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RESEARCH ARTICLE
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# Influence of Organic and Mineral Fertilization on Yield Components of *Zingiber officinale* Roscoe Grown in Côte d'Ivoire

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## ABSTRACT

Ginger (*Zingiber officinale* Roscoe) is a spice of significant global importance, with a wide range of medicinal properties. Despite its socio-economic importance, the production of ginger in Côte d'Ivoire is limited by a number of constraints, including the reduction in the area under cultivation and the failure to adhere to technical itineraries. The objective of this study is to evaluate the impact of organic and mineral fertilization on the yield components of ginger cultivated in Côte d'Ivoire. To this end, the rhizomes of two varieties of ginger, one with white flesh and the other with yellow flesh, were cultivated and amended with organic fertilizer (poultry manure), mineral fertilizer (NPK 12-22-22) and a combination of the two types of fertilizer. The resulting data on emergence, growth and yield parameters were subjected to a two-factor analysis of variance (ANOVA 2). The analysis revealed that the interaction between variety and type of fertilizer showed no significant effect ($p > 0.05$) on rhizome emergence parameters after sowing (delay, percentage and average emergence time), irrespective of the ginger variety. The results also demonstrated that the growth parameters of ginger plants, namely plant height, number of leaves, diameter at stem base and number of tillers per plant, were significantly improved with the combined application of organic and mineral fertilizers, irrespective of the ginger variety. This study demonstrates that the integration of organic and mineral fertilizers enhances ginger yields. The combination of these two fertilizers resulted in 12.79t/ha for the white-fleshed variety and 11.07t/ha for the yellow-fleshed variety.

**Keywords:** Ginger, Poultry droppings, Agromorphology, Tropical zone.

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## INTRODUCTION

The Third World economy is fundamentally dependent on agriculture. In Côte d'Ivoire, for instance, the agricultural sector accounts for 33% of gross domestic product. It is a significant employer, accounting for two-thirds of the working population, and more than 70% of the population derive their livelihoods directly from agricultural activity (World Bank, 2023). Nevertheless, concerns have been raised regarding the country's ability to achieve food self-sufficiency, a situation compounded by natural constraints, including erratic rainfall patterns and suboptimal soil quality, as well as institutional impediments. The focus of agricultural research institutions and extension services has been predominantly on cash crops (cocoa, oil palm, rubber, etc.), with comparatively less emphasis placed on traditional crops (Kouonon et al., 2020). These crops, which are often underutilized and neglected, are categorized as minor crops (Gnamien et al., 2010). Nevertheless, these minor crops play a significant role in ensuring local food security and offer farmers and consumers a reliable source of livelihoods (Tadele, 2019). A case in point is ginger (*Zingiber officinale* Roscoe), a spice that is highly prized worldwide for its aromatic character and pungency. Its use as a spice is documented for over two millennia (Mao et al., 2019; Das et al., 2020; Kouadio et al., 2023; Zimazi et al., 2025).

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Ginger (*Zingiber officinale*) is of major economic importance throughout the world. The popularity and acclaim of this spice has increased significantly on a global scale (Alharbi et al., 2022; Ozkur et al., 2022; Rostamkhani et al., 2023). Indeed, in 2019, global ginger production was estimated at over four million tonnes (FAOSTAT, 2019). The primary producers are India (1,788,000 tonnes) and Nigeria (691,239 tonnes). Within the African context, Nigeria stands as the preeminent producer, followed by Cameroon, which yielded 79,273 tonnes in 2019. Ivorian production was estimated at 7,085 tonnes (FAOSTAT, 2019). The medicinal properties of the bark have been utilized for the treatment of various ailments, including indigestion, stomach upsets, malaria, fevers, colds and cancer (Alolga et al., 2022; Lashgari et al., 2022; Wang et al., 2025). Furthermore, its extracts are extensively utilized in the food, beverage and confectionery industries (Verma and Bisen, 2022). In Côte d'Ivoire, ginger is produced in the localities of Bongouanou (Moronou region), Divo (Lôh-Djiboua region), Gagnoa (Gôh region), Soubré (Nawa region), Tiassalé (AgnebyTiassa region) and Koun-Fao (Gontougo region) (FIRCA, 2019). The ginger rhizomes are widely used to produce a drink commonly known as "Gnamankoudji" in Côte d'Ivoire (Kouadio et al., 2023). Additionally, the ginger rhizomes are often available for purchase on the streets of Côte d'Ivoire, both in dried and fresh forms (Kouonon et al., 2020).

In 2021, the price of fresh rhizomes on Ivorian urban markets was found to be as high as 700 F CFA (approximately 1 euro/kg), which is equivalent to the price of dried cocoa beans or twice that of cashew nuts (Kouadio et al., 2023). Consequently, this species has become a significant source of agricultural income diversification and the raw material for a category of food industries, and the essential oils extracted supply an important export network between Côte d'Ivoire and Europe. Despite the culinary and therapeutic benefits of ginger, and its role in the socio-economic activities of populations in Côte d'Ivoire, the cultivation of ginger is confronted with numerous factors that limit the expansion of the sector. The paucity of reliable data on national production and the sector's organizational structure is a matter of concern (Kouonon et al., 2020).

