RESEARCH ARTICLE

Optimization of Amaranthus production under irrigation and poultry manure application using grey relational analysis

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Abstract
This study was carried out to optimize Amaranthus production under varying irrigation levels and poultry manure applications using Grey Relational Analysis. The experimental design was split-plot, where irrigation treatment was the main plot, while poultry manure was the subplot treatment. The irrigation levels are FIT50, FIT75, FIT100 and FIT135 which correspond to 50% Full irrigation, 75% full irrigation, 100% full irrigation and 135% full irrigation treatments, in combination with the poultry manure application rates M0t/ha, M5t/ha, M10t/ha and M20t/ha. Sixteen experimental treatments were arranged in a 4 x 4 factorial experimental design and replicated 3 times. Sprinkler irrigation system was adopted for the study. Results showed that there was corresponding increase in the response of Amaranthus growth characteristics and yield to the combination of irrigation and poultry manure treatments. The Crop Water-use efficiency initially showed a linear corresponding increase to an average value of 473kg/ha/mm but later exhibits a diminishing return beyond FIT100 irrigation. While production cost showed continual increase to average value of $377/ha as the inputs treatment level also increased to FIT135 irrigation combined with the poultry manure M20t/ha. Grey Relational Grades (GRG) calculated were 0.854, 0.790, 0.787, 0.765, 0.740, 0.629, 0.621, 0.620, 0.546, 0.543, 0.515, 0.475, 0.458, 0.443, 0.417 and 0.403 respectively. Amaranthus cultivated under FIT100_M20t/ha treatment matched with the highest GRG value 0.854, making FIT100_M20t/ha treatment the optimum. Analysis of variance for the GRG showed that irrigation and poultry manure are highly significant input variables for Amaranthus production. The findings from this study guide farmers on the optimal combination of water and organic fertilizer to maximize Amaranthus yield and minimize resource waste, thereby enhancing sustainability in crop production.

Keywords: Amaranthus; Grey relational grades; Water; Treatments; Yield; Irrigation

Introduction

Amaranthus, commonly known as amaranth, is a vital leafy vegetable crop recognized for its high nutritional content, including proteins, vitamins and minerals (Umakanta, et al., 2020). It holds significant agricultural and economic potential, especially in regions where its cultivation is widespread (Yahia et al., 2019). Being one the most demanded leafy vegetables, it is majorly grown in Southern Western Nigeria because of their leaves (Ogwu, 2020, Akinboye et al., 2024). The harvested leaves when boiled briefly and mixed with other condiments are eaten with pounded yam, Eba, Amala and other local dishes. The leaves have been reported to contain significant quantities of vitamins, crude fibre, phytochemicals and mineral (Umakanta, et al., 2024). The optimization of Amaranthus production is critical to enhance its yield and quality under varying environmental conditions, particularly under irrigation regimes and organic amendments like poultry manure. Proper management of these factors is essential for sustainable food production and improved crop performance. Irrigation plays a pivotal role in ensuring the successful cultivation of Amaranthus, especially in regions experiencing irregular rainfall or water scarcity (Egbebi et al., 2024). It influences not only the yield but also the overall quality of the crop. Studies have shown that water availability significantly affects plant physiological processes, including photosynthesis, transpiration, and nutrient uptake (Olufayo et al., 1996, Fasinmirin and Olufayo, 2009, Roberto and Roberto, 2022). Optimizing irrigation is crucial during the period of dry season when there is complete cessation of rainfall when water is a limiting factor. Besides, the need to efficiently manage water as a natural resource is becoming one of the major news headlines as tensions and clashes that are arising from natives due to conflicting demands is becoming frequent in sub-Sahara Africa. Freshwater is gradually becoming scarce as per head consumption increases due to global population explosion. Also, climate change signatures is taking its toll on food production as crop water demands also increase (Geraldo and Henrique, 2023). Practice of wild application of water to the field from surface irrigation is no longer acceptable in the environment. Therefore efficient water management strategies for crop production are keenly sought for by policy makers.

Irrigation scheduling and guided application rates offer a promising water management strategy, ensuring optimal water-use efficiency while preventing water stress and reducing unnecessary waste (FAO, 2021). However, in tropical regions, where water scarcity often coincides with poor soil fertility, it is crucial to manage both resources in tandem. Most African soils are inherently low in organic carbon, slightly acidic, and relatively sandy (Lal, 2009; Lehmann and Joseph, 2009, Sophie et al., 2021, Odebiri et al., 2024), making nutrient input as vital as water management for crop productivity. While efficient irrigation maximizes water use, nutrient availability particularly through organic amendments like poultry manure helps improve soil health and sustain crop yields (Hussain et al., 2023). Therefore, a balanced approach to both water and organic nutrient management is essential to overcoming the dual challenges of water and soil limitations in tropical regions, ultimately optimizing crop production. Organic amendments, particularly poultry manure have gained significant attention in recent years due to their ability to improve soil structure, enhance nutrient availability and promote sustainable agriculture (Emeghara, 2023). When documentation on comparing performance of inorganic and organic fertilizers were considered on soil, findings shown that inorganic fertilizers have not been helpful in maintaining soil health (Ozlu and Kumar 2018, Rashmi et al., 2020). They disrupt the natural balance of nutrients in the soil, leading to nutrient imbalances and reduced soil quality. The combined effects of these have been proven to result in the loss of soil organic matter, decreased soil fertility and increased susceptibility to erosion. This was also confirmed by Farmerline (2023). Poultry manure is rich in essential macro and micronutrients like nitrogen, phosphorus, and potassium, which are key for Amaranthus growth. Applying poultry manure as a soil amendment has been proven to increase soil organic matter, improve soil microbial activity, enhance water retention capacity and ultimately improving crop yield and quality (Ramadevi et al., 2023). The application rate of poultry manure, however, requires optimization, as excessive use can lead to nutrient imbalances and environmental concerns such as nitrate leaching (Mary et al., 2022). Thus, determining the ideal combination of irrigation levels and poultry manure application can maximize Amaranthus production while minimizing environmental impact. Optimization techniques, such as Grey Relational Analysis (GRA), have emerged as powerful tools to handle multi-response problems (Deng, 1982;

