soil fertility management towards sustainable ways that are economically cost-effective at the same time

and can restore soil health, increase tomato yield and least environmental impact.

Exploring organic waste, such as plantain peels, materials in this context is a very innovative alternative. Plantain peels, as the most significant agricultural by-products, are the sources of the primary nutrients [9]. Potassium, phosphorus, and calcium, which are necessary for tomato growth and fruit development, are present in these materials, thus making them suitable for the destined use. After all, the reduction of chemical fertilizers use can be achieved through the utilization of such organic materials, their availability being the key; also, soil fertility would be improved and protection of the environment through agriculture will have been enriched. Consequently, this research work focuses on the application of plantain peels as an organic amendment towards the growth and yield of tomato plants as a solution for low tomato yield. The research will contribute to the increasing trend of plantain peel-based fertilizer as a sustainable method for enhancing crop productivity in Nigeria.

1.3 Objective of the Study

Production of tomato (Solanum lycopersicum L.) is still an important part of the Nigerian agricultural sector, but the yield levels do not meet the global standards and they are still very low because of soil nutrient depletion and the high price of synthetic fertilizers which is prohibitive [4], [5]. The fertility problem is being addressed with organic alternatives like plantain peels which are an abundant agricultural by-product and have been recognized for their possible use as soil amendments rich in nutrients. The peels possess high enough levels of macro nutrients, such as potassium (K), phosphorus (P), and calcium (Ca), thereby becoming indispensable for the vegetative growth, flowering, and fruit development of tomatoes [9], [10].

With the increasing focus on sustainable agricultural practices and organic soil fertility management, it's vital to assess the agronomic capability of such organic materials scientifically through controlled experiments. Thus, this research will focus on the investigation of the impacts of plantain peel application at different levels on the growth and yield of tomato plants.

1.3.1 Specific Objective

The specific aim of this research is to see how different levels of plantain peel application affect the growth and fruiting of tomato (Solanum lycopersicum L.). This way, the research will pinpoint a perfect application measure that not only maximizes tomato yield but also retains soil fertility, thus being part of eco-friendly and economically sustainable farming practices in Nigeria.

1.4 Significance of the Study

The significance of this study is mainly due to its potential impact on sustainable agricultural practices, waste recycling and enhanced crop productivity. The rising cost of inorganic fertilizers has become a serious problem for Nigeria and other developing countries, especially for those smallholder farmers who rely on fertilizers for soil fertility improvement [6]. On the other hand, the improper disposal of organic wastes from agriculture and households, like plantain peels, is a serious issue that leads to pollution and health hazards [9]. Making these wastes into useful soil amendments not only helps in waste management but also promotes environmental sustainability.

This research study has taken a step further in the line of action of the principle of waste-to-wealth conversion by advocating for the use of plantain peels as an organic fertilizer. The agricultural waste is then treated as a valuable input back into the cropping system. Besides, the soil fertility is continuously improved through the gradual release of essential nutrients such as potassium, phosphorus, and calcium, nutrients that are particularly important for tomato [10] and fruits. Moreover, the addition of organic matter from plantain peels can lead to substantial improvements in soil productivity by affecting soil structure, increasing microbial activity, and retaining moisture [7]. In financial terms, the use of plantain peels is a cheap alternative to synthetic fertilizers, thus lowering production costs and farmers' profit margins increasing. This practice is especially noticeable in rural areas where the high price of inorganic fertilizers or the lack of distribution networks limits their access [4]. It also eliminates the reliance on the chemical production of fertilizers, which uses a lot of energy and is the main cause of nutrient runoff that flows into water bodies causing eutrophication [5], thus being the environmentally friendly approach to the production of fertilizers. Besides, this research work supports the Sustainable Development Goals (SDGs) achievement, specifically zero hunger and responsible consumption and production, by encouraging sustainable crop production and proper waste management. The research findings will give empirical data that will help farmers, agricultural extension workers, and policymakers get to know the potential of plantain peel-based

International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 11 Nov. 2025, pp: 235-244 www.ijaem.net ISSN: 2395-5252

organic fertilizer to be an effective and eco-friendly soil amendment for tomato production.

In the end, this research supports the recycling of waste and the production of crops in a sustainable manner. The nitrogen cycle in agricultural practices is, thus, closed in a better way, and it leads to not only food security but also environmental protection and rural economic development in Nigeria.