Notwithstanding its acknowledged nutritional and therapeutic virtues, the cultivation of ginger in Côte d'Ivoire is confronted with several challenges that are jeopardizing the viability of the industry, despite its significant role in the socio-economic activities of the local population. A body of previous research on ginger in Côte d'Ivoire has demonstrated that the crop is cultivated on small areas on a shifting cultivation basis. The cropping systems identified are generally of the traditional type, and farmers are not trained or instructed in good farming practices (Kouonon et al., 2020). The utilization of fertilizers during cultivation is characterized by significant variations in application periods and doses, as revealed by a survey conducted in 2019 (Kouonon et al., 2020). Ginger is a shallow-rooted plant. It is a nutrient-demanding crop, requiring an ample supply of potassium (K), calcium (Ca), nitrogen (N) and phosphorus (P) during the various stages of growth to facilitate optimal development. Imbalance, low or no fertilizer supply, is a constraint that negatively affects plant growth and yield (Srinivasan et al., 2019). Conversely, the excessive and indiscriminate use of chemical fertilizers has been shown to have a detrimental effect on the physical, chemical and biological environment of the soil. This has been shown to result in a significant decline in crop yields (Patra and Sengupta, 2022). The judicious combination of organic fertilizers with inorganic chemical fertilizers in optimal proportions emerges as a viable option for achieving sustainable crop production, ensuring soil health and safeguarding the environment (Konan et al., 2020; Azizah et al., 2022; Zhang et al., 2024). Among the various cultivation techniques that influence ginger production, fertilization exerts a significant effect on ginger growth and yield. Ginger (*Zingiber officinale*) is a long-duration crop that requires a balanced and judicious supply of different nutrients to achieve high rhizome productivity and superior quality. The crop has a growth period of seven and eight months (Das et al., 2020).

It is widely acknowledged that organic manures and amendments are effective soil conditioners, gradually releasing nutrients to support crop growth over an extended period. It is vital to recognise the significance of a slow and steady release of nutrients by organic manure over an extended duration, a factor that is of particular importance for long-duration crops such as ginger (Das et al., 2020). However, little or no fertilizer application is one of the factors affecting yield. It was against this backdrop that field experiments were carried out. The objective of this study was to assess the influence of organic and mineral fertilizers on the agronomic parameters of ginger. The specific objectives of the study were as follows : 1) To determine the chemical composition of the soil and poultry droppings prior to amendment, and 2) To measure the effect of different fertilizers and that of NPK taken as a reference on some agronomic parameters of ginger growth and yield. The findings of this study have the potential to provide a more effective solution for enhancing soil fertility and optimizing ginger growth and yield. This approach is characterized by numerous advantages. The utilization of poultry manure not only constitutes a more economical option but also assists in addressing the challenges associated with the management of livestock production by-products. The utilization of poultry manure has the potential to reduce the reliance on agrochemicals, thereby facilitating the production of chemical-free feed. The combination of mineral fertilizer and poultry manure has been shown to offer farmers a number of key advantages, including reduced input costs and enhanced productivity. Furthermore, there is an increased demand for this organic crop, which results in a favorable price (Jabborova et al., 2020).

## MATERIALS & METHODS

### Study Site

The study was carried out at the Université Nangui Abrogoua (UNA) in Abidjan, The present study was conducted at the Université Nangui Abrogoua (UNA) in Abidjan, situated in the southern region of Côte d'Ivoire. The university is situated within the confines of the Banco National Park, occupying a geographical location that falls between the latitudes of 03°87'585 North and the longitudes of 05°95'866 West (Fig. 1). The soils of the

