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OPTIMISING EGGPLANT-COWPEA INTERCROPPING PRODUCTIVITY USING INTEGRATED SOIL FERTILITY MANAGEMENT IN CÔTE D'IVOIRE

OPTIMISATION DE LA PRODUCTIVITÉ DE L'ASSOCIATION CULTURALE AUBERGINE-NIÉBÉ PAR LA GESTION INTÉGRÉE DE LA FERTILITÉ DES SOLS EN CÔTE D'IVOIRE

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ABSTRACT

African eggplant (*Solanum aethiopicum* L.) is an important vegetable crop in West Africa, contributing to nutritional security and household incomes. However, its productivity remains constrained by declining soil fertility, particularly in tropical farming systems. Intercropping with legumes such as cowpea (*Vigna unguiculata*) is considered a promising strategy for improving system performance, notably through biological nitrogen fixation (BNF) and more efficient use of resources including light, water and soil nutrients. The objective of this study was to improve eggplant production through the implementation of Integrated Soil Fertility Management (ISFM) in eggplant–cowpea intercropping systems in Côte d'Ivoire. A field experiment was conducted during May to October, 2023. Treatments included two cropping systems (mono-cropping and inter-cropping with cowpea); and seven fertilisation treatments, including an unfertilised control, organic inputs (solid and liquid compost), mineral fertilisation at the recommended rates, and integrated treatments combining compost(s) with half the recommended mineral fertiliser rate, corresponding to ISFM practices. The study was laid out in a split-plot design with three replications. Results showed that ISFM treatments significantly improved ($P < 0.05$) eggplant yield, with maximum values of 15.57 t ha^{-1} in mono-cropping and 8.55 t ha^{-1} in inter-cropping systems ($P < 0.001$). Although eggplant yield decreased under inter-cropping likely due to interspecific competition, integrated fertilisation treatments improved overall system

productivity, as reflected by the highest Area Equivalent Yield (AEY) (15.92 t ha^{-1}) and nitrogen input (166 kg N ha^{-1}) obtained under treatments combining organic and mineral inputs. These findings suggest that cowpea integration contributed to biomass production and nitrogen input, which may have supported improved system performance under intercropping conditions. Among the integrated treatments, the combination of solid compost with half the recommended mineral fertiliser rate, showed a favourable balance between eggplant yield and overall system productivity, with the highest eggplant yield under inter-cropping and an AEY statistically comparable to the highest AEY value. Overall, the results indicate that integrating organic amendments with reduced mineral fertiliser rates in eggplant–cowpea inter-cropping systems can improve crop productivity and nitrogen input under tropical farming conditions.

Key Words: Area Equivalent Yield, *Solanum aethiopicum*, *Vigna unguiculata*

RÉSUMÉ

L'aubergine africaine (*Solanum aethiopicum* L.) est une culture maraîchère importante en Afrique de l'Ouest, contribuant à la sécurité nutritionnelle et aux revenus des ménages. Cependant, sa productivité demeure limitée par la baisse de la fertilité des sols dans les systèmes agricoles tropicaux. La culture associée avec des légumineuses telles que le niébé (*Vigna unguiculata*) est considérée comme une stratégie prometteuse pour améliorer les performances du système, notamment grâce à la fixation biologique de l'azote et à une utilisation plus efficace des ressources telles que la lumière, l'eau et les nutriments du sol. Dans ce contexte, l'objectif de cette étude était d'améliorer la production d'aubergine à travers la mise en œuvre de la Gestion Intégrée de la Fertilité des Sols (GIFS) dans des systèmes de culture associée aubergine–niébé en Côte d'Ivoire. Une expérimentation au champ a été conduite en 2023, de mai à octobre. Les traitements comprenaient deux systèmes de culture (culture pure et culture associée avec le niébé) et sept traitements de fertilisation, incluant un témoin sans fertilisation, des apports organiques (compost solide et liquide), une fertilisation minérale à la dose recommandée, ainsi que des traitements intégrés combinant un ou plusieurs composts avec la moitié de la dose recommandée d'engrais minéral, correspondant aux pratiques de GIFS. L'étude a été conduite selon un dispositif en split-plot avec trois répétitions. Les résultats ont montré que les traitements GIFS ont significativement amélioré ($P < 0,05$) le rendement de l'aubergine, avec des valeurs maximales de 15,57 t ha^{-1} en culture pure et de 8,55 t ha^{-1} en culture associée ($P < 0,001$). Bien que le rendement de l'aubergine ait diminué en culture associée en raison de la compétition interspécifique, les traitements de fertilisation intégrée ont amélioré la productivité globale du système, comme l'indiquent les valeurs les plus élevées du rendement équivalent en surface (15,92 t ha^{-1}) et de l'apport en azote (166 kg N ha^{-1}) obtenues sous les traitements combinant des apports organiques et minéraux. Ces résultats suggèrent que l'intégration du niébé a contribué à la production de biomasse et à l'apport en azote, ce qui pourrait avoir favorisé une amélioration des performances du système en culture associée. Parmi les traitements intégrés, la combinaison du compost solide avec la demi-dose recommandée d'engrais minéral a montré un équilibre favorable entre le rendement de l'aubergine et la productivité globale du système, avec le rendement d'aubergine le plus élevé en culture associée et un AEY statistiquement comparable à la valeur d'AEY la plus élevée. Dans l'ensemble, les résultats indiquent que l'intégration d'amendements organiques avec des doses réduites d'engrais minéraux dans les systèmes de culture associée aubergine–niébé peut améliorer la productivité des cultures et l'apport en azote dans les conditions agricoles tropicales.

