Journal of Environmental Issues and Agriculture in Developing Countries
Volume 17, Number 1, April 2025
ISSN(p): 2141-2731 ISSN(e): 2795-2967
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

Econometric Analysis of the Impact of Soil Amendment Variability on Okra (Abelmoschus esculentus) Production in Ekowe Community, Bayelsa State, Nigeria

Inibehe George Ukpong
Department of Agricultural Extension and Management,
School of Agricultural Technology,
Federal Polytechnic, Ekowe, P. M. B. 110, Yenagoa,
Bayelsa State, Nigeria.
Email: inibeheukpong@gmail.com
ORCID: https://orcid.org/0000-0003-3213-7645.

ABSTRACT

This study investigates the econometric relationship between soil amendment variability and okra (Abelmoschus esculentus) production, with a focus on the effects of various organic waste-based treatments. Five soil amendment treatments were experimented: T1 (soil only), T2 (soil and rice husk), T3 (soil, rice husk, goat/sheep faeces), T4 (soil, rice husk, pig dung), and T5 (soil, rice husk, pig dung, and goat/sheep faeces). The results indicate that a higher seed germination rate does not necessarily translate to increased yield, suggesting that soil amendments, water availability, spacing, and seed genetics may be influential factors. Furthermore, trend analysis reveals that seed germination alone is not a strong predictor of yield, emphasizing the need for targeted soil management strategies. There is a significant impact of organic amendments on okra fruit production, food security and sustainable agriculture. The break-even analysis result indicates that the farmer reaches break-even early in the second harvest cycle, where the output (83 fruits) significantly exceeds the calculated break-even point of 25 fruits. The results show that adopting strategy amendments and performance evaluations enhances productivity, profitability, and food security through resilient, data-driven agriculture. The findings provide valuable insights for policymakers, researchers, and farmers seeking to improve crop productivity through effective soil amendment practices.

Keywords: *Okra yield, seed germination, soil amendment, econometric analysis, organic waste, food security.*

Journal of Environmental Issues and Agriculture in Developing Countries
Volume 17, Number 1, April 2025
ISSN(p): 2141-2731 ISSN(e): 2795-2967
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

INTRODUCTION

Soil amendments play a crucial role in optimizing crop production, particularly in regions with nutrient-deficient soils. Exploring the potential of using organic soil amendments is an effective and sustainable strategy for addressing the intense decline in soil quality, low crop productivity, and food insecurity. Organic amendments significantly improve soil nutrient profiles and enhance crop yield (Shu *et al.,* 2022; Zhao *et al.,* 2021). Soil amendment involves the addition of substances to the soil to help improve its chemical, biological, and physical properties (Abd El-Hady & Mosaad, 2024). Such amendments can be either organic or inorganic, with organic amendments consisting of additions such as crop residues, animal manure, compost, and biochar. The inorganic amendments involve the addition of chemical fertilizers and soil conditioners such as lime and gypsum (Khan *et al*., 2024).

Organic amendments enhance soil structure by increasing porosity, water retention capacity, and microbial diversity, essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K) for plant growth (Zhao *et al.*, 2021). For instance, the application of animal manure has been linked to increased microbial activity, better root development, and enhanced crop yields (Liu *et al.*, 2024). Similarly, biochar and rice husk have improved soil aeration and nutrient-holding capacity, soil amendment, germination, and increased crop productivity (Selvarajh *et al.*, 2023).

Thus, understanding the importance of these amendments and the relationship between crop growth such as seed germination, and yield is crucial for optimizing crop production. Germination is the first critical stage of plant growth, and to a large extent, influences early seedling vigour, nutrient uptake, plant growth, and subsequent yield performance (Khalequzzaman *et al.*, 2023; Capo *et al., 2023*). However, a high germination rate does not always translate to healthy plants or increased productivity, as factors such as overcrowding, plant health, environmental stressors and competition for nutrients can impact the final yield (Reed *et al.*, 2022).

Econometric models allow researchers to evaluate these relationships and their implications. In the context of this study, the different models enable quantifying and interpreting the relationships between agricultural inputs (e.g., germinated seeds) and outputs (e.g., crop yield). For instance, in this study, a regression model was used to assess the impact of germinated seeds on okra yield, revealing a weak statistical relationship, which suggests that factors beyond germination, such as soil amendments, water availability, and genetic variations in seed batches, also play a more significant role in determining yield.