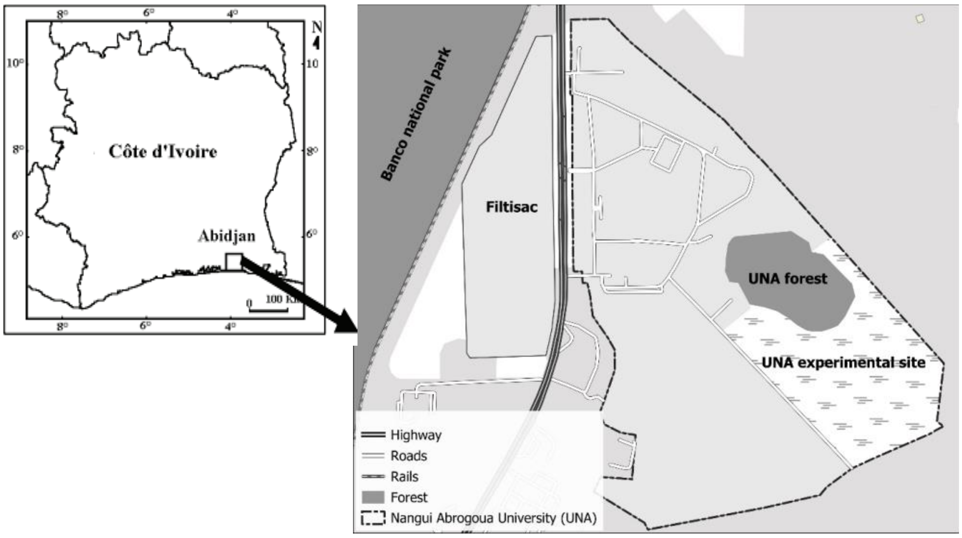


**Fig. 1**: Location of the study site (UNA) in the district of Abidjan.

Abidjan district consist of ferralitic soils (ferralsols) and hydromorphic soils (fluvisols) in marshy areas. The pH of the soil is more acidic at the surface than at depth. The region's climate is predominantly influenced by two factors: rainfall and temperature. The mean monthly temperature ranges from a minimum of 24.4°C in August to a maximum of 27.88°C in March, while the mean monthly rainfall varies from a minimum of 28.26 mm in January to a maximum of 406.08 mm in June. The city of Abidjan is typified by four distinct seasons, characterized by variations in rainfall. These are distinguished by two rainy seasons and two dry seasons (Kambiré et al., 2021).

## Plant Material

The plant material utilized in the present study comprised two distinct varieties of ginger cultivated in Côte d'Ivoire. The first was characterized by a yellowish hue, while the second exhibited a white pigmentation (Fig. 2). These specimens were procured from the 'gouro' market in Adjamé, a commune situated within the Abidjan district.

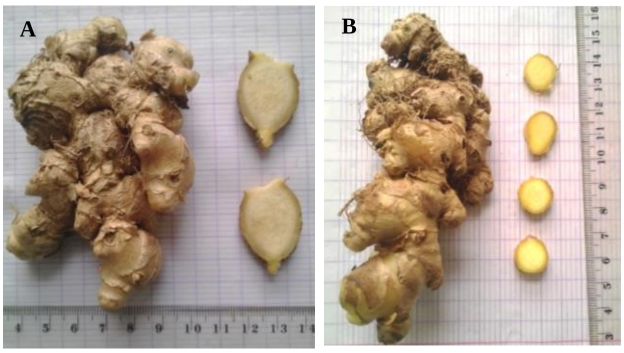


**Fig. 2**: Two varieties of ginger, (a) white-fleshed variety, (b) yellow-fleshed variety.

## Methods

### Analysis of Soil Samples and Poultry Droppings

Prior to the initiation of the experimental protocol, soil samples were collected from the designated test site and poultry excreta samples were obtained for analysis (S0). Five distinct locations on the trial site were selected for the collection of soil samples, which were then amalgamated to create a composite sample of 1.5 kilograms. These samples were then dried in an air-drying process, with the weight of the composite sample and the poultry droppings being recorded as a constant value. These samples were then sieved using a 2 mm diameter sieve. The powder obtained was then utilized for the chemical analysis of total nitrogen, iron, aluminium, lead, total phosphorus, sodium, potassium, magnesium, calcium, pH, carbon content and organic matter.

Total soil nitrogen is obtained by subjecting soil organic matter to hot mineralisation (300°C) in the presence of sulphuric acid, using the Kjeldahl method (Kjeldahl, 1981). pH values were measured directly using a pH meter with a soil/distilled water ratio of 1/2.5 (Thomas, 1996). The estimation of total phosphate content was conducted by means of UV visible spectrometry at a wavelength of 430nm. Minerals were measured by atomic absorption (SAA 700nm).

The Walkey and Black (1934) method was used to determine total carbon and organic matter levels. The principle of this method involves the oxidation of organic matter using potassium dichromate and concentrated sulphuric acid. The excess potassium dichromate is then measured using Mohr's salt.

## Setting up the Tests

### Preparation of the Experimental Plot

Preparation of the soil was initiated immediately following the onset of the first rainfall. This was due to the fact that the plant's edible portion (the rhizome) was located underground. The designated area was demarcated with stakes. The plot was then cleared by systematically destroying all the underground roots that could interfere with the development of the rhizomes. This was achieved using a daba and a machete. Each ridge measured 2 m² (2 m x 1 m).

### Seed Preparation and Sowing

The rhizomes obtained from the market were initially washed in tap water to remove clumps of soil and other impurities, and then left to dry in the shade for a period of four hours. The rhizomes were then cut into pieces measuring 3-5cm in length, with at least one viable 'eye' bud present to facilitate further development. Following this, the pieces were immersed in a solution comprising a blend of Furasol 5G (5g/L) and Mancozeb 880 WP (15g/L) for a duration of 30min. Thereafter, they were placed in a state of desiccation for 4 hours in a shaded environment, thereby enabling the seeds to absorb the phytosanitary solution. The rhizomes were then pre-germinated for a period of three weeks to allow the buds to develop. Following this, the sowing was conducted at a rate of one rhizome per planting, with a spacing of 30cm x 30cm. The rhizomes were sown with the buds facing the soil surface. The seedlings were sown to a depth of approximately 5cm. The seedlings were sown on ridges consisting of two rows. Each row comprised five clusters. This configuration yielded a total of 10 plants per treatment.

