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Research Article

Economic Optimization of Poultry Manure in Organic African Spinach (*Amaranthus hybridus*) Production

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Abstract

Organic crop production is a potential sustainable solution to food insecurity in Sub-Saharan Africa, including Nigeria; however, the rising cost of poultry manure, commonly used in organic crop production to boost soil fertility in depleted soil, poses a challenge to its economic viability and sustainability. Thus, a field experiment was conducted in 2024 at the Teaching and Research Farm of the Department of Horticultural Technology, Enugu State Polytechnic, Iwollo, Southeast Nigeria, to evaluate the economic viability of using different application rates of poultry manure for *Amaranthus hybridus* production under organic conditions towards optimizing its use and profitability. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The treatments comprised five poultry manure rates: 0, 5, 10, 15, and 20 tons per hectare. Data on shoot weight per plant and derived yield per hectare were collected, and analyses of variance at the 5% significance level were conducted. The treatment means with significant differences were separated using Fisher''s least significant difference at the 5% probability level. Economic analysis, such as gross margin as well as return on investment (RoI), was performed to assess the profitability of different poultry manure application rates. The results showed that poultry manure significantly ($p<0.05$) improved Amaranthus hybridus shoot yield, with optimum yield obtained at 20 tons per hectare. The highest gross margin was obtained at 20 tons, but the highest return on investment was at 10 tons per hectare. A graph of RoI against poultry manure rates showed a steady increase in RoI from 0 tons to 10 tons beyond which it began to diminish. Poultry manure application at a rate of 10 tons per hectare was the most profitable rate and, therefore, the most economically viable rate; it could be recommended for organic *Amaranthus hybridus* production in the study area and similar agro-environments for enhanced food security.

Keywords

Economic Viability, Food Security, Optimization, Organic Farming, Sustainability

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1. Introduction

Food insecurity continues to be a significant issue that affects millions of people worldwide [1]. Food security is the ability of individuals to access sufficient, safe, and nutritious food for an active and healthy life [2]. In Sub-Saharan Africa, many people struggle to access safe and nutritious food, and this has led to hunger, malnutrition and widespread diseases [3]. In 2020 alone, approximately 811 million people experienced hunger globally, with Sub-Saharan Africa having the highest prevalence [4]. In Nigeria, food insecurity remains a critical issue, with over 26.5 million people projected to experience severe hunger in 2024 [5]. With the rapidly growing population especially in developing countries including Nigeria, achieving food security requires adopting sustainable and environmentally friendly agricultural practices. Organic food production, which promotes soil fertility, conserves biodiversity and helps mitigate the effects of climate change, is a potential solution to food insecurity [6]. Organic crop production avoids synthetic chemicals but relies on natural practices to control pests, manage diseases, and improve soil fertility [7]. Despite its benefits and growing demand, organic crop production faces numerous challenges, including the need for alternative fertilizers, effective pest and disease management and costly manual weed control. There is also a lack of premium pricing for organic crops that makes it difficult for farmers to cover the increased costs associated with organic crop production. In the tropics, especially in southeastern Nigeria, soil degradation caused by the erosion and continuous farming practices due to increasing population and unfavourable land tenure system deplete soil fertility. This makes it essential to use organic amendments such as manure, to restore soil health and support crop production in organic farming in the affected areas. Among the available organic fertilizers that can be used to improve soil fertility in organic crop production, poultry manure stands out due to its high nutrient content and ability to improve soil structure and microbial activity [8]. Poultry manure is a rich source of macronutrients such as nitrogen, phosphorus, and potassium; micronutrients such as zinc, copper, and manganese, which are essential for plant growth and development [9]. In Iwollo, Nigeria, farmers use poultry manure to boost soil fertility and crop yield. However, the increasing demand for poultry manure due to the high cost of inorganic fertilizers and growing awareness of its benefits has continued to cause a significant rise in its price in the study area. Determining the optimal rate of poultry manure application is crucial for profitable organic crop production to ensure sustainable production and food security. An appropriate manure application rate is vital to the success of crop production as it greatly influences not only the yield but also the cost of production and profitability. Agbede *et al*. [10] and Olajide *et al*. [11] reported increased crop growth and yield from the application of a higher rate of poultry manure. However, application of poultry manure beyond the optimal level can have a detrimental effect on crop performance [12]. It is therefore important to apply poultry manure in a way that matches the nutrient requirements of crops to achieve optimal growth and yield. Ewulo *et al*. [13] found that the application of poultry manure at 2.5 tons/ha was optimal for the growth and yield of Amaranthus. Ibeawuchi *et al*. [14] found that applying 8 tons/ha of poultry manure resulted in increased grain yield, dry matter, and leaf area in maize. Enujeke [15] observed that maize plants that received 30 t/ha of poultry manure showed increased growth and yield.