To reiterate the importance of food security, soil amendments impact food security by influencing soil fertility and crop yields (Amin *et al.,* 2024). Thus, improved soil conditions lead to increased agricultural output, higher farmer incomes, and better food availability (Singh *et al.,* 2024). Therefore, the use of organic amendments, particularly in nutrient-deficient soils, has been widely recognized as a sustainable strategy to enhance food production while reducing dependency on synthetic fertilizers (Urra *et al*., 2019).

Furthermore, the break-even analysis provides insight into profitability and cost recovery to crop yield under various amendment conditions. The break-even analysis is a fundamental economic tool used to determine the minimum level of output required to cover production costs (Mbachu *et al.*, 2024). In other words, break-even analysis provides insight into the profitability, sustainability, and margin of safety of agricultural investments by calculating the point at which total revenue equals total costs (Thakur *et al*., 2025). In crop production, break-even analysis enables farmers and policymakers to understand the viability of various agricultural practices, including soil amendment strategies.

In this study, significant variation in yield across different harvest cycles strongly suggests the need to determine break-even points. Farmers must assess the cost-effectiveness of applying specific soil amendments, while also evaluating whether increased yields justify the associated input costs. For instance, treatments with pig dung and goat/sheep faeces may lead to higher yields but also require additional labour and transportation costs. A break-even analysis would help farmers determine whether these investments are economically viable and at what harvest point (or cycle) they have recovered production costs. Beyond individual farm profitability, the break-even analysis has broader implications for food security and sustainable agriculture. This approach enables farmers to maximize output and minimize financial risks, contributing to overall agricultural sustainability and resilience. To this end, this study specifically focused on the effects of the soil amendment conditions on the germination profile and yield of the okra plant.

MATERIALS AND METHODS

This study involved a field practical experiment using excavated soil where five different soil amendment treatments were applied for the planting of okra (Abelmoschus esculentus). The treatments were labeled and described as follows:

- **T1**: Soil only (control)
- **T2**: Soil and rice husk
- **T3**: Soil, rice husk, and goat/sheep faeces
- **T4**: Soil, rice husk, and pig dung
- **T5**: Soil, rice husk, pig dung, and goat/sheep faeces

These treatments were designed to evaluate the effects of different organic waste combinations (such as animal waste and rice husk) on okra germination and fruit yield. Each treatment consisted of five replicates (bags) with eight okra seeds planted, making a total of 40 seeds planted per treatment. The soil used was excavated from a farm in Ekowe Community; a coastal community by the coast of the Nun River in Bayelsa State, in the southern region of Nigeria. Data analysis includes; descriptive analysis (such as means), statistical tests (such as ANOVA, Kruskal-Wallis test, Dunn's test, regression), pairwise comparisons (rank-biserial correlation, bar chart), trend analysis (trend plot), and break-even analysis.

RESULTS AND DISCUSSION

Table 1: Summary of Seed Germination and Yield Record

Treatment	Germinated Seeds out of 40 seeds planted per treatment	Mean number of okra Fruits per treatment
T1	39	5.0
T2	26	8.5
T3	26	8.75
T4	26	13.5
T5	27	7.75

As shown in Table 1, the experiment observed variations in seed germination and yield (mean number of okra fruits per treatment) across the five treatments (T1–T5). The results suggest that higher germination does not guarantee higher yield. For instance, T1 had the highest seed germination (39 out of 40 seeds), yet it recorded the lowest mean fruit yield (5.0 fruits per plant). In contrast, T4 had only 26 germinated seeds but produced the highest mean fruit yield (13.5 fruits per plant).

The result also indicated moderate germination with a higher yield. For instance, T2, T3, and T5 had similar germination rates (26–27 seeds), but their fruit yields varied, with T4 showing the best yield (13.5 fruits), followed by T3 (8.75), T2 (8.5), and T5 (7.75).

The results suggest the possibility of other factors influencing yield. For instance, the quality of soil amendments, nutrient availability, or plant spacing might have played a role in fruit yield, as T1 had the highest germination but the lowest fruit count. Thus, T4's superior yield despite moderate germination suggests that it may have had better soil conditions, plant vigour, or nutrient efficiency.