**Experimental Set-up**

The experimental design utilized was a completely randomized Fisher block design, with three replications. A plot measuring 360 m² (20m x 18m) was established, comprising three blocks. The spacing between two neighbouring blocks was 2m, and each block consisted of four ridges spaced 0.5 m apart.

**Formulation and Application of Fertilizers**

The fertilizer comprised poultry manure, mineral fertilizer (NPK 12-22-22) and a combination of poultry manure and mineral fertilizer (NPK 12-22-22), with a control group receiving no fertilizer. The four treatments were randomly allocated to the experimental units (ridges) within the three blocks.

The treatments were applied according to their formulation.

**Treatment 1: Organic Fertilizer**

The organic matter employed in this study was poultry manure composted for a minimum of three months. Following the composting process, the manure was dispersed at a rate of 5 kilograms per experimental unit and integrated with the soil on each designated plot. One week after the application of the compost, ginger rhizomes were sown.

**Treatment 2: Mineral Fertilizer**

The mineral fertilizer, NPK (composition 12-22-22), was administered at a rate of 10g per plant on the 45th and 90th days after emergence, using the ring method to avoid contact with the stem base of the plants. The mineral fertilizer was administered in a ring-shaped pattern around each plant (ring method) to avoid contact with the stem base of the plant.

**Treatment 3: A Combination of Organic and Mineral Fertilizers**

The poultry manure was subjected to a minimum of three months of composting. Following this, the compost was distributed at a rate of 5kg per experimental unit and incorporated into the soil on each designated plot. One week after the application of the manure, ginger rhizomes were sown. NPK mineral fertilizer with a composition of 12-22-22 was applied at a rate of 5g per plant on days 45 and 90 after emergence. The mineral fertilizer was applied in such a way as to avoid contact with stem base of the plants. The poultry manure was subjected to a minimum of three months of composting. Following the composting process, the manure was dispersed at a rate of 5kg per experimental unit and integrated into the soil on each designated plot. One week after spreading, the ginger rhizomes were sown. NPK mineral fertilizer with a composition of 12-22-22 was administered at a rate of the poultry manure was subjected to a minimum of three months of composting. Following this, the compost was distributed at a rate of 5kg per experimental unit and incorporated into the soil on each designated plot. One week after the application of the manure, ginger rhizomes were sown. NPK mineral fertilizer with a composition of 12-22-22 was applied at a rate of 5g per plant on days 45 and 90 after emergence. The mineral fertilizer was applied in such a way as to avoid contact with the stem base of the plants. The poultry manure was subjected to a minimum of three months of composting. Following the composting process, the manure was dispersed at a rate of 12-22-22 per experimental unit and integrated into the soil on each designated plot. One week after spreading, the ginger rhizomes were sown. NPK mineral fertilizer with a composition of 12-22-22 was administered at a rate of 5g per plant on days 45 and 90 after emergence. The mineral fertilizer was administered with the utmost care to avoid any contact with the plants' necks per plant on days 45 and 90 after emergence. The mineral fertilizer was administered with the utmost care to avoid any contact with the plants' stem base.

**Treatment 4: Control**

No fertilizer is applied.

**Assessment of Agromorphological Parameters of Seedlings**

The influence of the various treatments was assessed using agromorphological parameters. These were plant height (PH), number of leaves (NL), diameter at stem base (DS), number of tillers (NT), mean emergence time (MET), emergence delay (ED), emergence percentage (EP) and yield (YD) in tonnes/hectare.

**Emergence Parameters**

The emergence time is defined as the time required for the initial seedling to emerge. The calculation of the mean emergence time is achieved by determining the weighted mean of the emergence times. The calculation of the mean emergence time was performed utilizing the following formula:

$$ATE = \Sigma n.Jn / N$$

The variable n denotes the number of seedlings that have germinated on day D; the variable Jn denotes the number of days after sowing that n seedlings have germinated; and n is the total number of seedlings that have germinated.

The emergence percentage is indicative of the percentage for which rhizomes are likely to emerge throughout the crop.

$$\text{Percentage of emergence } (\mathbf{PE}) = \frac{\textit{Number of emerged plants}}{\textit{Total Number of rhizomes sown}} \boldsymbol{X100}$$

### Plant Vegetative Growth Parameters

The height of the plant is measured on the main shoot using a double tape measure from the collar to the v formed by the last two leaves. The measurement is expressed in centimetres (cm).

The number of leaves is counted on the main tillers.

The number of tillers is then calculated by subtracting the number of main tillers from the total number of tillers. This calculation provides the number of tillers per plant.

The diameter at the stem base is measured at the collar of the bead using a calliper on the main bead. The measurement is expressed in mm.