Amaranthus hybridus known as smooth amaranth is a leafy vegetable crop that belongs to the Amaranthaceae family. It is known for its adaptability to different climates and its short life cycle. It is widely cultivated in Southeast Nigeria, particularly in Iwollo where it serves as a valuable source of income to smallholder farmers in the community. It is a fast-growing leafy vegetable and can be used to combat food insecurity. The leaf is rich in vitamins, fibre, minerals, and antioxidants and is commonly used in traditional dishes [16]. There is a dearth of information on the most economically viable rate of poultry manure for organic *Amaranthus hybridus* production. Previous studies were centered on determining the optimum poultry manure application rate for optimal growth and yield of *Amaranthus hybridus* and other crops with little consideration on the economic viability of different application rates. As the price of poultry manure continues to rise, there is a need to evaluate not just the agronomic benefits but also the profitability of different application rates. Increasing the rate of poultry manure application may result in higher yields, but the incremental cost of the additional poultry manure can result to economic loss if it is greater than the incremental revenue. Thus, the study aimed to evaluate the yield and economic viability of different poultry manure application rates for organic *Amaranthus hybridus* production in Iwollo, Southeast Nigeria. The findings will provide valuable insights into the most profitable rate of poultry manure application rates that will help to optimize its use in organic *Amaranthus hybridus* production, help smallholders farmers in the study area and similar agro-environment improve their economic status and contribute to food security through sustainable organic farming practices.

2. Materials and Methods

2.1. Field Experiment

The experiment was conducted in 2024 at the Teaching and Research Farm of the Department of Horticultural Technology, Enugu State Polytechnic, Iwollo, Southeast Nigeria, during the rainy season (from July to October). The farm is at coordinates 007°16.834' E and 06°16.834' N.

A land area measuring 12 x 8 meters was cleared and tilled manually for the experiment (Figure 1). Five soil samples were collected from five different locations of the field before treatment application and mixed together to form a composite soil sample. The composite soil sample was used to determine the pre-planting physical and chemical properties of the soil. The experiment was laid out in a randomized complete block design (RCBD) with three replications (Figure 2). The treatments comprised five poultry manure application rates: 0, 5, 10, 15, and 20 tons per hectare. The tilled field was divided into three blocks, each containing five plots (2m x 2m), corresponding to one of the five treatments. Adjacent blocks and plots were separated by 1m and 0.5m alleys, respectively. The treatments were randomly assigned to experimental units using a table of random numbers. The poultry manure was incorporated into the soil during land preparation according to the treatments.

Figure 1. *Field preparation in progress.*

Figure 2. *Field layout showing the treatments in Randomized Complete Block Design (RCBD) with three replications.*

A landrace *Amarathus hybridus* cultivar that is traditionally grown by local farmers in Iwollo was used for the study and it was sourced from Iwollo market. The seedlings were raised in a shaded nursery box. The nursery box was filled with a nursery mixture containing top soil, poultry manure and sharp sand in the ratio of 3:2:1, respectively. The seeds were sown to a depth of about 2.5cm in lines that were 4cm apart. The nursery was watered at when due throughout the nursery duration. The seedlings were transplanted into the field four weeks after sowing using 50 cm x 50 cm in-between rows and within rows spacing, giving a plant density of 40,000 per hectare (Figure 3). Weeding was carried out manually while pest and disease control was achieved by spraying 20ml/L of neem (*Azadirachta indica*) extract prepared using the method as described by Biswas [17] on the plants at two-week intervals after each cutting.

Figure 3. *Performance of Amarathus hybridus in different treatments in Block 3 before first cutting.*

Shoots harvesting began one month after transplanting and continued at two-week intervals. Fourteen plants per plot were used for data collection and the first harvest was done by cutting the shoots 15 cm above ground level. The harvested shoots were weighed using an electronic scale (Figure 4). The fresh shoot weight per plant was calculated by dividing the total weight of the harvested shoots in kg (kilogram) by the number of sample plants per plot.

$$\text{Fresh shoot weight per plant (kg)} = \frac{\text{Total weight of harvested fresh shoot per plot}}{\text{Number of sample plants}} \quad (1)$$

The derived fresh shoot yield per hectare (ha) in tons was calculated by multiplying the fresh shoot weight per plant (kg) by the expected plant population per hectare (40,000 plants). The resulting value was then converted to tons by dividing by 1000.

$$\text{Derived fresh shoot yield per hectare (tons)} = \frac{\text{Fresh shoot yield per plant (kg)} \times 40{,}000}{1000} \quad (2)$$

Figure 4. *Yield data collection on harvested Amarathus hybridus shoots per treatments per replicates using electronic weighing machine.*

2.2. Statistical Analysis

The data collected from the experiment were subjected to analysis of variance (ANOVA). Treatment means were separated using the Least Significant Difference (LSD) at 0.05 probability level to detect significant differences among the five treatments.