Journal of Environmental Issues and Agriculture in Developing Countries
Volume 17, Number 1, April 2025
ISSN(p): 2141-2731 ISSN(e): 2795-2967
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

Test for Significant differences between seed germination and yield

Two statistical tests were conducted to examine whether there is a significant difference between **seed** germination rates and yield (mean number of okra fruits harvested per treatment), these include, and the one-way Analysis of Variance **(**ANOVA) and Kruskal-Wallis test (Non-Parametric Alternative).

1. One-Way ANOVA Results

Table 2. Summary of ANOVA Results

Statistic	Value
F-Statistic	47.96
p-value	0.00012

The ANOVA result in Table 2, shows the value of F-statistic (47.96) to be quite large, meaning that the variance between groups is much greater than the variance within groups. The p-value (0.00012) is very small (below the standard threshold of 0.05), which means that we reject the null hypothesis, thus, suggesting that there is a statistically significant difference between the mean number of okra fruits harvested and seed germination rates. However, since ANOVA does not indicate distinctively which treatments are significantly different from each other, this requires post-hoc tests to which the Kruskal-Wallis test was considered.

2. Kruskal-Wallis Test Results (Non-Parametric Alternative)

Table 3: Summary of Kruskal-Wallis Test results

Statistic	Value
H-Statistic	6.99
p-value	0.0082

The Kruskal-Wallis Test results shown in Table 3, indicate the H-statistic (6.99) which measures the difference in rankings between groups, and the p-value (0.0082) which is less than 0.05. Thus, the null hypothesis was rejected, suggesting that there is a statistically significant difference between the median ranks of seed germination rates and the mean number of okra fruits harvested. For clarity, the results of the two tests are compared and further explained as shown in Table 4.

Table 4: Comparison of ANOVA and Kruskal-Wallis Results

	Assumptions	Statistic	p-value	Conclusion
ANOVA	Assumes normal distribution & equal variances	**F = 47.96**	**0.00012**	Significant difference
Kruskal-Wallis	No normality assumption uses ranks	**H = 6.99**	**0.0082**	Significant difference

As shown in Table 4, both tests confirm that seed germination rates significantly impact okra fruit yield. In particular, the Kruskal-Wallis test indicates a significant difference between treatments (T1–T5) in the mean number of okra fruits per treatment, and since both tests agree, it is confident that the difference is not due to random chance. Hence, the need to conduct Dunn's test to analyze pairwise comparisons, to identify the differences between treatments (T1–T5) as shown in Table 5.

Table 5: Summary of the Dunn's Test results

Group 1	Group 2	U- Statistic	Adjusted P-Value
T5	T2	0.0	0.0398
T5	T4	0.0	0.0398
T5	T3	0.0	0.0398
T5	T1	25.0	0.0398
T2	T4	0.0	0.0398
T2	T3	0.0	0.0398
T2	T1	25.0	0.0398
T4	T3	25.0	0.0398
T4	T1	25.0	0.0398
T3	T1	25.0	0.0398

Table 5 summarizes the pairwise comparisons, indicating that all treatment pairs exhibit statistically significant differences ($p < 0.05$). The Dunn's test (a non-parametric alternative to Tukey's HSD) was conducted to compare pairwise differences between treatments (T1–T5). The test results show that the adjusted p-values for all pairwise comparisons are statistically significant (adjusted p-value = 0.0398 for all comparisons, which is below the common significance level of 0.05. This indicates that there are statistically significant differences in the mean number of okra fruits per treatment between all treatment pairs. The result further confirms that different treatments had a meaningful impact on the number of harvested okra fruits. The U statistic values indicate differences in the rankings of the treatments based on the mean number of fruits. Thus, since all comparisons show significance ($p< 0.05$), every treatment is adjudged to be statistically different from the others in terms of okra fruit yield. The results confirm that different treatments had a meaningful impact on okra fruit production**.** For instance, Treatment T4 (highest mean yield) is significantly different from the others, while T1 (lowest yield) is also significantly different from the rest. Since all treatments differ, selecting the best treatment (T4) would be beneficial for higher yield (ceteris paribus).