### Yield Parameters

The fresh weight of rhizomes per plant is defined as the mass of rhizomes from each plant that is weighed after harvesting. This measurement is expressed in grams (g). The yield per hectare for each treatment is defined as the weight per area of the experimental units. The total yield was calculated using the following formula:

$$\text{Yield (t/ha)} = \frac{\text{Production (t)}}{\text{Area (ha)}}$$

### Statistical Analysis

Statistical analysis of the data was conducted using STATISTICA version 7.1 software for all experiments. A two-factor analysis of variance (ANOVA II) was employed to examine the overall effect of the various factors and their interactions on the parameters under investigation. The objective of this analysis was to identify significant differences between the various types of fertilizer and the parameters under investigation. When a significant difference was observed ($P<0.05$), Tukey's multiple rank test at the 5% threshold was adopted to separate the means.

## RESULTS

### Physico-chemical Analysis of Soil, Poultry Manure and Mineral Fertilizer

The findings of the soil and poultry manure analyses are presented in Table 1. The mineral fertilizer was found to contain higher levels of nitrogen, phosphorus and potassium in comparison to the organic fertilizer (poultry manure) and crop soil. The mineral fertilizer exhibited levels of 12, 22 and 22% for nitrogen, phosphorus and potassium, respectively. In comparison, the organic manure exhibited levels of 2.63, 4.374 and 5.373%, while the cultivated soil exhibited levels of 0.42, 0.088 and 0.18%, respectively. The organic matter found in the poultry manure (66.05%) is higher than that found in the cultivated soil (6.94%). The organic carbon content of the former was higher (24.05%) than that of the latter (4.03%). Conversely, the sodium and magnesium content of the soil was found to be higher (0.56 and 0.28%) than that of the poultry manure, which was lower (0.01 and 0.01%). Poultry manure exhibited a markedly elevated calcium content (43.78%) in comparison with cultivated soil. The pH value obtained indicates that the crop soil and manure have a slightly acidic pH of 5.85 and 6.50, respectively. The absence of iron and aluminium in the soil is notable, while the poultry droppings exhibited concentrations of 21.58 meq/g and 0.01% of iron and aluminium, respectively.

**Table 1:** Chemical composition of cultivation soil and fertilizers

| Composition | Soil analysis | Poultry manure | Mineral fertilizer |
|---|---|---|---|
| Organic matter (%) | 6.94 | 66.05 | - |
| Organic carbon (%) | 4.03 | 24.05 | - |
| Nitrogen (%) | 0.42 | 2.63 | 12 |
| Calcium (%) | 0.03 | 43.78 | - |
| Sodium (%) | 0.56 | 0.01 | - |
| Potassium (%) | 0.18 | 5.37 | 22 |
| Phosphorus (%) | 0.09 | 4.37 | 22 |
| Magnesium (%) | 0.28 | 0.01 | - |
| Lead (meq/g) | 0.00 | 0.12 | |
| Aluminum (%) | - | 0.01 | - |
| Iron (meq/g) | - | 21.58 | - |
| pH | 5.85 | 6.50 | - |

### Effect of Organic and Mineral Fertilization on the Emergence of Ginger Plants

The results of the experiment are summarized in Table 2. Statistical analysis revealed no statistical differences in emergence time, mean emergence time and shoot emergence percentage ($P>0.05$) between the ginger varieties used.

The emergence time of ginger plants was found to be between 12 and 13 days after sowing, irrespective of the variety of ginger and the type of fertilizer employed. In the white-fleshed variety, rhizomes fertilized with organic fertilizer and the combination of organic and mineral fertilizer had an average emergence time of 17 days, with 95% of plants emerging. In contrast, mineral fertilization (NPK 12-22-22) and the control group exhibited an average emergence time of 19 days, with 87% of plants emerging for the NPK and 85% for the control. For the yellow-fleshed variety, the average emergence time was 18 days after sowing, irrespective of the fertilizer type. The percentage of seedling emergence for this ginger variety ranged from 84 to 94%.

### Effect of Fertilization on Ginger Growth Parameters

The experimental values of the ginger growth parameters obtained are presented in Table 3.

### Plant Height

A subsequent analysis of variance of ginger plant height growth revealed a significant difference in the interaction between varieties and fertilizer type ($P<0.001$) (Table 3). In the white-fleshed variety, plants treated with the combination of organic and mineral fertilizers exhibited the greatest increase in height (63.46cm), followed by the organic fertilizer (53.35cm), in comparison to plants fertilized with the mineral fertilizer (36.94cm) and the control (27.02cm). For the yellow-fleshed variety, the combination of organic and mineral fertilizers and organic fertilization alone resulted in plant heights of 54.58cm and 50.08cm, respectively, compared with 43.96cm for mineral fertilization and 26.73cm for the control.