Sonja et al., 2015). GRA is part of Grey System Theory, which is applied when information is incomplete or uncertain. It is a multi-criteria decision-making (MCDM) technique that assesses the similarity between a reference series and alternative options (Chia-Chen et al., 2019). It helps identify which alternative is closest to an ideal solution based on various performance indicators. The process involves several key steps: Normalization which involves standardization of initial data to allow for fair comparison across different criteria. Then calculation of Grey relational coefficient**,** the coefficient quantifies the degree of similarity between the reference series and alternatives. Thereafter, alternatives ranking based on the grey relational grades to identify the most suitable option. It is being integrated in different fields of science and engineering (Huai et al., 2021; Dmitrovic et al., 2022, Dumitru et al., 2023, Shivakumar and Murali, 2024). In agricultural systems, integration of Grey Relational Analysis (GRA) is particularly useful for addressing multi-response optimization because it will allow for the evaluation and comparison of multiple performance criteria simultaneously. In agricultural studies, various factors such as yield, water-use efficiency, nutrient uptake and crop quality need to be optimized, which often have conflicting or interdependent relationships. GRA simplifies this complexity by providing a systematic method to rank and prioritize different outcomes based on their relative performance, even when the units or scales of the responses vary (Li et al., 2022). It is also effective in dealing with uncertainty which is common in agriculture due to environmental variability and fluctuating conditions (Xie et al., 2020). In addition, it allows flexibility by integrating diverse factors and offering a holistic approach to finding the optimal combination of inputs for enhanced agricultural productivity. By using GRA, agricultural researchers and practitioners can make data-driven decisions to improve overall crop performance across multiple criteria. In agricultural management, GRA can also be applied to various aspects such as resource allocation, crop selection and risk assessment. It can aggregate insights from multiple stakeholders, reducing individual biases and enhancing overall decision quality (Xu, 2024). Also the ability to evaluate numerous factors simultaneously makes it suitable for complex agricultural decisions where trade-offs are common. Research has demonstrated GRA's effectiveness in agricultural contexts, such as evaluating sustainable farming practices or optimizing input use (Edinam et al., 2022). For instance, studies have shown that using GRA can significantly improve decision accuracy in selecting crops based on environmental conditions and market demand (Oduniyi and Chagwiza, 2021; Lampteym, 2022). The integration of Grey Relational Analysis in Amaranthus production enables the identification of the best irrigation and poultry manure combinations to maximize multiple growth parameters including leaf area index, plant height, crop yield, water use efficiency and quality. By analyzing the interaction effects of water and nutrient inputs, GRA provides a quantitative framework for decision-making in agricultural management (Romero-Gelve et al., 2020). It allows for the simultaneous evaluation of multiple performance indicators, such as plant height, leaf greenness and crop water use efficiency, making it a suitable tool for optimizing complex agricultural systems.

The objective of this study is to optimize Amaranthus production under varying irrigation levels and poultry manure applications rates using Grey Relational Analysis. By applying this method, the study aims to determine the most favorable treatment combinations that enhance crop productivity while maintaining resource efficiency and environmental sustainability.

Materials and methods

The field experiment was conducted at the Teaching and Research Farm of the Department of Agricultural Education, Federal College of Education (Technical), Akoka, Lagos, longitude 6.3167ºN, latitude 3.2250ºE, with an altitude of 10m above sea level on coastal area of Southwestern Nigeria as shown in Figure 1. Lagos state has a landmass of 356,861 hectares, of which 169,613 hectares are designated for agriculture (Lagos State Government, 2018).

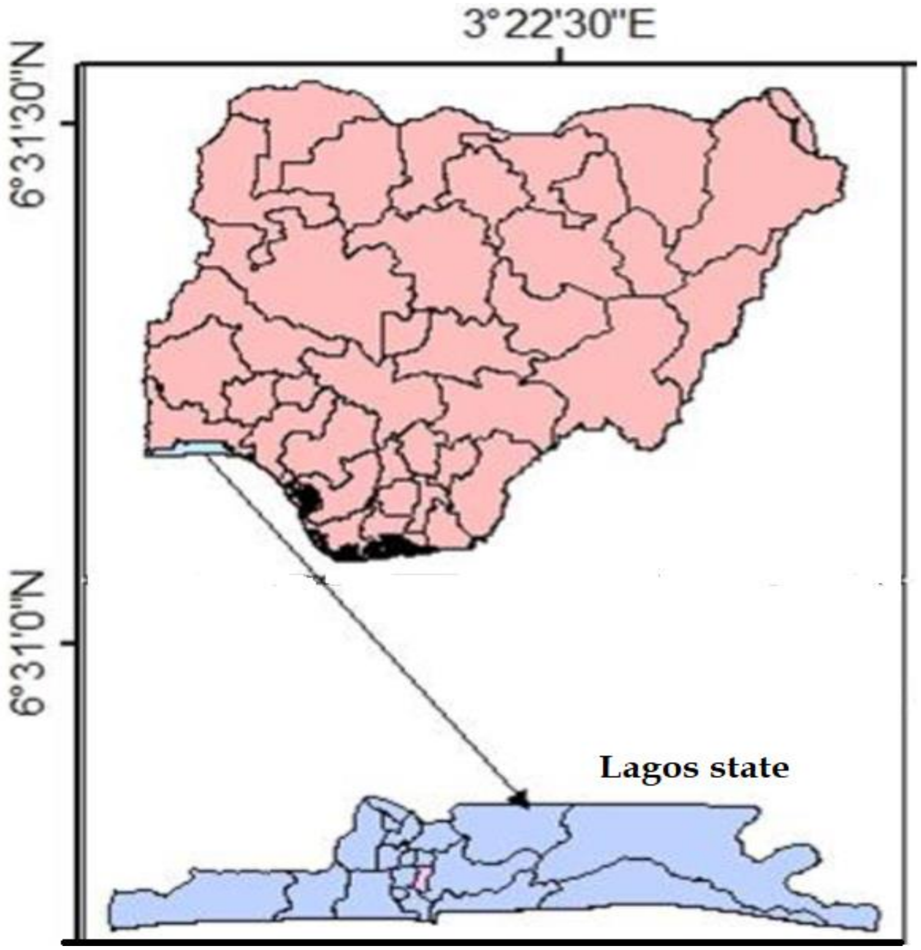

Figure 1: Map of Nigeria showing geographical location of Lagos State

The experiment was carried out between the months of January to February 2020 during the dry season. The averages of the weather parameters over the study site at the period of the experiments are recorded in Table 1.

Table 1: Average weather parameters over the study site for 2020

Months	Maximum Temperature ^0C	Minimum Temperature ^0C	Relative Humidity %	Wind Speed m/sec	Solar Radiation MJ/m^2.day	ET_o mm/day	Rainfall mm
January	35.64	23.87	70.74	2.24	17.91	3.69	15.40
February	31.57	22.60	71.15	2.52	17.33	3.51	0.00

The study site has been on continual use for crop production for over 10 years. An area of 15m x 10m portion of the field was cleared and appropriate land preparation was carried out to permit effective seed bed formation. Soil samples were collected randomly from twelve points to a depth of 0.45m and analyzed using standard soil analysis procedure prior to the starting of the experiment. The soil texture within the depth considered is sandy loam according to Soil Survey Staff (2006). Other results of the soil sample analysis are given in Table 2.

Table 2: Soil particle size analysis and the textural classification of the study site

Particle size fractions	Minimum (%)	Maximum (%)	Standard Deviation	Coefficient of Variation (%)
Sand (%)	80.9	88.4	3.1	3.7
Silt (%)	6.1	10.6	1.7	21.6
Clay (%)	4.4	10.4	2.3	27.6
Textural Class	Sandy loam			

The experimental design was split-plot, with irrigation treatments as main plots and poultry manure as random treatments within the subplots. The treatments consisted of four irrigation levels based on water requirement. They were FIT50, FITI75, FIT100 and FIT135. The implication of this irrigation levels is explained thus: 50% Full irrigation represents a significant reduction in water availability, simulating drought or water stress conditions, which is important to understand how crops respond under water scarcity, 75% full irrigation reflects a moderate water stress due to water deficit, 100% full irrigation is the baseline treatment, representing ideal irrigation conditions where the crop receives the full amount of water required for optimal growth and FIT135 was considered excessive water application helps to assess the effects of over-irrigation. These levels correspond to realistic agricultural scenarios. Four levels of poultry manure were 0t/ha, 5t/ha, 10t/ha and 20t/ha. 0t/ha represents typical farming without manure application, 5t/ha this represent low manure application rate, scenarios where limited resources are available, 10t/ha this also represent moderate manure application rate, balancing nutrient supply with economic and environmental sustainability) and 20t/ha this mimics a high application rate, which can help explore the upper limits of nutrient input and its effects on plant growth, yield and soil properties. The experimental design was 4 by 4 full factorial combination of irrigation and poultry manure replicated 3 times.