II. MATERIALS AND METHODS

2.1 Study Area

The research was performed at the Research Farm set up by the Department of Agricultural & Engineering, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria. The experimental location is between 4°55'N latitude and 6°05'E longitude. This place has a humid tropical climate with a yearly rainfall of 2,000 to 2,500 mm and a temperature of 27°C on average. Relative humidity is high all year round ranging from 75% to 95%. The soil in the area is sandy loam, has moderate drainage, is low in organic matter, and is typical of the coastal alluvial soil of the Niger Delta region.

2.2 Experimental Design

The experiment was designed in a randomized complete block design (RCBD) with five treatments and three replications, resulting in a total of 15 experimental plots. The size of each plot was 2 m × 2 m while 1 m was left as the space between plots and 1.5 m between blocks in order to limit the nutrient exchange. The treatments included five different rates of plantain peel application as mentioned below:

- T_1: 0 g plantain peel per plant (control)
- T_2: 100 g plantain peel per plant
- T_3: 200 g plantain peel per plant
- T_4: 300 g plantain peel per plant
- T_5: 400 g plantain peel per plant

The incorporation of plantain peel powder into the soil was done two weeks prior to transplanting so that the soil would be mineralized and the nutrients released. Random assignment of each treatment within the blocks was done to achieve uniformity and reduce the bias of experiment.

2.3 Planting Materials

The tomato (Solanum lycopersicum L.) variety 'Roma VF' was selected for this research because of its wide adaptability, good fruit quality, and moderate resistance to diseases. The seeds were sourced from the National Horticultural Research Institute (NIHORT), Ibadan, Nigeria. The seeds were planted in nursery trays with sterilized loamy soil and kept under proper moisture levels. After four weeks, the strong and similar-sized seedlings were planted in the field at a distance of 50 cm × 50 cm between plants and rows, which meant a density of 40,000 plants per hectare.

2.4 Preparation of Plantain Peels

The peels of matured and fully ripened plantains (Musa paradisiaca) were sourced from local markets and the Amassoma community Bayelsa State, residential waste. Initially, the peels were subjected to washing in order to get rid of the dirt that was attached to them; then, they were left in the air for 10 to 14 days until they became crisp, and finally they were dried in an oven at 60°C for 24 hours to take away the residual moisture. The dehydration process that resulted in the crisp peels was then followed by grinding them into a fine powder using a mechanical grinder and sieving through a 2 mm mesh. The powdered material for the nutrient composition analysis (N, P, K, Ca, Mg) of the processed raw material was obtained in advance and processed by following standard methods of the [12]. The powdered peel was treated according to the treatment rate for each planting hole and thoroughly mixed with topsoil ensuring even distribution.

2.5 Data Collection Parameters

Growth and yield data were collected during the experiment at regular intervals. The parameters measured included:

- **Plant Height (cm):** 2-week intervals measurement from soil surface to apex of the plant with a meter rule.
- **Leaves per Plant:** It was counted during the whole process of the experiment on each tagged plant.
- **Number of Fruits per Plant:** total fruits at the time of harvest per plant.
- **Fruit Weight (g):** fruits were weighed using an electronic weighing balance to determine weight.
- **Yield per Hectare (t/ha):** the mean fruit weight per plot was calculated and then extrapolated to hectare basis using formula:

$$\text{Yield}\left(\frac{\text{t}}{\text{ha}}\right) = \frac{\text{Total fruit weight per plot (kg)}}{\text{Plot area (m}^2\text{)}} \text{ X } 10{,}000$$

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2.6 Statistical Analysis

The data that had been collected was run through Analysis of Variance (ANOVA) with the help of the Statistical Analysis System (SAS) software version 9.4 to confirm the treatment's influence on the parameters that were measured. The means of the treatments were separated using the Least Significant Difference (LSD) test at the 5% probability level ($p < 0.05$). The results were shown in tables and figures wherever it was suitable.

III. RESULTS AND DISCUSSION

3.1 Growth Parameters of Tomato Plants

The study's findings indicated that the application of plantain peels led to a significant difference in the growth and yield of tomato plants during the experiment ($p < 0.05$). The plant height and leaf count showed an increase with time and differed among the various treatments. From Table 1 it can be seen that tomato plants treated with 300 g of plantain peel per plant (T_4) obtained the maximum plant height (67.8 cm) and leaf count (43.6) at 8 weeks after transplanting (WAT). The control (T_1) had the minimum values, with an average height of 42.5 cm and 28.3 leaves per plant, respectively. The increase in vegetative growth in the case of higher plantain peel application is attributed to the improvements in soil nutrient status and the increased microbial activity due to the decomposing organic matter.