### Number of Sheets

A subsequent analysis of variance revealed a highly significant difference in the number of leaves between fertilizers and varieties ($P<0.001$) (Table 3). The final number of leaves on the yellow-fleshed and white-fleshed varieties ranged from 15 to 25. In the white-fleshed variety, plants fertilized with a combination of organic and mineral

**Table 2:** Emergence parameters of ginger plants in relation to the type of fertilizer

| Variables | | Time to emergence (JAS) | Mean emergence time (MET) | Emergence percentage (%) |
|---|---|---|---|---|
| White flesh | Fertilizer + NPK | 12.11±1.05 | 17.65±5.77 | 95.56±5.27 |
| | Manure | 12.11±1.05 | 17.81±5.87 | 95.56±5.27 |
| | NPK | 13.78±2.23 | 19.08±6.54 | 85.56±8.82 |
| | Witness | 13.78±1.39 | 19.22±6.19 | 87.78±8.33 |
| Yellow chair | Fertilizer + NPK | 12.67±1.41 | 18.00±6.26 | 94.44±8.82 |
| | Manure | 12.56±1.94 | 18.64±5.43 | 94.44±7.26 |
| | NPK | 13.44±1.67 | 18.19±4.80 | 84.44±14.24 |
| | Witness | 13.89±1.45 | 18.46±5.43 | 84.44±7.26 |
| P-value | | 0.83 | 0.48 | 0.97 |

In a column, the averages followed by the same letters are not significantly different at the 5% threshold (Tukey test). Control with no fertilizer applied; NPK: Mineral fertilizer treatment (NPK 12-22-22); manure: Poultry manure treatment; manure+NPK: Combination of poultry manure and mineral fertilizer

**Table 3:** Growth parameters of ginger plants in relation to fertilizer application

| Treatment | | Plant height | Number of leaves | Number of tillers | Neck diameter |
|---|---|---|---|---|---|
| White flesh | Fertilizer + NPK | 63.46±12.29 $^{a}$ | 25.56±3.83 $^{a}$ | 20.22±9.67 $^{ab}$ | 8.47±1.08 $^{a}$ |
| | Manure | 53.35±13.43 $^{b}$ | 22.14±4.15 $^{b}$ | 16.75±6.11 $^{bc}$ | 8.40±1.07 $^{a}$ |
| | NPK | 36.94±13.98 $^{d}$ | 18.00±4.98 $^{c}$ | 13.04±9.95 $^{c}$ | 6.45±1.76 $^{abc}$ |
| | Witness | 27.02±11.19 $^{e}$ | 15.91±4.30 $^{c}$ | 5.45±4.48 $^{d}$ | 5.66±1.19 $^{bc}$ |
| Yellow chair | Fertilizer + NPK | 54.58±12.57 $^{b}$ | 23.04±3.5 $^{ab}$ | 22.04±11.68 $^{a}$ | 7.80±1.15 $^{ab}$ |
| | Manure | 50.08±12.9 $^{bc}$ | 22.11±4.10 $^{b}$ | 15.38±7.49 $^{bc}$ | 7.81±1.27 $^{ab}$ |
| | NPK | 43.96±10.3 $^{cd}$ | 20.60±3.89 $^{b}$ | 14.31±7.93 $^{c}$ | 8.10±9.48 $^{a}$ |
| | Witness | 26.73±7.46 $^{e}$ | 15.89±3.23 $^{c}$ | 4.87±3.03 $^{d}$ | 5.47± 0.97 $^{c}$ |
| P-value | | < 0.001 | < 0.001 | < 0.001 | < 0.001 |

In a column, the averages followed by the same letters are not significantly different at the 5% threshold (Tukey test). Control with no fertilizer applied; NPK: Mineral fertilizer treatment (NPK 12-22-22); manure: Poultry manure treatment; manure+NPK: Combination of poultry manure and mineral fertilizer

fertilizers exhibited a greater number of leaves (25 leaves) in comparison to plants fertilized with organic fertilizers alone (22 leaves). Conversely, plants fertilized with mineral fertilizer exhibited a reduction in leaf number, with an average of 18 leaves recorded, in comparison to the control, which exhibited an average of 15 leaves. For the yellow-fleshed variety, mineral fertilization, organic fertilization, and a combination of organic and mineral fertilization produced 20 leaves, 22 leaves, and 23 leaves per plant, respectively, compared with 15 leaves for the control.

### Number of Tillers per Plant

A subsequent analysis of variance revealed a highly significant difference (P<0.001) in the number of tillers between fertilizers and varieties (Table 3). The mean number of final tillers in the two varieties ranged from 4 to 22 tillers per plant. The combination of organic and mineral fertilizers resulted in the greatest number of tillers (22). Furthermore, the organic and mineral fertilizers produced an average of 15 and 14 tillers, respectively, compared with 4 tillers for the control in the yellow-fleshed variety. In the case of the white-fleshed variety, the combination of organic and mineral fertilizers resulted in a high number of tillers (20 tillers). In the case of the white-fleshed variety, plants fertilized with a combination of organic and mineral fertilizers produced an average of 16 tillers, while plants fertilized with inorganic fertilizers produced an average of 13 tillers.