Table 3: Chemical analysis of the soil in the study area and poultry manure applied

Chemical Properties	Concentration	
	Soil	Poultry Manure
pH	6.72 ±0.32	6.22 ±0.83
Organic matter (%)	5.48±1.76	36.87±1.21
Total N (g/kg)	8.56 ±1.10	10.18 ±1.42
P (mg/kg)	25.32 ±0.55	4.86 ±0.35
K (cmol/kg)	0.51 ±0.08	6.97 ±0.78
Ca (cmol/kg)	0.29 ±0.06	24.91 ±0.34
Mg (cmol/kg)	0.29 ±0.53	3.79 ±0.42
Na (cmol/kg)	0.53 ±0.06	2.35 ±0.42
Fe (g/kg)	0.52 ±0.58	2.30 ±0.28
Al (g/kg)	0.97 ±0.65	3.12 ±0.31
Cu (mg/kg)	21.59 ±0.11	34.96 ±0.35
EC (mS/m)	36.41 ±6.72	58.56 ±7.03

The poultry manure that was used for the experiment was collected from the Poultry Section of the Teaching Farm of the Agricultural Education Department, Federal College of Education (Technical), Akoka. The poultry manure were divided into five samples, later air dried, grounded into its fineness and was analyzed for its chemical properties. The soil samples collected were from twelve points and were analyzed for their chemical properties using the standard procedure as recommended by the Soil Science Society of America (SSSA) shown in Table 3. The manure was incorporated into the top 0.25m and was evenly mixed manually with the soil within each subplot at different rates aforementioned. These application rates were modified from the previous works of Enujeke (2013) and were studied from other related literatures to be appropriate for boosting vegetable production in soils with low fertility status (Xiang et al., 2022). Seeds of Amaranthus Hybridus (cultivar-$NHAC_3$ purchased from Lagos State Ministry of Agriculture, Alausa, Ikeja, Nigeria. The seeds were mixed thoroughly with sand at the rate 10g seed/ 100g of dry sand to ensure even distribution. Seeding by broadcasting was carried out on 18th January, 2020.

Irrigation water source was from the centralized Industrial Overhead Reservoir meant for the FCET Waterworks. The water was directed through an existing PVC pipe connection into a 3000 litres capacity tank placed at a height of 5m above the ground. The tank was connected to a 25.4mm diameter PVC pipe main line which delivers water under gravity to the submains and finally to the networks of 25.4mm diameter flexible HDPE (High Density Polyethelyn) hoses which run along the furrows as lateral with closed ends. Plastic hose risers accompanying the micro-sprinklers were connected to the laterals through the connecting accessories (barbs). The micro-sprinklers erected with the aid of its plastic spikes within the subplots. The arrangement of the micro sprinkler was carried out such that the radius of their throws overlap. The sprinklers discharge was measured using catch cans using the method reported by Oluwagbayide et al.,(2021). The pressure created from the 3000litres capacity over head tank made addition of water pump to power the micro sprinklers unnecessary. The irrigation treatments were imposed on the field by controlling the duration of water application usually in the evening by 6pm. The 135% full irrigation usually receives water late into the night. Prior to seeding, the field was adequately watered through unrestricted irrigation. This continued in the first week of planting to facilitate higher proportion of seeds germination and early establishment. Thereafter, different irrigation level treatments were initiated. Plants stands within each seed bed were thinned to 50 plant stands per $1m^2$ subplot giving a planting density of 50,000 stands /ha.

Since the experiment was to commence in January (one of driest months of the year in Nigeria), the amount of water required to prepare the land to facilitate higher proportion of seed germination, early crop establishment and meet crop water requirement was computed from the guidelines given by Raveendra et al, (2017) and Luca et al., (2020). For the land wetting or soaking, water required was calculated using Equation 1;

$$WR_{LS} = W_s + k.\ ET_o + (P - P_e) \qquad (1)$$

WR_{LS} = land wetting or soaking water requirement (mm), Ws = depth of water required to saturate the soil (mm), k = Evaporation coefficient (k = 0.90), ET_o = Reference crop evapotranspiration for the growing period computed from Daily reference evapotranspiration obtained using the FAO 56 Penman-Monteith method (Allen et al., 1998), P_e = Effective rainfall (mm), P = Deep percolation loss (mm),The Net Irrigation Water Requirement during the growing period of the Amaranthus Hybridus was calculated using Equation 2:

$$NIR = \sum_{i=1}^{n} (K_{c,i}\ ET_{o,i} + P_i) - (P_{e,i} + GW_{c,i}) \qquad (2)$$

K_c = Crop coefficient, K_c for the Amaranthus at the various growth stages was estimated from the previous work of Ufoegbune et al., (2016), GW=groundwater contribution in terms of capillary rise (mm)

The Total Net Irrigation Demand was calculated using Equation 3:

$$NIWR = NIR + WR_{LS} \qquad (3)$$

The Gross Irrigation Water Requirement was determined from using equation 4:

$$GIWR = \frac{NIWR}{Ea * Ec} \qquad (4)$$

E_a = Irrigation application efficiency, E_c = Field application efficiency
In order to determine the duration of irrigation (T_d) at each irrigation event, the gross irrigation ($GIWR_g$) was determined by dividing the irrigation amount (NIWR) by the irrigation application efficiency (E_a). The irrigation amount i.e the volume of irrigation water applied in litres (L) per irrigation events was computed from Equation 5

$$NIWR = W_a \times I \qquad (5)$$

Wa is the wetted area (m^2) and I is the irrigation (mm). I is irrigation depth (mm). Irrigation application efficiency of 70% was used (ASAE, 1990).
The total crop evapotranspiration (ET) was estimated in each of the treatments using the soil water balance equation in Equation 6.

$$ET = P + I - D - R - [S_{i+1} - S_i] \qquad (6)$$

where; ET is total crop evapotranspiration (mm), P = precipitation (mm) measured using installed manual rain gauges, I = irrigation amount (mm) which was applied to bring the soil water to field capacity. D = Deep percolation (mm), R = runoff (mm). Deep percolation was assumed to be negligible in treatments with deficit irrigation since the experiment was carried out in the dry season characterized by little rainfall. However, it was computed after deduction of other components in the treatments with surplus irrigation. Runoff from the over irrigated plots were collected using runoff collectors installed and was measured. $S_{i+1} - S_i$ is the change in soil water storage (mm) determined based on the difference in soil water content between two successive measurements within the soil depth during the first and next successive soil moisture contents.