Table 1: Effect of Plantain Peel Application on Growth Parameters of Tomato

Treatment	Plantain Peel Rate (g/plant)	Plant Height (cm)	Number of Leaves	Stem Girth (cm)
T_1	0	42.5 ± 1.8d	28.3 ± 1.2d	0.91 ± 0.04d
T_2	100	52.7 ± 2.1c	33.6 ± 1.4c	1.08 ± 0.05c
T_3	200	61.4 ± 2.5b	39.5 ± 1.6b	1.22 ± 0.06b
T_4	300	67.8 ± 2.7a	43.6 ± 1.5a	1.36 ± 0.05a
T_5	400	65.3 ± 2.3a	42.2 ± 1.7a	1.31 ± 0.07a

Means followed by the same letter within a column are not significantly different at $p < 0.05$ (LSD)

3.2 Fruit Yield and Yield Components

The fruit counting per plant and fruit weight were also influenced by the amount of plantain peel applied significantly ($p < 0.05$). According to Table 2, the 300 g treatment (T_4) produced the greatest number of fruits per plant (22.4) and fruit weight (2.85 kg per plant), which then resulted in a yield of 45.6 t/ha. The 400 g treatment (T_5) also led to high yields (43.2 t/ha) but was not significantly different from T_4, implying that the fertilization of 300 g per plant is the limit for increased productivity. The control treatment (T_1) gave the lowest yield (23.7 t/ha), which means that soil fertility alone would not be able to support maximum tomato production without nutrient amendments.

Table 2: Effect of Plantain Peel Rates on Tomato Yield and Yield Components

Treatment	Fruit Number per Plant	Mean Fruit Weight (kg/plant)	Estimated Yield (t/ha)
T_1 (0 g)	12.6 ± 0.8d	1.48 ± 0.06d	23.7 ± 1.2d
T_2 (100 g)	16.3 ± 0.9c	1.89 ± 0.08c	31.2 ± 1.5c
T_3 (200 g)	19.7 ± 1.0b	2.36 ± 0.07b	39.4 ± 1.4b
T_4 (300 g)	22.4 ± 1.1a	2.85 ± 0.09a	45.6 ± 1.7a
T_5 (400 g)	21.8 ± 1.2a	2.71 ± 0.08a	43.2 ± 1.6a

Means with the same letter within a column are not significantly different (LSD, $p < 0.05$).

3.3 Soil Nutrient Composition Before and After Treatment

The application of plantain peels resulted in the soil nutrients having a completely new composition (Table 3). After harvesting, there was a remarkable increase in the organic carbon, nitrogen, phosphorus, and potassium contents, and that was especially true for the 200 g, 300 g, and 400 g treatments. To give an example, the available potassium increased from 0.19 cmol/kg (before planting) to 0.45 cmol/kg in the 300 g treatment after harvest. In the same way, total nitrogen went up from 0.08% to 0.19% and organic carbon went up from 0.92% to 1.64%. There is substantial evidence that the application of plantain peels not only boosts crop yield but also improves the soil nutrient status, hence the potential of it being a sustainable biofertilizer is supported.

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Table 3: Soil Chemical Properties Before and After Plantain Peel Application

Parameter	Before Planting	After Harvest (T_1)	After Harvest (T_4)	After Harvest (T_5)
pH (H_2O)	5.6	5.8	6.2	6.3
Organic Carbon (%)	0.92	1.01	1.64	1.59
Total Nitrogen (%)	0.08	0.09	0.19	0.18
Available P (mg/kg)	6.3	7.2	12.6	11.8
Exchangeable K (cmol/kg)	0.19	0.22	0.45	0.43

3.4 Statistical Significance and Treatment Effects

ANOVA results revealed that all growth and yield parameters differed significantly ($p < 0.05$) among treatments. The LSD test confirmed that T_4 (300 g/plant) produced statistically higher values for plant height, number of fruits, and fruit weight in relation to the control and lower treatment rates. The pattern of increasing yield up to the 300 g rate, followed by a slight drop at 400 g, indicates an optimal nutrient threshold, where excess organic matter may not contribute further or could even lead to slight nutrient imbalance.

3.5 Summary of Findings

• Tomato plant growth and yield were markedly boosted by plantain peel application relative to the control.
• The treatment T_4 that involved 300 g per plant gave the highest yield of 45.6 t/ha, which means a 92% increase from the control group.
• Soil nutrient levels improved after the experiment;thus, plantain peels had the residual fertility impact positively.
• Moderate application rates (200–300 g/plant) caused optimal performance but no significant yield was noticed in the upper range.