### Diameter at Plant Stem Base

The two-factor analysis of variance demonstrated that the interaction between variety and fertilizer exerted a significant influence on diameter at stem base (P<0.001) (Table 3). In the case of the white-fleshed variety, the combination of organic and mineral fertilizers, as well as the organic fertilizer, favored a large diameter at plant stem base (8mm diameter). Conversely, the mineral fertilization and the control treatments resulted in diameters of 6mm and 5mm, respectively. In the case of the yellow-fleshed variety, mineral fertilization resulted in a large diameter at plant stem base (8mm). Conversely, the application of organic fertilization, in conjunction with either organic or mineral fertilization, yielded an average diameter of 7mm, while the control group exhibited an average diameter of 5 mm.

### Effect of Fertilizer Type on Ginger Rhizome Yield Parameters

As illustrated in Table 4, the fresh weight of rhizomes per ginger plant was determined following the application of diverse fertilizer types. Analysis of variance revealed a significant difference in rhizome fresh weight (P<0.001) between fertilizers. Furthermore, the analysis of variance also revealed a significant difference in rhizome fresh weight (P<0.001) between varieties. The white-fleshed variety exhibited a higher rhizome fresh weight with the combined use of organic and mineral fertilizers (255.90g), followed by organic and mineral fertilizers (198.21 g) and the control (107 g). For the yellow-fleshed variety, the combination of organic and mineral fertilizers produced a fresh weight of 221.56g. The latter yielded 172.88g and 136.07g, respectively, while the control yielded 97.03g. The results demonstrate that the utilization of fertilizers enhances yields. The average yield of ginger rhizomes exhibited a range from 4.85 to 12.79t/ha. For the white-fleshed variety, the highest yield was obtained with the combined use of organic and mineral fertilizers (12.79t/ha), followed by organic and mineral fertilizers (9.91 and 6.66t/ha respectively) and the control (5.35t/ha). For the ginger variety with yellow-fleshed rhizomes, the combination of organic and mineral fertilizers yielded the greatest results, with an average of 11.09t/ha. In contrast, the combination of organic and mineral fertilization yielded an average of 8.64 and 6.80t/ha, respectively, as compared to the control, which exhibited a low yield of 4.85t/ha.

**Table 4:** Average weight and yield of rhizomes from plants of yellow- and white-fleshed ginger varieties subjected to organic and mineral treatments

| Treatment | | Fresh weight of rhizomes per plant (g) | Yield per hectare (t/ha) |
|---|---|---|---|
| White flesh | Fertilizer + NPK | 255.90±7.78 [a] | 12.79 |
| | Manure | 198.21±7.71 [c] | 9.91 |
| | NPK | 133.39±9.50 [of] | 6.66 |
| | Witness | 107.00±10.72 [ef] | 5.35 |
| Yellow chair | Fertilizer + NPK | 221.56±8.75 [b] | 11.09 |
| | Manure | 172.88±8.82 [c] | 8.64 |
| | NPK | 136.07±9.04 [d] | 6.8 |
| | Witness | 97.03±10.75 [f] | 4.85 |
| P-value | | < 0.001 | |

In a column, the averages followed by the same letters are not significantly different at the 5% threshold (Tukey test); Control with no fertilizer applied ; NPK : Mineral fertilizer treatment (NPK 12-22-22); manure: Poultry manure treatment; manure+NPK: Combination of poultry manure and mineral fertilizer.

## DISCUSSION

This study examined the impact of organic and mineral fertilizers on the yield components of two varieties of ginger (white flesh and yellow flesh). The analysis of the plot soil and poultry manure revealed that both substrates have low acidity, with pH values of 5.85 and 6.50, respectively. The analysis of the poultry manure showed high levels of organic matter (66.05%), organic carbon (24.05%), calcium (43.78%), iron (21.58%), phosphorus (4.37%), potassium (5.37%) and nitrogen (2.63%), in contrast to the soil analysis, which showed low levels of mineral elements. This discrepancy could be attributed to the potential richness of the manure in specific mineral elements. The presence of a high organic matter content in the manure could stimulate the activity of micro-organisms responsible for the solubilization of nutrients. The nutrients are then utilized by the ginger plants over time. According to Mawlong et al. (2020), it is essential to study how integrated nutrient management regimes affect the biochemical and microbiological characteristics of soils.