2.3. Economic Analysis

The cost of production and the revenue generated from the *Amaranthus hybridus* production were assessed across the different poultry manure application rates. Gross margin (GM) analysis and return on investment (RoI) analysis were done to evaluate the profitability of different poultry manure application rates. Gross margin (GM) was calculated in Naira (₦) using the following formula:

$$GM = TR - TVC \tag{3}$$

Where: TR = Total revenue; TVC = Total variable cost.

$$\text{The return on investment (RoI) was calculated as: } RoI = GM / TVC. \tag{4}$$

The total variable cost (TVC) included expenses for inputs and labour. The Total revenue (TR) was determined by multiplying the yield (kg/ha) for each treatment by ₦200 per kilogram, which was the farm-gate unit price for *Amaranthus hybridus* shoot during the period.

3. Results and Discussion

The results of the pre-planting soil analysis showed that the soil of the experimental site was slightly acidic (5.7), and belongs to sandy loam textural class. The nitrogen, available phosphorus, and potassium values were 0.080%, 7.10 ppm, and 0.06 me/100g, respectively. Most of the nutrients were below the critical level as reported by Umekwe *et al.* [18], making the application of manure necessary, for healthy plant growth and good yield.

Table 1. *Pre-planting soil properties of the experimental site.*

Properties	Values
Clay (%)	15
Silt (%)	5
Fine sand (%)	13
Coarse sand (%)	67
Textural class	Sandy Loam
pH value (KCl)	5.7
pH value (H_2O)	6.8
Organic Matters (%)	0.811
Organic Carbon (%)	0.442
N (%)	0.080
Na^+ (me/100g)	0.02
K^+ (me/100g)	0.06
Ca^{2+} (me/100g)	0.70
Mg^{2+} (me/100g)	1.40
Al^{3+} (me/100g)	0.22
Base Sat. (%)	36.92
CEC (me/100g)	5.80
AP (ppm)	7.10
H^+ (me/100g)	1.90

The results of the analysis of variance showed a significant difference ($p<0.05$) in the fresh shoot yield of *Amaranthus hybridus* across different poultry manure application rates (Table 2). The highest yield per plant (0.68 kg) and per hectare (26.93 tons) was recorded in the 20 tons per hectare rate, followed by the 15 tons per hectare treatment, which produced 0.57 kg per plant and 22.67 tons per hectare. At the 10 tons per hectare rate, the yield per plant was 0.51 kg, and per hectare, the yield was 20.53 tons, while at the 5 tons per hectare rate, yields were 0.39 kg per plant and 15.60 tons per hectare. The control (0 tons per hectare) treatment resulted in the lowest yields of 0.29 kg per plant and 11.47 tons per hectare. The yield showed that as the rate of poultry manure increased, both the fresh shoot yield per plant and hectare improved. These findings are consistent with previous studies that reported positive effects of poultry manure on *Amaranthus hybridus* yield [19, 20]. Poultry manure, being rich in nitrogen, phosphorus, and potassium, provides essential nutrients for plant growth, which likely contributed to the higher yields observed.

Table 2. *Fresh shoot yield of Amaranthus hybridus.*

Poultry manure rates (tons per hectare)	Fresh shoot weight per plant (kg)	Derived fresh shoot yield per hectare (tons)
0	0.29	11.47
5	0.39	15.60
10	0.51	20.53
15	0.57	22.67
20	0.68	26.93
Grand mean	0.49	19.44
$LSD_{0.05}$	0.13	5.36
SE	0.07	2.85
CV	14.71	14.64

LSD = Least significant difference; C.V = Coefficient of variation; SE= Standard error; p<0.05= probability value is less than 0.05

The results of the economic analysis showed that as the poultry manure rate increased, the total variable costs (TVC) also increased, from ₦786,395 in 0 tons, ₦1,048,795 in 5 tons, ₦1,291,200 in 10 tons, ₦1,502,000 in 15 tons to ₦1,796,005 in 20 tons per hectare (Table 3; Figure 5). This was due to the additional quantity of poultry manure and its associated costs.