To further strengthen the assumption of the previous tests, the effect size comparisons between the treatments were further evaluated, as shown in Table 6.

Table 6: Effect Size Comparisons between Treatments

Comparison	T1vsT2	T1vsT3	T1vsT4	T1vsT5	T2vsT3	T2vsT4	T2vsT5	T3vsT4	T3vsT5	T4vsT5
Effect Size	0.4	0.6	0.8	0.2	0.2	0.4	0.2	0.2	0.4	0.6

The effect size comparisons between treatments indicate normalized rank differences and Rank-Biserial correlation for Dunn's Test. As shown in Table 6, the result indicates the largest effect size (0.8) between T1 and T4, indicating the most substantial difference in mean okra yield. Moderate effect sizes (0.4 - 0.6) are observed in several comparisons (e.g., T1 vs T3, T1 vs T2, T4 vs T5), while the smaller effect sizes (0.2) indicate minimal differences between some treatments (e.g., T2 vs T3, T2 vs T5). The result implies that Treatments T1 and T4 exhibit the most substantial difference in okra yield, while T3 and T5 show some overlap but still differ significantly from T1 and T4. This confirms the earlier Dunn's test results that all treatments have statistically significant differences. To further clarify, the effect size of pairwise comparisons between the treatments are presented in Figure 1.

The bar chart in Figure 1, shows the magnitude of differences between treatments based on the rank-biserial correlation. Larger bars indicate stronger differences between treatments. T1 vs T4 has the largest effect size (0.8), reinforcing that these two treatments had the biggest difference in okra yield, while T2 vs T3 and T2 vs T5 have the smallest effect sizes (0.2), meaning their differences are minimal. The overall implication of these comparisons can be deduced from the fact that the Effect Size Plot for pairwise comparisons between treatments (T1–T5) provides insights into the practical significance of differences in okra yield, and measures the magnitude of these differences rather than just statistical significance.

To further iterate in the context of this study, larger Effect Sizes indicate meaningful yield differences; such that if some treatments (e.g., T4) show a significantly larger yield compared to others (e.g., T1), this suggests that adopting specific treatment methods can improve crop production, thereby contributing to higher food availability and food security. Also, smaller Effect Sizes suggest minimal practical differences; such that if effect sizes between certain treatments are small, the differences in yield might not be substantial enough to impact food security meaningfully. This means that alternative interventions (e.g., soil quality improvement, better irrigation, or enhanced seed selection) may be necessary to achieve a notable increase in food production.

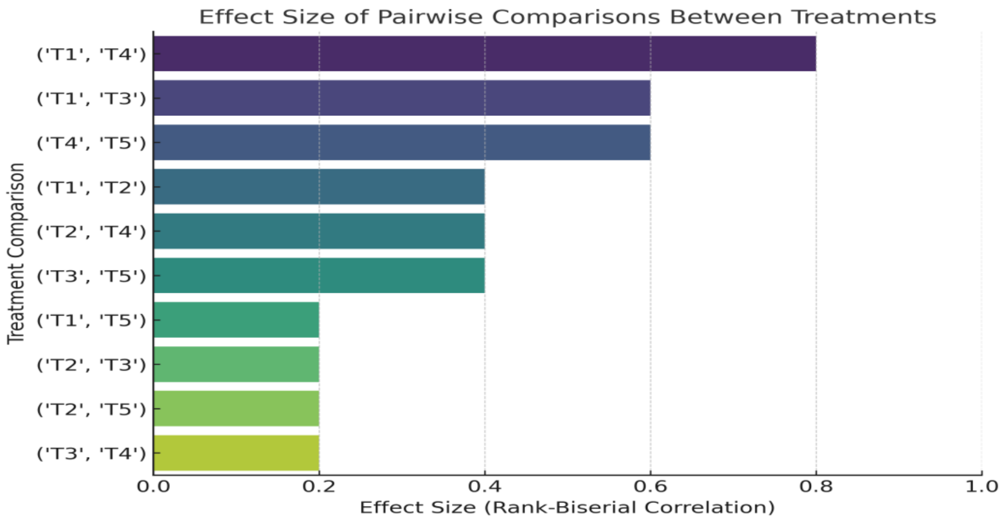

Figure 1: Bar Chart showing Effect Size of Pairwise comparisons between treatments