The analysis of the cultivation soil indicates that it is poor in quality and not very suitable for the purpose of plant production. The utilization of poultry manure is thus proposed as a means of enhancing the availability of mineral salts, thereby addressing the nutrient deficiencies experienced by ginger plants. The experiment was conducted to assess the effectiveness of the fertilizers over time. A number of agronomic and morphological parameters were used to evaluate this effectiveness, including time to emergence, percentage of emergence, average time to emergence, number of leaves, diameter at the crown, number of tillers, plant height, yield per plant and yield per hectare. The application of fertilizers showed no significant effect ($P>0.05$) on the emergence parameters of ginger seedlings, regardless of the variety used. This outcome can be attributed to the pre-germination of the rhizomes for a period of three weeks prior to sowing, a process that has been demonstrated to promote accelerated emergence and a high percentage. This is similar to the findings of Sangaré et al. (2024) who had a better germination percentage and emergence of *Garcinia kola*. The possible fact for better percent germination by priming may be that it stimulates series of biochemical changes in the seed that are essential to initiate the emergence process like break down dormancy. The effectiveness of the fertilizers employed during the experiment was evaluated in terms of several agronomic parameters. The application of fertilizers, categorized as mineral or organic, resulted in an enhancement of plant height, plant collar diameter, leaf number, and the number of plant tillers. Furthermore, the study demonstrated that the combination of organic fertilizer (poultry manure) and mineral fertilizer (NPK 12-22-22) exhibited a highly favorable impact on the growth parameters evaluated. Poultry manure applied alone and mineral fertilizer (NPK 12-22-22) applied alone also had a favorable effect on growth parameters. All types of fertilizer exhibited superior performance in comparison to the control (i.e. the absence of fertilization) across all parameters. This phenomenon can be ascribed to the disparate nutrient content of the poultry manure and the mineral fertilizer. Indeed, according to Nair (2019), organic manure combined with mineral fertilizer improves the efficiency of mineral fertilizers, as these combinations make plant growth elements such as phosphorus, potassium and nitrogen more available. The results of the physico-chemical analysis of the poultry manure showed this. The results of the experiment demonstrated that plant growth was positively correlated with fertilizer application, suggesting that the fertilizers promoted increased nutrient uptake by the ginger plants. Jabborova et al (2020) reported the positive effect of organic manure amendment on soybean uptake of plant nutrients. They have shown that the addition of organic manure plays a vital role in increasing the soil microbial activity that provides more nutrition to the plant. The addition of organic manure can induce changes in nutrient availability and may provide additional N, P and K. The application of organic and mineral fertilizers resulted in a marked improvement in the overall yield of ginger plants. For the white-fleshed ginger variety, the combination of organic and mineral fertilizers yielded the highest result of 12.79t/ha, followed by organic fertilizer alone at 9.91t/ha, which is well above the average yield of ginger growers in Côte d'Ivoire. The application of mineral fertilizer alone, in comparison with the control, yielded 6.66t/ha, while the application of organic fertilizer alone yielded 5.35t/ha.

In the yellow-fleshed ginger variety, the highest yield was also obtained with the combined application of organic and mineral fertilizer, at 11.09t/ha, followed by organic fertilizer alone, which gave 8.64t/ha. The single application of mineral fertilizer and the control yielded 6.8t/ha and 4.85t/ha, respectively. The observed increase in yields of fresh ginger rhizomes when mineral and organic fertilizers were applied together, or when organic and mineral fertilizers were applied alone, is hypothesized to be due to greater availability of mineral elements for the plants. This pattern of yield increase due to fertilizer application (organic, mineral) is similar to that of some earlier studies, in particular those by Das et al. (2020) and Fei et al. (2024). According to these authors, inorganic fertilizers providing readily available nutrients during the early stages of growth and organic fertilizers slowly releasing nutrients throughout the growth period, resulting in better growth, increased yield components and greater ginger rhizome production.

In addition, the organic manure component of the soil amendment in inorganic fertilizer and organic manure mixtures mineralizes over time, ensuring greater nutrient accumulation and consequently higher growth and development of ginger plants and maximum yield (Srinivasan et al., 2019; Shang et al., 2025).

### Conclusion

The objective of the experimental study was to ascertain the most efficacious fertilizer type (organic, mineral, or a combination of organic and mineral) for the cultivation of rhizomes of the white-fleshed and yellow-fleshed varieties of ginger. The utilization of fertilizers is of paramount importance, particularly in light of the low levels of nitrogen, phosphorus, potassium and organic matter in the soil. The study's findings indicated that the combination of organic and mineral fertilizers was highly effective in promoting growth and yield parameters in both ginger varieties. The findings indicate that the integrated application of organic and mineral fertilizers yielded the highest productivity, with 12.79 t/ha of rhizome, followed by organic fertilizers alone at 9.91 t/ha. This is in comparison to the yields of 6.66 and 5.35t/ha obtained with mineral fertilizer and the control, respectively, in the white-fleshed variety. For the yellow-fleshed variety, the highest yield was obtained with the organic and mineral combination, which gave 11.09t/ha, followed by the organic fertilizer with 8.64t/ha. The mineral fertilizer and the control gave 6.8 and 4.85 t/ha, respectively. These results indicate that a combination of organic manure and mineral fertilizer is paramount for achieving optimal soil fertility management and enhancing agricultural productivity.

## DECLARATIONS

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**Conflict of Interest:** The authors declare no conflicts of interest regarding the publication of this paper.

**Data Availability:** All the data is available in the article.

**Ethics Statement:** This research does not require ethical review because it does not involve data with human or animal subjects.

**Author's Contribution:** KM conceived and designed the experiment. YS performed the study and conducted lab analyses. KL-C and KM supervised and coordinated the experiments. KBAS and GYG performed statistical analyses of experimental data. YS, KL-C and GYG prepared the draft of the manuscript. All authors critically revised the manuscript and approved the final version.

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