Table 3. *Gross margin analysis and Return on Investment.*

Variables	Quantity	Unit cost (₦)	Amount per hectare for the poultry manure treatments (₦)				
			0 t ha^{-1}	5 t ha^{-1}	10 t ha^{-1}	15 t ha^{-1}	20 t ha^{-1}
Variable cost							
Amaranthus seeds	3kg	7,000/kg	21,000	21,000	21,000	21,000	21,000
Poultry manure for the production	Varied according to the treatments	30,000/ton	0.00	150,000	300,000	450,000	600,000
Poultry manure for the nursery	200kg	30/kg	6,000	6,000	6,000	6,000	6,000
Transport of poultry manure (200m distance)	Varied according to the treatments	2000/ton	0.00	10,000	20,000	30,000	40,000
Preparation of neem extract	120 litres	200	24,000	24,000	24,000	24,000	24,000
Nursery operation	10 MD	5,000	50,000	50,000	50,000	50,000	50,000
Land preparation	40 MD	5,000	200,000	200,000	200,000	200,000	200,000
Poultry manure application	1MD /ton	5,000	0.00	25,000	50,000	75,000	100,000
Transplanting	15 MD	5,000	75,000	75,000	75,000	75,000	75,000
Weeding	45 MD	5,000	225,000	225,000	225,000	225,000	225,000
Spraying of neem extract	9 MD	5,000	45,000	45,000	45,000	45,000	45,000

Variables	Quantity	Unit cost (₦)	Amount per hectare for the poultry manure treatments (₦)				
			0 t ha^{-1}	5 t ha^{-1}	10 t ha^{-1}	15 t ha^{-1}	20 t ha^{-1}
Harvesting	4MD /ton	5,000	130,600	202,600	256,000	280,000	381,400
Twine	10 rolls/ton	150	9,795	15,195	19,200	21,000	28,605
Total variable cost (TVC)			786,395	1,048,795	1,291,200	1,502,000	1,796,005
Yield (tons ha^{-1})			11.47	15.60	20.53	22.67	26.93
Total Revenue (TR)		200/kg	2,294,000	3,120,000	4,106,000	4,534,000	5,386,000
Gross margin (GM) = TR – TVC			1,507,605	2,071,205	2,814,800	3,032,000	3,589,995
Return on investment (RoI) = (GM/TVC)			1.92	1.97	2.18	2.02	2.00

MD = Man days

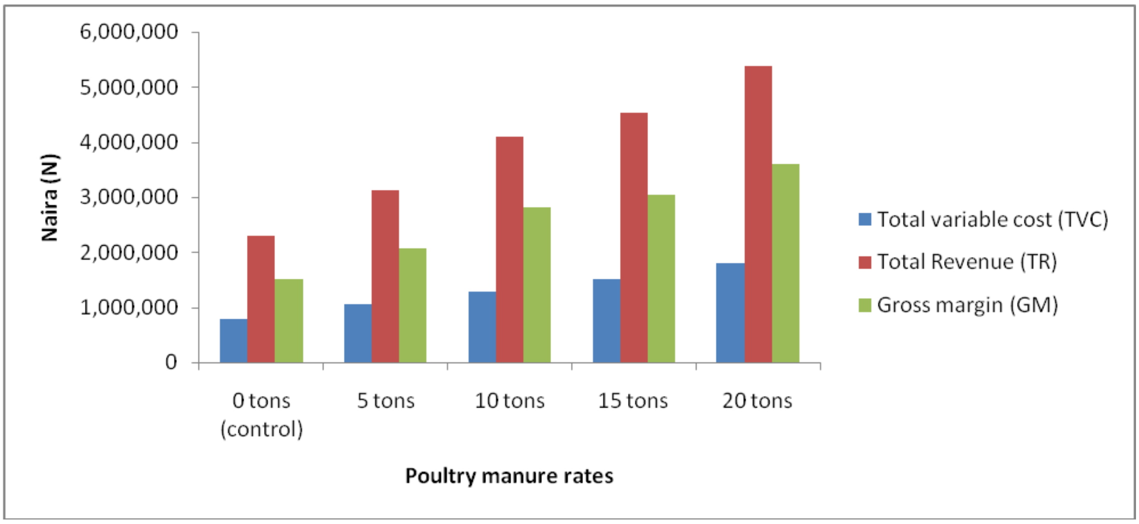

Figure 5. *Total Variable cost (TVC), Total Revenue (TR) and Gross Margin (GM) from the use of different poultry manure rates.*