Agronomic measurements

The average plant height, number (N) of leaves per stand, length (L) and width (W) of leaves from 4 selected Amaranthus plants per plot, were monitored on weekly basis at the center of the middle row in each plot until when the vegetable was matured for market standard. The leaf area (LA) was calculated following the procedure described by Blanco and Folegatti (2003).

Leaf area

The average leaf area was calculated by multiplying the length of leaf by the widest width and by a factor 0.851 given in Equation 7.

$$\text{Leaf Area } (cm^2) = L \times W \times 0.851 \qquad (7)$$

Leaf area index (LAI)

The Leaf Area Index (LAI) was computed by dividing the total Leaf Area (LA) of the Amaranthus plants by the land area they occupied (equal plot size of each replicate) given in Equation 8;

$$\text{Leaf Area Index} = \frac{\text{Total Leaf Area per plant X total number of plants}}{\text{Plot total Area}} \ldots\ldots\ldots\ldots..(8)$$

Canopy cover

The active plant canopy cover was measured using Canopeo application version for android smart phone. Canopeo is automatic colour threshold image analysis tool developed in the MATLAB programming language (Mathworks, Inc., Natick, M.A) using colour values in the red-green-blue (RGB) system. It analyses image based on the selection of pixels according to the ratios of Red/Green, Blue/Green and excess green index (Liang et al., 2012, Paruelo et al., 2000, Biró et al., 2024) The results of the analysis is converted into a binary image where white pixels correspond to the pixels that satisfied the selection criteria (green canopy) and black pixels correspond to the pixels that did not meet the selection criteria (not green canopy). Fractional green canopy cover ranges from 0 (no green canopy cover) to 1 (100% green canopy cover) (Andres and Tyson, 2015). The application automatically records geographical coordinates, date and time so that the identity of each image can be traced. The relationship connecting the total leaf area per plant and the canopy cover was established using the regression model given in Equation 9

Active Canopy cover (%) = 0.0113 Total Leaf Area + 37.584 ………………….(9)

Leaf greenness index

The leaf greenness measurement was taken using Colour Analyser, a digital imaging application on Android smart phone. Images of Amaranthus leaves were taken using the smart phone camera between the hours of 10 am and 11 am. The image was processed by the MATLAB based program developed into colour analyser application. The application converts the image into colour values of red-green-blue (RGB) system given in Equation 10.

$$f(x, y) = p00 + p10*x + p01*y \ldots\ldots\ldots\ldots(10)$$

Where p00, p10 and p01 are modal parameters or constants. According to Amar et al., (2016), the values obtained for the modal parameters are 775.4, -1218 and -827.3 respectively. In equation, the variables x and y are the mean brightness ratios r and g respectively. The three primary colors (Red, Green and Blue) are converted into mean brightness ratios (r, g, b) to get better results. Where r, g and b are given in Equations 11, 12 and 13 respectively:

$$r = \frac{R}{(R+G+B)} \ldots\ldots\ldots\ldots(11)$$

$$,g = \frac{G}{(R+G+B)} \ldots\ldots\ldots\ldots(12)$$

$$b = \frac{B}{(R+G+B)} \ldots\ldots\ldots\ldots..(13)$$

Yield

The harvesting of the vegetable was carried out at the optimum age of 4 weeks after sowing when their stems and leaves were fully developed. At the age of 4 weeks the vegetable has not lignified. Therefore, suitable for market standard. Harvesting was carried out by uprooting the shoots. Thereafter, root depth were measured and severed manually using knives. The yield was determined by weighing using Equation 14 below.

$$\text{Fresh Harvestable Yield} = \frac{\text{Weight of fresh Amaranthus (tons)}}{\text{Area Harvested (m}^2\text{)}} \quad \ldots\ldots\ldots\ldots(14)$$

Water-use efficiency

The water use efficiency was determined from the ratio of the yield to irrigation depth given in Equation 15 below

$$\text{Crop water use efficiency} = \frac{\text{crop yield (kg/ha)}}{\text{total irrigation depth (mm)}} \quad \ldots\ldots\ldots\ldots(15)$$

Grey relational analysis

The raw experimental data from the physical characteristics expressed as vegetative, yields, water use efficiency, and production cost were first normalized using Equations 16 and 17

Highly desired plant qualities such as plant height, number of leaves, leaf area, leaf area index, stem girth, canopy cover, greenness index, harvestable yield and water use efficiency (the higher-the-better) is normalized using:

$$x_{ij} = \frac{y_{ij} - \min(y_{ij})}{\max(y_{ij}) - \min(y_{ij})} \quad \ldots\ldots\ldots\ldots(16)$$

While the undesired qualities such as production cost (the lower-the-better) is expressed as:

$$x_{ij} = \frac{\max(y_{ij}) - y_{ij}}{\max(y_{ij}) - \min(y_{ij})} \quad \ldots\ldots\ldots\ldots(17)$$

Where y_{ij} are the raw experimental data. x_{ij} is the reference value for performance of experiment i for j response. min y_{ij} is the minimum value of y_{ij} for the jth response, and max y_{ij} is the maximum value of y_{ij} for the jth response (Sonja et al., 2015).

The grey relational coefficient was calculated from the normalized experimental data using the Equation 18.

$$\gamma(x_{0j}, x_{ij}) = \frac{(\Delta_{min} + \xi\Delta_{max})}{(\Delta_{ij} + \xi\Delta_{max})} \quad for\ i = 1, 2, \ldots, m\ and\ j = 1, 2, \ldots, n \quad \ldots\ldots(18)$$

Where $y(x_{0j},x_{ij})$is the grey relational coefficient between x_{0j} and x_{ij}

The deviation sequence is calculated using Equation 19

$$\Delta_{ij} = |x_{0j} - x_{ij}|, \quad \ldots\ldots\ldots\ldots(19)$$

$$\Delta_{min} = min\{\Delta_{ij}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n\}$$

$$\Delta_{max} = max\{\Delta_{ij}, i = 1, 2, \ldots, m; j = 1, 2, \ldots, n\}$$

ξ is the distinguishing coefficient; it can assume range between 0 and 1. It is the index of distinguishability. The lesser it is, the higher its distinguishability. Therefore, ξ is assumed as 0.5 in this present study. The Grey Relational Grade $\Gamma(X_0, \acute{X}_i)$ is computed using Equation 20

$$\Gamma(X_0, X_i) = \sum_{j=1}^{n} w_j \gamma(x_{0j}, x_{ij}) \quad \text{for } i = 1, 2, \ldots, m \qquad \ldots\ldots\ldots\ldots\ldots\ldots..(20)$$

$\sum_{j=1}^{n} w_{jj}$: is the weighting of response wj

Overall ranking of the amaranthus physical characteristics was based on the grey relational grade. In this way, optimization of the various physical characteristics can be converted into optimization of a single grey relational grade. The highest grey relational grade is the best input interactions that yield the physical characteristics with the best optimization.

Statistical analysis

The Grey relational grade sequence was subjected to Two-way ANOVA to determine which input factors (irrigation and manure) significantly affect the optimum performance characteristic of the Amaranthus. The percentage contribution by each input factors to the performance characteristic of the Amaranthus at the optimal level was determined.