In a broader perspective, variability in treatments and agricultural practices indicates that if the effect sizes vary significantly across treatments, it implies that certain agricultural techniques or inputs have a stronger influence on yield than others. This can guide policymakers and farmers in making informed decisions about which farming techniques to prioritize for better food security outcomes. These variations for resource allocation imply that if specific treatments result in significantly higher yields, smallholder farmers and agricultural extension programs can focus on promoting these best-performing methods, leading to better crop yields and improved food availability in rural areas. This is equally, significant for ensuring resilience to climate change and food supply stability, such that a significant effect size in favor of one treatment suggests that adopting such a treatment can make food production more resilient to environmental challenges. This is critical for ensuring a stable food supply, particularly in regions where climate variability and other environmental inconsistencies affect agricultural productivity.

Relationship between seed germination and crop yield

To further establish the relationship between germinated seeds and the mean number of okra fruits, the regression analysis was used, as shown in Table 7.

Table 7: Regression Results for the Relationship between Germinated Seeds and Mean Number of Okra Fruits

Predictor Variable	Coefficient (β)	Standard Error	t-Value	P-Value	R^2	Interpretation
Germinated Seeds	-0.375	0.255	-1.47	0.189	0.488	No statistically significant effect on the mean fruit count
Intercept	18.5	9.72	1.90	0.133	-	Baseline value when germinated seeds = 0
Model Fit (R^2)	**0.488**	-	-	-	-	48.8% of the variance in mean fruit count is explained by germinated seeds
Significance	-	-	-	**0.189**	-	Above 0.05 threshold → No significant relationship

The result in Table 7, indicates a high P-value (0.189) greater than 0.05, meaning there is no statistically significant relationship between germinated seeds and mean fruit count; suggesting that the number of germinated seeds does not significantly predict the mean number of fruits harvested. The result also shows a moderate R^2 value of 0.488; indicating that about 48.8% of the variance in the mean number of okra fruits can be explained by the germination count, suggesting other factors (such as soil quality, and nutrient availability) may play a stronger role. The negative Coefficient (-0.375), suggests that a slight inverse relationship is observed, but this is not statistically significant, meaning increasing seed germination does not necessarily lead to higher fruit production. The trend analysis plot of the relationship is shown in Figure 2.

The Trend Analysis Plot shown in Figure 2 examines the relationship between the number of germinated seeds and the mean number of okra fruits harvested. This has direct implications for crop production and soil amendment strategies in agricultural production, and indeed, food security. For instance, the weak or no significant relationship between germination and yield, as indicated by the regression analysis showed that the number of germinated seeds did not strongly predict the mean number of fruits harvested (P-value > 0.05). This suggests that factors beyond seed germination, such as soil quality, nutrients, and treatment methods—are influencing okra yield. Also, the potential influence of soil quality on yield, as indicated by the fact that if an increased number of germinated seeds does not result in a proportional increase in yield, it may indicate soil nutrient deficiencies, poor water retention, or other limiting factors. This means that soil amendment techniques (e.g., organic compost, biochar, or fertilizers) might be necessary to enhance crop productivity. Food production and food security implies that low fruit yield despite successful seed germination could lead to lower food production and reduced availability of fresh produce. Thus, addressing soil fertility issues through amendments can boost agricultural output, ensuring a more stable food supply and reducing food insecurity, particularly for smallholder farmers.