Higher poultry manure application rates also resulted in higher revenue with the highest revenue (₦5,386,000) per hectare realized from 20 tons per hectare treatment, followed by 15 tons (₦4,534,000), 10 tons (₦4,106,000), 5 tons (₦3,120,000) and the lowest was from 0 tons (₦2,294,000) (Table 3; Figure 5). The gross margin (GM) followed the same trend, from ₦1,507,605 in 0 tons, ₦2,071,205 in 5 tons, ₦2,814,800 in 10 tons, ₦3,032,000 in 15 tons to ₦3,589,995 in 20 tons per hectare of poultry manure application (Table 3; Figure 5).

The Return on Investment (RoI), however, increased from 1.92 in 0 tons to 1.97 in 5 tons and peaked in 10 tons (2.18) with lesser RoI in 15 (2.02) and 20 tons (2.00) compared to 10 tons even when higher gross margin was obtained from those rates (Table 3; Figure 6). A graph of RoI against poultry manure rates showed a steady increase in RoI from 0 tons to 10 tons beyond which it began to diminish (Figure 6). Even though 15 and 20 tons produced a higher gross margin when compared to 10 tons, the incremental cost of the additional poultry manure failed to give a marginal economic return as the incremental revenue did not offset it. This could be attributed to nutrient saturation which probably led to diminishing returns. Excess nutrients from the over-application of manure are often not absorbed by the plants and may be lost through leaching or volatilization [21].

In sandy loam soils such as the soil in the experimental site, high macroporosity and low clay content limit the cation exchange capacity (CEC), which reduces the soil's ability to retain ammonium and nitrate ions, leading to leaching especially, during heavy precipitation [22]. Application rates exceeding 10 t/ha in these conditions failed to provide marginal economic benefits, probably due rapid mineralization of the manure, which exceeded the crop's immediate uptake capacity, leading to nutrient loss rather than increased productivity.

Return on Investment is a measure of profitability. The higher the return on investment value the higher the profitability. Thus, 10 tons per hectare with the highest RoI from the study is the most profitable rate. The RoI of 2.18 obtained from 10 tons of poultry manure application rate implies that for every ₦1 spent, ₦2.18 is realized as profit. This finding was in agreement with the findings of Agbede [23] who reported that 10 t ha^{-1} of poultry manure application rate was the most cost-effective and beneficial for improving soil properties and maize productivity due to the best benefit-to-cost ratio obtained from the treatment.

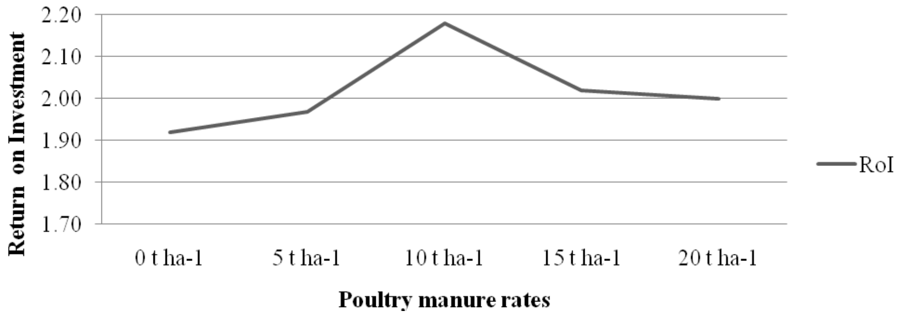

Figure 6. *Graph of the Return on Investment from the use of different poultry manure rates.*

4. Conclusion

The study showed that the use of poultry manure significantly improved the yield of organically produced *Amaranthus hybridus* in the study area. The 10 tons per hectare rate was the most profitable rate and could therefore be recommended for organic *Amaranthus hybridus* production in Iwollo, Southeast Nigeria, and similar agro-environments for sustainable production and enhanced food security.

Abbreviations

RCBD	Randomized Complete Block Design
RoI	Return on Investment
Kg	Kilogram
Ha	Hectare
ANOVA	Analysis of Variance
TVC	Total Variable Cost
TR	Total Revenue
GM	Gross Margin

Author Contributions

Adinde Jonathan Okenna: Conceptualization, Methodology, Resources, Investigation, Data curation, Formal analysis, Writing–original draft, Writing – review & editing

Nwankwo Ogechi Gabriella: Conceptualization, Methodology, Resources, Investigation, Formal Analysis, Writing – original draft

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Conflicts of Interest

The authors declare no conflicts of interest.

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