Mots Clés : rendement équivalent en surface, *Solanum aethiopicum*, *Vigna unguiculata*

INTRODUCTION

African eggplant (*Solanum aethiopicum* L.) is a major vegetable crop in West Africa, contributing to nutritional security by providing essential micronutrients and diversifying household incomes through its market value (Doss, 2018; FAO, 2020). It is cultivated across diverse agroecological zones, either as a sole crop or in association with food legumes such as cowpea (*Vigna unguiculata*) (Moustier and Danso, 2006). This intercropping system presents significant agronomic interest because cowpea is well adapted to low-input conditions and contributes to biomass production and nutrient recycling, which may improve resource-use efficiency within the cropping system (Brooker *et al*., 2015; Kermah *et al*., 2017). The complementarity between associated species enhances utilisation of light, water and soil nutrients, leading to increased overall system productivity (Zhang *et al*., 2020). In addition, African eggplant includes several varieties, including the local variety Ngoyo, which is widely appreciated for its nutritional and therapeutic properties (Schippers, 2000; Adeniji *et al*., 2013).

Despite its nutritional and socio-economic importance, African eggplant production is declining despite increasing consumption trends. This situation results from a combination of biophysical and socio-economic constraints. Among these, low soil fertility, pest and disease pressure, and erratic rainfall patterns are particularly important (Thornton *et al*., 2014). Tropical agricultural soils are generally acidic, nutrient depleted and low in organic matter due to continuous cultivation; and use of mineral fertilisers and conventional pesticides (Bationo *et al*., 2012). Furthermore, the low productivity and high susceptibility of some traditional varieties to pests and diseases, have prompted farmers to adopt improved varieties (Fuglie *et al*., 2021). However, this shift in practice is likely to ontribute to the erosion of local genetic resources if not properly managed.

To address these constraints, several approaches have been proposed to improve crop productivity. Some strategies rely on the exclusive use of mineral fertilisers in conventional agriculture; whereas others promote organic amendments in organic farming systems. However, although organic fertilisation improves soil biological properties, it is characterised by low nutrient endowment and slow mineralisation, which may limit its ability to satisfy the nutrient requirements of short-cycle crops such as eggplants (Lazcano *et al*., 2013). Conversely, the inappropriate use of mineral fertilisers, in addition to their prohibitively high cost for smallholder farmers, may contribute to the degradation of natural resources such as soil, water, and biodiversity (Damalas and Koutroubas, 2016).

In this context, an integrated approach combining different nutrient sources and adapted to local conditions is required to improve agricultural productivity sustainably. Integrated Soil Fertility Management (ISFM) has been widely recognised as a key strategy for improving agricultural productivity in sub-Saharan Africa (Vanlauwe *et al*., 2014). This approach is based on four key principles; namel (i) the use of improved varieties, (ii) the application of organic resources such as compost, green manures; and legume residues; combined with (iii) the judicious use of mineral fertilisers, and (iv) the adaptation of practices to local conditions (Bationo *et al*., 2012; Vanlauwe *et al*., 2014). Within this framework, legume-based inter-cropping systems may complement ISFM practices by enhancing biomass production and improving overall system performance (Pretty *et al*., 2018).