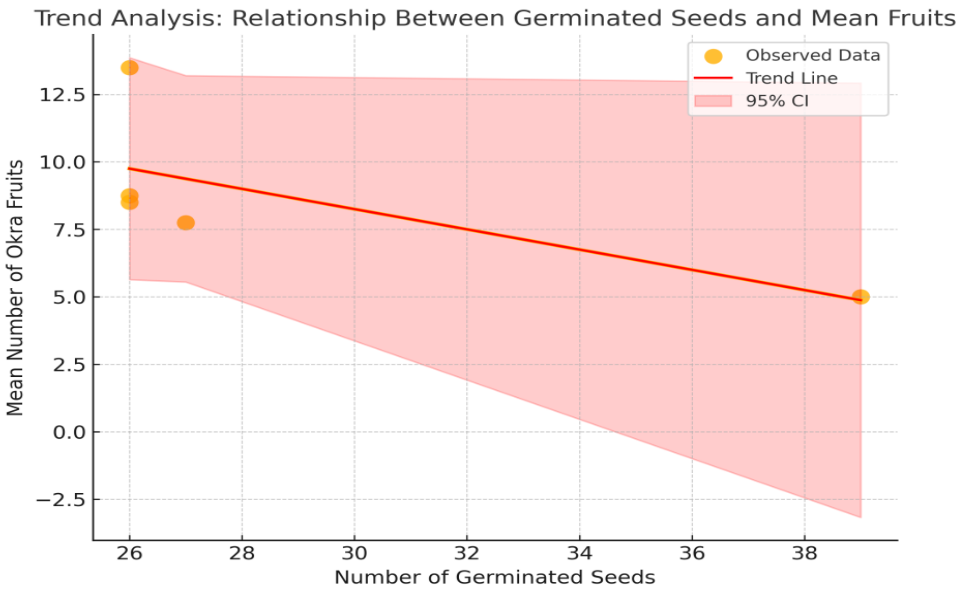

Figure 2: Trend Analysis Plot of the relationship between the number of germinated seeds and the mean number of okra fruits harvested.

These inferences provide the need for targeted agricultural interventions. For instance, since germination alone does not guarantee high yield, farmers should adopt evidence-based soil improvement practices such as; organic matter addition (e.g., compost, animal manure) to enhance soil nutrient content; biofertilizers and microbial inoculants to improve root nutrient uptake, as well as, mulching and irrigation to optimize moisture retention.

Break-even Analysis and Implications

Break-even point (BEP) indicates the level of output or sales at which the total revenue equals the total costs, resulting in neither profit nor loss (Mbachu *et al.*, 2024). Break-even analysis helps the farmer and businesses to determine the minimum output or sales that is required to avoid losses. In the context of this study, to determine the harvest cycle(s) at which the farmer reaches a break-even point, a hypothetical scenarios was assumed with same cost of production per harvest cycle **and** revenue per fruit for the cycles, using the break-even formula**:**

$$Breakeven\ Point(Fruits) = \frac{Total\ Costs\ per\ cycle}{Revenue\ per\ fruits} \qquad Equation\ 1$$

In the context of this study, break-even point is calculated using Equation 1, and considering **t**he total costs per harvest cycle and revenue per fruit which were determined based on prevailing local market price, and valued in Naira (Nigerian currency).

$$Breakeven\ Point(Fruits) = \frac{500}{20} = 25\ fruits\ per\ harvested\ cycle$$

Based on prevailing local market prices, the total cost per cycle is ₦500, and the estimated revenue per fruit is ₦20. By using the formula, it is assumed that the ₦500 cost per cycle is entirely fixed across cycles, with no variable cost component, and each fruit is sold at a fixed price of ₦20, with no fluctuations, while all harvested fruits are sold without wastage or unsold inventory. The calculation considers only one production cycle, excluding long-term cost variations. Thus, the break-even point determines the minimum number of fruits needed to cover all production costs. To achieve this, output per harvest cycle was compared with the break-even output to determine whether the farmer achieves profitability, as indicated in Table 8.

Table 8 Summary of Break-even Analysis for okra production

Harvest Cycle	Number of Fruits harvested per cycle	Analysis Assumptions
1st Harvest	23	Below breakeven point
2nd Harvest	83	Above breakeven point
3rd Harvest	47	Above breakeven point
4th Harvest	21	Below breakeven point
Total	174	

Note: Break-even Point (BEP): 25 fruits; Total Cost per Cycle: ₦500 (in Nigerian currency); Revenue per Fruit: ₦20; Total Fruits Harvested per Cycle: 174; Total Revenue: ₦3,480 (174x₦20).

As indicated in Table 8, the 1st Harvest yielded 23 fruits, which is below the break-even point of 25 fruits, indicating a loss for this cycle. The 2nd Harvest produced 83 fruits, surpassing the break-even point and resulting in a profit. This means the farmer only reaches the break-even point in the 2nd Harvest, where the output significantly exceeds the required 25 fruits. The 3rd Harvest generated 47 fruits, which is also above the break-even point, leading to a profit. However, the 4th Harvest yielded only 21 fruits, remaining below the break-even point, indicating a loss. The break-even point is represented graphically in Figure 3.