Results and discussions

Effect of irrigation levels and poultry manure application rates on amaranthus consumptive use

Table 4 provides the water balance components and evapotranspiration (ET) results for various treatments of Amaranthus during the growing. Irrigation levels ranged from 60.5 mm for FIT50 treatments to 160.5 mm for FIT135 treatments. Rainfall was constant at 15.4 mm across all treatments. Observation from the results revealed that higher irrigation levels result in increased values of ET. ET increases from 95.3 mm in FIT50_M0t/ha to 217.1 mm in FIT135_M0t/ha.

This is as more available water leads to higher plant transpiration and evaporation from the soil surface. The increase in ET from FIT50 to FIT100 suggests that Amaranthus responds positively to increased water availability, with a greater proportion of the available water being used for growth. The range of water use (ET) obtained during the amaranthus growing season closer to the range of 70mm –160mm reported by irrigation in the same ecological zone (Fasimirin et al.,2009; Fasina et al., 2015; Ufoegbune et al., 2016; Egbebi et al., 2024). Beyond FIT100, the increase in ET becomes excessive, indicating that FIT135 represents over-irrigation, as not all water is being effectively used by the plant. Runoff and deep percolation were only observed in the FIT135 treatments, with runoff ranging from -10.7mm to -19.9 mm and deep percolation ranging from -12.4mm to -16.8 mm. This is not unconnected moisture content of the soil under these treatments that were above the field capacity range due to excess water application. This indicates that much of the additional water is lost and does not contribute to crop water use after the soil field capacity is exceeded. Irrigation at this level suggests inefficiency and potential water wastage (Ogunlela and Sadiku, 2017, Ajayi et al., 2023). However, other treatments ranging from FIT50 to FIT100 had no runoff or deep percolation. Evapotranspiration increased with higher irrigation levels, ranging from 95.3 mm for FIT50 to 217.1 mm for FIT135. Negative ΔS values across all treatments indicate that soil moisture was depleted to meet the crop's water requirements. As irrigation increases, the depletion of soil water storage becomes less severe. Treatments FIT50 and FIT135 had ΔS -19.4 mm and -4.5 mm respectively, showing that higher irrigation levels provide sufficient water, reducing the need to deplete soil moisture.

Table 4: Water balance component data and evapo-transpiration for the Amaranthus treatments during the growing season

Treatments	Irrigation (mm)	Rainfall (mm)	Runoff (mm)	Deep percolation (mm)	Change in soil water storage (ΔS) (mm)	ET (mm)
FIT50_M0 t/ha	60.5	15.4	0.0	0.0	-19.4	95.3
FIT50_M5 t/ha	60.5	15.4	0.0	0.0	-18.2	94.1
FIT50_M10 t/ha	60.5	15.4	0.0	0.0	-14.4	90.3
FIT50_M20 t/ha	60.5	15.4	0.0	0.0	-11.4	87.3
FIT75_M0 t/ha	90.5	15.4	0.0	0.0	-14.5	120.4
FIT75_M5 t/ha	90.5	15.4	0.0	0.0	-11.7	117.6
FIT75_M10 t/ha	90.5	15.4	0.0	0.0	-15.8	121.7
FIT75_M20 t/ha	90.5	15.4	0.0	0.0	-10.5	116.4
FIT100_M0 t/ha	120.5	15.4	0.0	0.0	-8.4	144.3
FIT100_M5 t/ha	120.5	15.4	0.0	0.0	-9.4	145.3
FIT100_M10 t/ha	120.5	15.4	0.0	0.0	-7.5	143.4
FIT100_M20 t/ha	120.5	15.4	0.0	0.0	-8.6	144.5
FIT135_M0 t/ha	160.5	15.4	-19.9	-16.8	-4.5	217.1
FIT135_M5 t/ha	160.5	15.4	-12.6	-13.5	-2.5	204.5
FIT135_M10 t/ha	160.5	15.4	-10.7	-12.4	-1.8	200.8
FIT135_M20 t/ha	160.5	15.4	-14.6	-14.6	-1.6	206.7

Under each irrigation regime, higher manure application rates (M5t/ha, M10t/ha, M20t/ha) slightly reduce ET. For instance, in the FIT50 treatment, ET decreases from 95.3 mm under M0t/ha treatment to 87.3 mm M20t/ha treatment, showing that manure improves soil moisture retention, reducing the need for water loss through transpiration. Manure application helps boost soil organic matter, which improves water-holding capacity, thus reducing the overall ET required by the crop. Are et al., (2017) found that organic amendments like poultry manure improve soil physical properties, including bulk density and porosity, enhancing water retention and reducing soil evaporation. This explains the lower ET values observed in manure-treated plots.

Growth parameters

The plant height, stem girth, number of leaves, root depth, average leaf area, leaf area index, canopy cover and leaf greenness, are some of the important parameters that directly reflect the growth of the Amaranthus plants. From Table 5, Under Plant height, FIT50_M0t/ha has a height of 25.12cm, while FIT100_M20t/ha shows the highest height 53.46cm. This suggests that both irrigation and poultry manure significantly improve plant height. The combination of FIT75 and M10t/ha gives an intermediate height 51.25cm, indicating that beyond a certain level, adding more manure or irrigation water may plateau the height response. The stem girth improves as manure and irrigation increase. FIT100_M10t/ha has the largest stem girth 2.33cm, showing a substantial improvement compared to the treatment FIT100_M0t/ha that recorded girth 1.51cm. The percentage increase from FIT100_M0t/ha treatment to FIT100_M10t/ha is around 54.3%. The notable enhancement in girth at higher manure levels may point to increased nutrient availability facilitating stem thickening.

The number of leaves increases with both irrigation and manure application, peaking at treatment FIT75_M20t/ha with 35.67leaves, while treatment FIT100_M0t/ha has 31.67leaves. This corresponds to a modest 12.65% increase from the performance of FIT100_M0t/ha. However, the highest manure application rate M20t/ha enhances leaf count at each irrigation level. As for the leaf wideness, FIT100_M20t/ha exhibits the highest average leaf area 48.29cm², which is an increase of 41.5% compared to FIT100_M0t/ha that has 34.12cm²**.** Higher leaf area improves the photosynthetic capacity of the plant, contributing to better growth (Sokoto and Victor, 2017). The leaf area index (LAI) improves with increasing irrigation and manure. Treatment FIT135_M10t/ha has the highest LAI 0.155, compared to FIT50_M0t/ha 0.027. A substantial increase, this reflects the improved plant density and canopy spread (Luka et al., 2023).