3.6 Discussion

The outcomes of this experiment revealed that the use of plantain peels not only increased the growth rate of the tomato plants but also their overall yield compared to the untreated control plants. Nutrient supply and soil fertility improvement due to decomposed plantain peels, which are high in potassium (K), phosphorus (P), calcium (Ca), and organic carbon, are the main causes of this fertigation [7], [9]. These nutrients are essential for physiological processes like photosynthesis, enzyme activation, fruit formation, and general plant strength.

3.6.1 Nutrient Supply from Plantain Peel

The plantain peel is a source of nutrients and, among others, potassium, which is the most important nutrient.Key characteristics of tomatoes such as fruit quality, color, and size are improved by this nutrient. The nutrient enrichment is indicated by the increased growth and yield that can be observed with increasing plantain peel application amount (up to 300 g per plant).The role of potassium is to support osmotic regulation and transport of carbohydrates while phosphorus is the one that encourages root growth and energy transfer within the plant system [10].The treatments T_3 and T_4 showed an increase in plant height, number of leaves and fruit weight which all are indicators of these nutrients' effects on both vegetative and reproductive growth. Moreover, the carbon content of the plantain peels in the soil plus their organic matter content improved soil structure and moisture retention which in turn created a favorable environment for root and nutrient absorption. Such process was also reported by [5] where tomato yield was significantly increased following the application of organic residues rich in potassium and carbon.

3.6.2 Effects on Soil Fertility and Microbial Activity

Post-harvest soil analysis indicated increased levels of organic carbon, nitrogen, phosphorus and potassium in the treated plots when compared with the control. This confirmed that plantain peels not only provided nutrients directly but also enhanced soil microbial activity and nutrient cycling. The decomposition of organic materials such as plantain peels encourages the growth of microbes and this process culminates in the soil being mineralized and gradually releasing nutrients [6].The soil fertility is thus improved in the long run as a result of the microbial activity and nutrient cycling that ensures nutrient availability even after the cropping season has ended. The treated plots' slight pH increases along the scale of neutrality indicate that plantain peels possibly have a soil acids neutralization effect and hence more congenial conditions for tomato growth. This is in line with the observations of [4] that continuous

organic matter application resulted in improved chemical balance of the soil.

3.6.3 Comparison with Other Organic Fertilizers

Plantain peel compared with organic fertilizers like poultry manure, compost, and cow dung showed similar as well as better effects on tomato growth particularly yield and fruit weight. The breakdown of plantain peels is quicker than that of animal manures so that the nutrients are released at such moderate rate that they avoid both leaching and burning completely [13]. Besides, plantain peels are among the most common, non-harmful, and economically-free sources which make them not only less toxic but also more practical than synthetic fertilizers and even compost materials requiring long curing time. Previous works by [7] and [9] supported the notion that organic wastes coming from fruit residues like banana and plantain peels have the same nutrient-holding capacity and thus can replace poultry manure when soil nutrients get depleted and vegetable crop yield is low. Hence, the current research's output strengthens the idea that plantain peels are biofertilizer materials with great potential for being adopted by smallholder farmers as an effective and sustainable soil amendment.

3.6.4 Diminishing Returns at Higher Application Rates

The highest application rate of 400 g/plant resulted in the yield decline, which may indicate a consumer disillusionment or a slight nutrient imbalance that happens when too much organic matter is incorporated. Potassium in high levels sometimes blocks the absorption of calcium and magnesium, which may eventually lead to low-quality fruit [10]. Moreover, the decomposition of a large amount of organic matter around the roots may cause a temporary decrease in oxygen level or generate acid conditions that can inhibit the roots and slow down nutrient uptake. This conclusion underlines the importance of evaluating optimal application rates specific to soil types and environmental conditions. The treatment of 300 g per plant proved the most efficient, ensuing an unaltered supply of nutrients and microbial activity without any side effects.

3.6.5 Implications for Smallholder Farmers and Sustainable Agriculture

This research has drawn significant attention to smallholder farmers and sustainable crop systems in Nigeria and other developing countries. The plantain peels as a biofertilizer give rise to waste recycling, lessen reliance on expensive synthetic fertilizers, and lessen the pollution of the environment that results from poor disposal of organic waste.