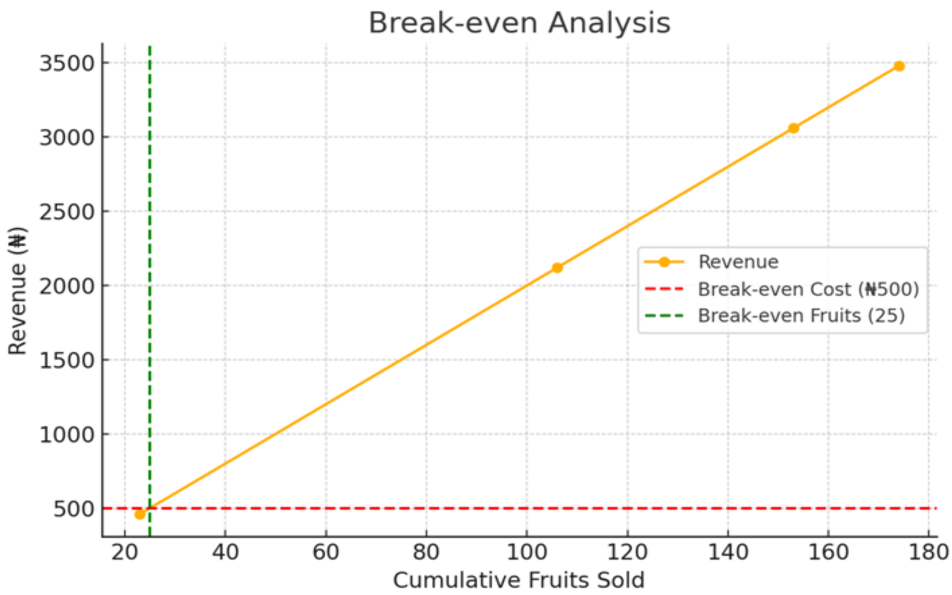

Figure 3. Graphical representation of the break-even point for okra plant

On the whole, the farmer reaches break-even early in the second harvest, meaning all sales beyond this point contribute to profit. However, with two out of four harvests falling below the break-even threshold, profitability remains a concern. The overall profitability of the okra farming operation may be at risk, as ongoing losses in the 1st and 4th harvests could threaten the long-term viability of the enterprise. Thus, there is a need to implement strategies that would enable farmers to work towards consistent profitability across all harvest cycles, ensuring the sustainability of their farming operations.

CONCLUSION

The variability in yield across treatments and harvest cycles highlights the need for further research. Future studies should examine the long-term effects of organic amendments on soil health, nutrient dynamics, and crop productivity. Additionally, integrating climate variables such as rainfall and temperature fluctuations could provide deeper insights into optimizing soil amendment practices under diverse environmental conditions.

Further research should also incorporate advanced econometric models like time-series analysis and machine learning to predict yield outcomes based on soil amendment strategies. These models could enhance decision-making for farmers and policymakers, ensuring that agricultural investments are both productive and sustainable. This study focuses on the econometric analysis of soil amendment variability and its effects on okra (Abelmoschus esculentus) production. It evaluates different organic amendments' impact on seed germination, yield variation, and break-even analysis, providing valuable insights into improving agricultural sustainability. The findings underscore the importance of data-driven strategies in food production and economic decision-making.

Results indicate that organic waste amendments significantly impact okra yield, with treatments incorporating pig dung and goat/sheep faeces (T4 and T5) producing the highest yields. This suggests that combining multiple organic amendments creates a balanced nutrient profile, improving plant growth and productivity. These insights are particularly useful for smallholder farmers seeking cost-effective and sustainable production methods.

The study further reveals that a higher number of germinated seeds does not necessarily result in higher yield. Instead, factors such as soil amendments, water availability, spacing, and genetic variations play a crucial role in okra fruit production. The effect size plot demonstrates the significance of soil amendments in improving yield, offering evidence-based recommendations for farmers, policymakers, and researchers to enhance food security and sustainable farming practices.