The canopy cover rises with both irrigation and manure, with FIT100_M20t/ha almost completely covering the area at 99.7%. This is a 30.6% increase over FIT100_M0t/ha, demonstrating the importance of combining both treatments to optimize plant coverage. Leaf greenness data is a proxy for chlorophyll content. It also improves with both irrigation and manure, with FIT100_M20t/ha yielding the greenest leaves (46.45%). This is crucial for photosynthesis and ultimately productivity. In all, the least growth response parameters were obtained under FIT50_M0t/ha treatment. This may be linked with the combined effect of water stress due to deficit irrigation imposed and zero soil fertility boost from no manure application (Emeghara, 2023)

Yield, water-use efficiency and production cost

At harvest, under the FIT50 Series, it is observed that as poultry manure application increases from 0 to 10 t/ha, there is a notable increase in yield (from 6.49 to 9.91 t/ha), suggesting that manure significantly enhances yield at lower irrigation levels. The highest yield at this irrigation level is achieved with M10 t/ha. Under FIT75 irrigation series, the yield increases dramatically with both irrigation and manure application; the highest yield is observed at M20 t/ha 37.58 t/ha, which is a 143.7% increase from M0t/ha at the same irrigation level FIT75. Under the scenario of over irrigation, FIT135 treatments series**,** increasing trends are observed, the maximum yield at M20t/ha is 42.41t/ha, which is only a slight improvement over M10t/ha. The highest yield is observed at FIT100_M20t/ha

Crop Water Use Efficiency (CWUE) increases under FIT50 irrigation treatment series with increasing manure application, peaking at M10 t/ha with 198.23 kg/ha/mm. This is similar to the findings of Egbebi et al., (2024) in their experiment on Amaranthus viridis during the dry season irrigation and fertilizer micro-dosing on water application in Isan Ekiti, Nigeria. However the most efficient water use observed in this study is at FIT75_M20 t/ha with 521.38 kg/ha/mm

The average cost incurred was highest under FIT135_M20t/ha treatment level with average value of 377.8$/ha. Lowest cost was incurred under FIT50_M0t/ha treatment level. This is because FIT135_M20t/ha treatment level received the highest quantity of production inputs in terms of water application and manure applications.

Grey relational analysis

The normalized values of Amaranthus growth characteristics, yield characteristics and production cost are shown in Table 6. Plant height, Stem girth, number of leaves, leaf area index and canopy cover gave normalized value of 1.000 at FIT135_M20t/ha treatment. This shows that these growth characteristics are in their best response under this treatment. While root depth, average leave area and leaf greenness had

normalized values less than 1.000 under the treatment. The fresh harvestable yield and water use efficiency had their best performance under different treatments. Production cost gave normalized value of 1.000 under FIT50_M0t/ha treatment. This is because the lower the production cost the better it is for production cycle.
Table 7 shows the deviation sequence. The deviation sequence measures the values of comparable sequences how far away to the values of reference sequence. If the value of deviation is close to 1.000, it is commented that comparable sequence is remote to reference sequence. On the other hand, if the value of deviation is close to 0, they are close to each other (Irfan et al., 2016). Table 8 shows the grey relational coefficients and grade for each treatment. The highest achievable (GRG) grey relational grade is 1.000. The larger the GRG, the closer is the amaranthus quality to the objective value (Bimal et al., 2023). The treatment number 12 which is FIT100_M20t/ha treatment, highlighted in green is the acceptable and closer to the reference sequence (ideal sequence), in which the highest GRG 0.841 was obtained. Next to treatment number 12 is number 11 (FIT100_M10t/ha) highlighted in yellow colour.

Table 5: Means and standard deviations of the Amaranthus growth parameters, yield, water-use-efficiency and production cost

Treatments	Plant height (cm)	Stem Girth (cm)	Number of Leaves	Root Depth (cm)	Average Leaf Area (cm^2)	Leaf Area Index	Canopy Cover (%)	Leaf Greenness	Fresh Harvestable Yield (t/ha)	Crop Water Use Efficiency (kg/ha/mm)	Expenditure ($/ha)
FIT50_M0t/ha	25.12±2.45	0.92±0.04	11.67±3.89	12.03±2.98	23.51±4.55	0.027±0.01	75.51±1.98	35.09±7.76	6.49±1.87	129.75±23.76	113.61
FIT50_M5t/ha	27.21±3.76	0.90±0.15	14.00±4.76	12.49±3.34	24.53±3.67	0.034±0.01	80.33±3.98	36.91±5.87	9.10±2.91	182.03±10.56	120.87
FIT50_M10t/ha	35.74±3.99	0.97±0.28	15.67±3.82	11.39±3.23	26.47±4.71	0.042±0.02	82.07±4.76	38.48±5.11	9.91±3.99	198.23±32.90	124.44
FIT50_M20t/ha	39.44±7.74	1.15±0.40	19.00±4.91	12.45±2.45	26.85±2.09	0.051±0.02	84.56±4.09	39.23±2.89	9.11±3.71	182.25±13.06	133.33
FIT75_M0t/ha	48.18±9.98	1.05±0.11	22.33±2.88	11.76±2.56	29.56±1.90	0.066±0.02	87.11±7.94	38.91±3.97	15.43±3.82	214.32±35.93	162.22
FIT75_M5t/ha	48.71±12.40	1.24±0.26	25.67±5.87	12.82±4.78	31.85±4.89	0.082±0.03	90.40±4.70	43.36±3.99	19.98±2.89	277.47±28.90	168.89
FIT75_M10 t/ha	51.25±10.41	1.81±0.29	27.33±4.80	11.69±3.54	31.54±4.63	0.086±0.02	91.21±4.50	43.27±7.67	25.33±3.21	351.82±45.91	173.33
FIT75_M20 t/ha	54.84±8.72	1.91±0.43	35.67±5.76	11.39±2.45	32.55±2.75	0.133±0.04	94.54±3.05	42.43±4.98	37.58±4.31	521.38±30.67	182.22
FIT100_M0 t/ha	54.49±10.50	1.51±0.37	31.67±3.96	13.86±4.67	34.12±2.98	0.108±0.06	96.27±5.87	39.50±3.72	17.04±4.90	177.54±13.07	215.56
FIT100_M5 t/ha	42.78±8.89	1.77±0.43	31.67±5.90	11.19±3.76	41.56±4.91	0.131±0.09	98.70±0.62	44.95±5.87	30.17±5.04	314.26±54.09	222.22
FIT100_M10 t/ha	52.19±7.31	2.33±0.54	33.00±6.02	9.89±4.10	43.54±4.10	0.143±0.08	99.20±0.03	45.51±4.87	42.61±6.12	443.88±89.55	226.67
FIT100_M20 t/ha	53.46±9.55	2.29±0.73	31.67±4.88	9.86±2.12	48.29±4.65	0.153±0.09	99.70±0.03	46.45±4.99	44.43±5.32	462.76±70.54	235.56
FIT135_M0 t/ha	47.20±8.02	1.17±0.45	31.33±5.12	8.53±2.19	30.55±3.99	0.096±0.03	97.90±0.08	36.10±5.31	21.38±8.55	133.62±13.78	357.78
FIT135_M5 t/ha	49.81±9.18	1.96±0.66	34.00±4.89	9.52±2.15	38.81±4.13	0.132±0.08	99.80±0.01	38.05±2.90	32.77±6.42	204.80±25.88	364.44
FIT135_M10 t/ha	53.18±7.41	2.01±0.34	36.65±3.84	11.55±4.78	43.21±3.77	0.155±0.06	99.87±0.05	45.12±3.98	40.29±5.67	251.59±28.33	368.89
FIT135_M20t/ha	53.26±10.38	2.19±0.98	33.33±9.58	11.26±3.45	43.58±5.89	0.152±0.05	99.80±0.01	42.29±5.09	42.41±4.08	265.83±19.76	377.78

Table 6: Normalized sequence of Amaranthus growth parameters, yield, water-use-efficiency and production cost