The application of plantain peels is a method that not only leads to the reduction of waste but also being a low-cost and eco-friendly solution to the soil and crop problems of smallholder farmers with scarce financial resources. This method coincides with worldwide efforts in the direction of sustainable agriculture, resource efficiency, and climate-smart farming practices. The direct contribution to the realization of Sustainable Development Goals (SDGs) 2 and 12, Zero Hunger and Responsible Consumption and Production, is another benefit of this method as it is, where the latter two, namely the first two, are acknowledged in their respect.

3.6.6 Summary of Discussion

To sum up, the research has proven that the application of plantain peels not only leads to the production of tomato but also enhances its growth by improving soil nutrient availability, microbial activity, and physical conditions. The highest yield was obtained at 300 g per plant and the gains declined after that. The study indicates that plantain peels can be considered as a source of organic fertilizer with great potential, thereby providing the agricultural sector with a more sustainable approach to production, soil restoration, and environmental conservation.

IV. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The result of the present study has established that plantain peels have the ability to serve as a good organic fertilizer for tomato growth and yield enhancement. The application of plantain peel powder on the plants significantly affected their height, number of leaves, fruits, and total yield when compared to the control group which received no treatment. Treatment with 300 g per plant gave the best yield (45.6 t/ha) among the different rates used because the nutrient supply and soil conditioning effects were optimum at this amount.

The improvement observed in soil nutrient composition, especially potassium, phosphorus, nitrogen, and organic carbon, provides confirmation again of the potential of plantain peel to improve soil fertility and support sustainable tomato production somehow. The decomposed peels released nutrients moderately and gradually, which in turn, led to improved microbial activity,

better soil structure, and enhanced water and nutrient uptake by plants. The utilization of plantain peels as fertilizer goes beyond agronomic benefits; it also supports the environment and recycling of waste. Plantain peels, instead of being treated as rubbish, can be processed into cheap bio-fertilizers, which in turn, cut down on waste volume and reduce pollution that comes with disposing of organic waste. It is a step forward in achieving the Sustainable Development Goals (SDGs), especially SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production). To summarize, the use of 300 g of plantain peel per plant is proposed as the best rate for yield enhancement of tomatoes in soils and climates similar to that of the study area. Smallholder farmers' adoption of this practice will not only lessen their fertilizer costs but also enhance soil fertility and thus promote the use of environmentally friendly and sustainable agricultural systems across Nigeria and other tropical regions.

4.2 Recommendations

Based on the findings of this study, the following recommendations are made with the aim of guiding farmers, researchers, and agricultural policymakers to the effective use of plantain peels as an organic fertilizer for tomato cultivation:

1. Appropriate Application Rate: The application of 300 g of plantain peel per plant is recommended as the optimum rate for attaining maximum yield of tomato under similar soil and climatic conditions. This rate gave the best balance between availability of nutrients, growth of plants, and yield of fruits without causing nutrient imbalance or wastage of material. For larger field applications, this would correspond to around 12–15 tons of plantain peel powder per hectare, depending on plant spacing and soil fertility status.

2. Further Research on Nutrient Mineralization and Long-Term Effects: More research should be conducted on the nutrient dynamics and mineralization rate of plantain peels in different soil types and under varying environmental conditions. Long-term field experiments are also necessary to assess the residual effects of continuous application of plantain peels on soil fertility, microbial diversity, and crop productivity. Such research will help to evaluate the sustainability and the accumulated advantages of using plantain peels within integrated soil fertility management practices.

3. Integration into Local Organic Farming Practices: The incorporation of plantain peel utilization into the local organic farming and sustainable agricultural practices in Nigeria and other tropical regions is an effort that should be made. Agricultural extension agencies and rural development programs should be the ones promoting the on-farm composting and processing of plantain waste, thus incorporating the farmers into the low-cost, eco-friendly biofertilizer that they are using. The community-level training and demonstration farms can also contribute to the awareness and adoption process by supporting organic certification programs and food security initiatives.

4. Policy Support and Waste Management Synergy: Policymakers should not neglect the plantain peels, instead they should consider them an important agricultural resource. There is the need to strengthen those policies that promote waste recycling, agro-waste collection, and bio-fertilizer production so as to entrench the circular economy principles in the agricultural sector. Through this, collaborations among research institutions, local governments, and agribusinesses can be a great contributor towards the scalability of this practice.

V. SUMMARY

In summary, the study finds that applying 300 g of plantain peel per plant would yield the highest tomatoes. Other crops should be studied to find the applicability of this botanical waste treatment for long-term soil health. The integration of this practice into the local organic farming system will not only improve the soil fertility and crop productivity, but it will also be a catalyst for waste reduction, environmental conservation, and sustainable agricultural development.

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