The Trend Analysis Plot suggests that soil amendments and better management practices, rather than seed germination alone, are critical for increasing okra productivity. This is especially relevant in regions where poor soil conditions limit agricultural output.

The significant yield variation across harvest cycles underscores the importance of identifying the break-even point to support economically sound decisions. Since the 2nd harvest surpasses the break-even threshold, it should be prioritized, with additional treatments or inputs applied to sustain higher yields. Optimizing market strategies, managing costs efficiently, and addressing environmental constraints will further improve profitability and long-term agricultural sustainability.

REFERENCES

Abd El-Hady, M. A., & Mosaad, I. S. (2024). Integrated Organic and Inorganic amendments for improving Productivity of Okra (Abelmoschus esculentus L.) in Alkaline Soil. *Egyptian Journal of Soil Science*, *64*(1), 207-219.

Amin, A., Tanveer, L., Abid, E., Absar, M., & Tariq, M. (2024). Mitigation strategies for greenhouse gases to ensure food security. *NUST Journal of Natural Sciences*, *9*(3), 12-30.

Capo, L., Sopegno, A., Reyneri, A., Ujvari, G., Agnolucci, M., & Blandino, M. (2023). Agronomic strategies to enhance the early vigor and yield of maize part II: the role of seed applied biostimulant, hybrid, and starter fertilization on crop performance. *Frontiers in Plant Science*, *14*, 1240313.

Khan, S., Irshad, S., Mehmood, K., Hasnain, Z., Nawaz, M., Rais, A., ... & Ibrar, D. (2024). Biochar production and characteristics, its impacts on soil health, crop production, and yield enhancement: A review. *Plants*, *13*(2), 166.

Khalequzzaman, Ullah, H., Himanshu, S. K., Islam, N. E. T., Tisarum, R., Cha-Um, S., & Datta, A. (2023). Seed priming improves germination, yield, and water productivity of cotton under drought stress. *Journal of Soil Science and Plant Nutrition*, *23*(2), 2418-2432.

Liu, Y., Lan, X., Hou, H., Ji, J., Liu, X., & Lv, Z. (2024). Multifaceted ability of organic fertilizers to improve crop productivity and abiotic stress tolerance: Review and Perspectives. *Agronomy*, *14*(6), 1141.

Mbachu, V. M., Chiabuotu, C. C., & Mbonu, M. O. (2024). Break even analysis for incentive based profit system in producer-distributor supply chain system. *Journal of Management and Science*, *14*(4), 51-54.

Reed, R. C., Bradford, K. J., & Khanday, I. (2022). Seed germination and vigor: ensuring crop sustainability in a changing climate. *Heredity*, *128*(6), 450-459.

Selvarajh, G., Ch'ng, H. Y., Zain, N. B. M., Ahmed, O. H., Jalloh, M. B., Damrongrak, I., ... & Naher, L. (2023). Enriched rice straw biochar improves soil nitrogen availability and rice plant growth under waterlogged environment. *Bragantia*, *82*, e20230104.

Shu, X., He, J., Zhou, Z., Xia, L., Hu, Y., Zhang, Y., ... & Wang, C. (2022). Organic amendments enhance soil microbial diversity, microbial functionality and crop yields: A meta-analysis. *Science of the Total Environment*, *829*, 154627.

Singh, N. K., Sachan, K., Bp, M., Panotra, N., & Katiyar, D. (2024). Building soil health and fertility through organic amendments and practices: a review. *Asian Journal of Soil Science and Plant Nutrition*, *10*(1), 175-197.

Thakur, N., Sharma, R., Roy, P., Sharma, A., & Roy, T. N. (2025). Unveiling margin of safety and break-even point of open vis-à-vis protected capsicum cultivation in the northwestern Himalayan state. *Current Science (00113891)*, *128*(5).

Urra, J., Alkorta, I., & Garbisu, C. (2019). Potential benefits and risks for soil health derived from the use of organic amendments in agriculture. *Agronomy*, *9*(9), 542.

Zhao, Y., Chen, Y., Dai, H., Cui, J., Wang, L., & Sui, P. (2021). Effects of organic amendments on the improvement of soil nutrients and crop yield in sandy soils during a 4-year field experiment in Huang-Huai-Hai Plain, Northern China. *Agronomy*, *11*(1), 157.