Plant height (cm)	Stem Girth (cm)	Number of Leaves	Root Depth (cm)	Average Leaf Area (cm^2)	Leaf Area Index	Canopy Cover (%)	Leaf Greenness	Fresh Harvestable Yield (t/ha)	Water Use Efficiency (kg/ha/mm)	Expenditure ($)
0.000	0.009	0.000	0.343	0.000	0.000	0.000	0.000	0.000	0.000	1.000
0.068	0.000	0.091	0.274	0.041	0.048	0.267	0.161	0.064	0.152	0.975
0.346	0.047	0.156	0.463	0.119	0.098	0.394	0.298	0.084	0.199	0.958
0.466	0.172	0.286	0.264	0.135	0.165	0.479	0.365	0.162	0.386	0.924
0.750	0.100	0.416	0.394	0.244	0.270	0.567	0.337	0.219	0.246	0.815
0.767	0.235	0.545	0.195	0.337	0.381	0.679	0.728	0.330	0.430	0.739
0.850	0.634	0.844	0.424	0.728	0.412	0.809	0.720	0.460	0.647	0.790
0.967	0.984	0.935	0.464	0.768	0.746	0.922	0.910	0.613	0.899	0.773
0.955	0.427	0.779	0.000	0.428	0.565	0.879	0.388	0.258	0.139	0.613
0.574	0.608	0.779	0.501	0.728	0.730	0.962	0.868	0.579	0.537	0.588
0.880	1.000	0.831	0.745	0.808	0.814	0.979	0.918	0.883	0.915	0.571
0.922	0.970	0.779	0.751	1.000	0.879	0.996	1.000	0.951	1.000	0.538
0.718	0.189	0.766	1.000	0.284	0.478	0.935	0.089	0.364	0.011	0.076
0.803	0.737	0.870	0.815	0.617	0.732	1.000	0.261	0.642	0.219	0.050
0.978	0.774	0.948	0.434	0.795	0.898	1.000	0.883	0.973	0.465	0.034
1.000	0.967	1.000	0.488	0.891	1.000	1.000	0.634	1.000	0.485	0.000

Table 7: Deviation sequence of Amaranthus growth parameters, yield, water-use-efficiency and production cost

plant height (cm)	Stem Girth (cm)	Number of Leaves	Root Depth (cm)	Average Leaf Area (cm^2)	Leaf Area Index	Canopy Cover (%)	Leaf Greenness	Fresh Harvestable Yield (t/ha)	Water Use Efficiency (kg/ha/mm)	Expenditure ($)
1.000	0.991	1.000	0.657	1.000	1.000	1.000	1.000	1.000	1.000	0.000
0.932	1.000	0.909	0.726	0.959	0.952	0.733	0.839	0.936	0.848	0.025
0.654	0.953	0.844	0.537	0.881	0.902	0.606	0.702	0.916	0.801	0.042
0.534	0.828	0.714	0.736	0.865	0.835	0.521	0.635	0.838	0.614	0.076
0.250	0.900	0.584	0.606	0.756	0.730	0.433	0.663	0.781	0.754	0.185
0.233	0.765	0.455	0.805	0.663	0.619	0.321	0.272	0.670	0.570	0.261
0.150	0.366	0.156	0.576	0.272	0.588	0.191	0.280	0.540	0.353	0.210
0.033	0.016	0.065	0.536	0.232	0.254	0.078	0.090	0.387	0.101	0.227
0.045	0.573	0.221	1.000	0.572	0.435	0.121	0.612	0.742	0.861	0.387
0.426	0.392	0.221	0.499	0.272	0.270	0.038	0.132	0.421	0.463	0.412
0.120	0.000	0.169	0.255	0.192	0.186	0.021	0.082	0.117	0.085	0.429
0.078	0.030	0.221	0.249	0.000	0.121	0.004	0.000	0.049	0.000	0.462
0.282	0.811	0.234	0.000	0.716	0.522	0.065	0.911	0.636	0.989	0.924
0.197	0.263	0.130	0.185	0.383	0.268	0.000	0.739	0.358	0.781	0.950
0.022	0.226	0.052	0.566	0.205	0.102	0.000	0.117	0.027	0.535	0.966
0.000	0.033	0.000	0.512	0.109	0.000	0.000	0.366	0.000	0.515	1.000

Table 8. Grey relational coefficient of Amaranthus growth parameters, yield, water-use-efficiency, production cost , Grey Relational Grades and their ranks

plant height (cm)	Stem Girth (cm)	Number of Leaves	Root Depth (cm)	Average Leaf Area (cm^2)	Leaf Area Index	Canopy Cover (%)	Leaf Greenness	Fresh Harvestable Yield (t/ha)	Water Use Efficiency (kg/ha/mm)	Expenditure ($)	Grey Relational Grade	Rank
0.333	0.335	0.333	0.432	0.333	0.333	0.333	0.333	0.333	0.333	1.000	0.403	16
0.349	0.333	0.355	0.408	0.343	0.344	0.405	0.373	0.348	0.371	0.952	0.417	15
0.433	0.344	0.372	0.482	0.362	0.357	0.452	0.416	0.353	0.384	0.922	0.443	14
0.483	0.377	0.412	0.405	0.366	0.375	0.490	0.440	0.374	0.449	0.869	0.458	13
0.667	0.357	0.461	0.452	0.398	0.407	0.536	0.430	0.390	0.399	0.730	0.475	12
0.682	0.395	0.524	0.383	0.430	0.447	0.609	0.648	0.427	0.467	0.657	0.515	11
0.769	0.577	0.762	0.465	0.647	0.459	0.723	0.641	0.481	0.586	0.704	0.620	8
0.938	0.968	0.885	0.482	0.683	0.663	0.866	0.848	0.564	0.832	0.688	0.765	4
0.918	0.466	0.694	0.333	0.466	0.535	0.805	0.450	0.403	0.367	0.564	0.546	9
0.540	0.561	0.694	0.500	0.648	0.649	0.930	0.791	0.543	0.519	0.548	0.629	6
0.807	1.000	0.748	0.662	0.723	0.729	0.960	0.858	0.810	0.854	0.538	0.790	2
0.865	0.943	0.694	0.668	1.000	0.805	0.993	1.000	0.911	1.000	0.520	0.854	1
0.639	0.381	0.681	1.000	0.411	0.489	0.885	0.354	0.440	0.336	0.351	0.543	10
0.718	0.655	0.794	0.730	0.567	0.651	0.999	0.404	0.583	0.390	0.345	0.621	7
0.958	0.689	0.906	0.469	0.709	0.830	0.999	0.811	0.948	0.483	0.341	0.740	5
1.000	0.939	1.000	0.494	0.821	1.000	1.000	0.577	1.000	0.493	0.333	0.787	3

Main effects of irrigation and manure on the grey relational grade

The main effects plots for the grey relational grade are shown in Figure 2.The graph provides valuable insights into the balance between nutrient management and water use for enhancing amaranthus yield and quality. Irrigation plot shows that the grey relational grades continue to increase as the irrigation level increase until it reached the optimal point at FIT100. Beyond this irrigation level, slight diminishing returns sets in. This indicates that further addition of irrigation water beyond FIT100 will not positively affect the growth and yield characteristics of the amaranthus. The water use efficiency diminishes beyond FIT100, which is the optimal irrigation level. This is because crop will not absorb beyond its water requirement. On the other hand, further addition of water beyond that peak will imply over-irrigation. This is a pathway to waterlogging, nutrient leaching, or other stress factors, which hamper growth. In the long run it will only lead to unhealthy environment, wastage of resources and increase in the production cost which is a major negative desire of the consumers.

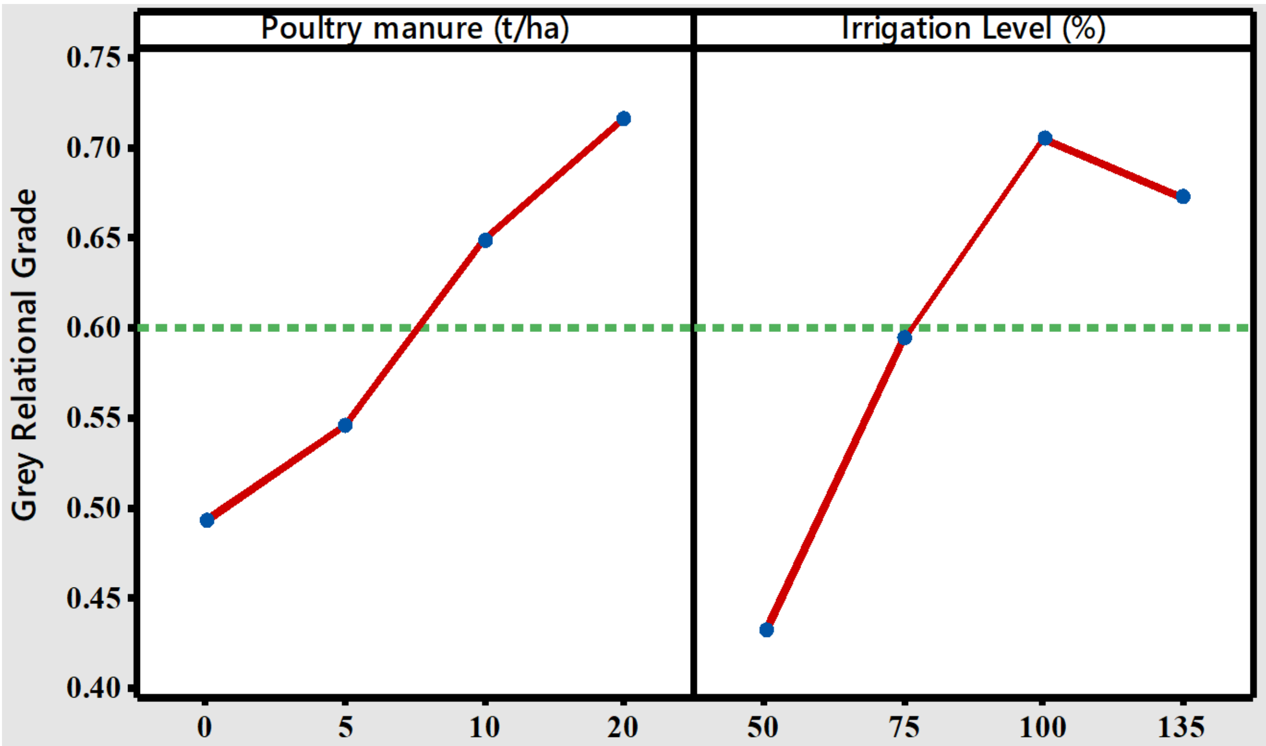

Figure 2: Grey relational grades main effects plot

Manure level increase was shown to increase the grey relational grade. The more the increase in manure levels, the closer the grey relational grade approaches unity (1.000), indicating that the more the performance response of the amaranthus. However, the trend seems to approaching plateau between 10 and 20 t/ha, indicating diminishing returns or a near-optimal range for manure application. Higher levels of manure likely enhance soil fertility, improve soil structure and increase organic matter content, all conducive to plant growth. The dotted green line at a GRG value of 0.60 represent a benchmark for satisfactory or average performance. In both panels, values above this threshold indicate better performance with increasing poultry manure and adequate irrigation. This agrees with the findings of Oworu et al., (2010). Similar findings were also reported by Zingore and Giller (2012) in Zimbabwe on Soyabean crop, a yield increase ratio of 1.18 to that of the control was obtained using cattle manure at 14t/ha. Chipomho et al., (2018) reported tomato yield increase approximately 2.7 times more than control in the same country using goat manure at 10t/ha. While Ndung'u et al., (2021) reported maize yield increase of 4times more than control at 16t/ha in Kenya. The optimal levels obtained for this study were found at 10t/ha and 20t/ha. Therefore, the optimal level of the input parameters is FIT100 irrigation level and 20t/ha manures treatment.

Analysis of variance of Grey relational grade

Table 9 presents the results of an Analysis of Variance (ANOVA) conducted on the Grey Relational Grade (GRG) values. Different irrigation levels contributed 55%, while poultry manure application rates contributes 35% of the total variability to the Grey Relational Grade values. Comparison between the two percentage contributions shows that irrigation is the most influential factor in determining the performance of the amaranthus under each treatment as measured by GRG. The F-value for irrigation and poultry manure is 15.77 and 9.82 respectively. This further suggests that irrigation has a more significant impact on the Grey Relational Grade. The P-value for the duo is 0.001 and 0.003 respectively. They are both far below the significance threshold (typically 0.05). The P-values confirm that both production factors are statistically significant.

Table 9: Analysis of variance for the Grey relational grade

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Contribution
Irrigation (%)	3	0.17713	0.059045	15.77	0.001	55%
Manure (t/ha)	3	0.11025	0.036751	9.82	0.003	35%
Error	9	0.0337	0.003744			10%
Total	15	0.32108				

Conclusions

It can be concluded that increase in the combination of irrigation and poultry manure treatment levels gave a corresponding increase in the response of Amaranthus growth characteristics. The crop water-use efficiency initially showed a linear corresponding increase but later exhibits a diminishing return beyond FIT100 irrigation level. So, the optimal levels of production input parameters for the desired performance characteristics of Amaranthus is obtained within FIT100_M20t/ha treatment. With this combination it is possible to decrease irrigation water, and maximize the growth characteristics yield, water use efficiency and minimize production cost of Amaranthus. Based on the ANOVA of the GRG results, it is observed that irrigation and manure exerted a significant influence on the amaranthus multiple response parameters. However, while the FIT100_M20t/ha treatment is highly effective for optimizing the growth, yield, and water-use efficiency of Amaranthus in the tropical rainforest agro ecological zone, its application should be carefully managed to account for environmental variability, long-term soil health and potential economic constraints. By addressing these factors, the treatment can be refined and adapted to suit a wide range of farming systems and contribute to sustainable crop production practices.

Declaration

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Data availability: Data available on request

Authors contribution: Fasanu Olugbenga: carried out the field experiment, data gathering, analysis and manuscript writing. Oluwagbayide Samuel Dare: carried out the proof reading of the manuscript Sosanya Abolade Olayinka: carried out the editing of the manuscript. Omofunmi, Eric Olorunwa: Carried out the final editing and proof reading of the manuscript.

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