Despite these advances, the performance of ISFM in vegetable-based inter-cropping systems remains insufficiently documented. In particular, the interactions between organic and mineral inputs within ISFM and legume-based intercropping systems remain poorly understood, especially regarding their combined effects on crop productivity under tropical conditions (Vanlauwe *et al*., 2015; Pretty *et al*., 2018). Therefore, the objective

of this study was to improve eggplant production through the implementation of Integrated Soil Fertility Management (ISFM) in eggplant-cowpea intercropping systems in Côte d'Ivoire.

MATERIALS AND METHODS

Study site description. This study was conducted during May to October, 2023 in the city of Korhogo (northern Côte d'Ivoire), within the vegetable experimental field of Péléforo Gon Coulibaly University. The site is located at 9.43° N latitude, 5.63° W longitude, and at an altitude of 374 m above sea level. The climate of the area is of the Sudano-Guinean type, characterised by a dry season from November to April and a rainy season from May to October. This region is marked by rainfall variability and increasing temperature trends typical of West African tropical climates (Nicholson, 2013; Worou *et al*., 2023). Mean annual rainfall ranges between 1100 and 1600 mm, with a mean annual temperature of approximately 27°C.

The natural vegetation is dominated by savanna ecosystems characteristic of the Sudano-Guinean transition zone. The soils are classified as Ferralitic soils (Ferralsols), which are highly weathered and characterised by low nutrient reserves and limited cation exchange capacity (IUSS Working Group WRB, 2015).

Plant material. The plant materials used in this study consisted of a traditional African eggplant variety (Ngoyo) and an improved cowpea variety (Touba); the latter used as companion crops in the intercropping system. The Touba variety was obtained from the National Agronomic Research Center (CNRA) and selected based on its high grain yield potential and ability to produce nitrogen-rich biomass. It is also characterised by an upright growth habit, making it suitable for intercropping systems.

Selection of the eggplant variety Ngoyo was based on its high nutritional value and recognised medicinal properties, reported in both traditional uses and scientific studies (Han *et al*., 2021; Choi *et al*., 2024), as well as its relative rarity in current production systems.

Treatments and experimental design. Treatments included two cropping systems: (i) eggplant mono-cropping and (ii) eggplant–cowpea inter-cropping. Fertiliser treatments consisted of: (i) control without fertiliser (T0), (ii) solid organic compost (T1), (iii) liquid organic compost (T2), (iv) mineral fertiliser at the recommended rate (T3), (v) solid compost + half the recommended mineral fertiliser rate (T4), (vi) liquid compost + half the recommended mineral fertiliser rate (T5), and (vii) solid compost + liquid compost + half the recommended mineral fertiliser rate (T6).

The experiment was laid out in a split-plot design with two factors and three randomised blocks as replications. The cropping system constituted the main plot treatment, whereas fertiliser combinations constituted the subplot treatments.

The experimental setup consisted of three blocks and two sub-blocks per block. Each sub-block represented one cropping system (mono-cropping or inter-cropping); while seven unit plots within each sub-block were randomly assigned to the fertiliser treatments. Adjacent blocks were separated by 1 m wide paths. Each unit plot measured 2 m x 3 m, whereas each block measured 5 m x 27 m. The entire experimental area covered 19 m x 27 m.

Preparation of solid organic compost. The solid organic fertiliser consisted of a mixture of cattle manure and plant residues composted over a period of three months. The compost was prepared by stacking alternating layers of cattle manure and plant residues, each layer being approximately 20 cm thick. Dry leaves were incorporated at an average rate of 10 kg per 100 kg of cattle manure over a surface area of approximately 1 m², with about three successive layers of each component. Plant residues consisted mainly of dry leaves, stems,

and crop residues collected from vegetation available near the composting site. The cattle manure also contained agricultural by-products derived from livestock feed.

The plant materials were moistened using well water, including a solution prepared from wood ash and biologically active soil. These components were added to reduce acidity, repel termites, and enhance microbial decomposition of organic matter (Bernal *et al*., 2009).

The compost heap was covered with a black plastic sheet to conserve heat and promote microbial activity. Moisture, temperature and pH were monitored weekly using a hygrometer, compost thermometer and pH meter, respectively; to ensure proper progression of the composting process. Whenever moisture levels were insufficient, the compost heap was water-sparyed and covered again to maintain optimal conditions. The compost heap was turned every two weeks to ensure adequate aeration by bringing the upper layers to the bottom and adding water when necessary.

Compost maturity was assessed using physical and chemical indicators. Compost temperature, initially elevated during the active decomposition phase, gradually decreased until reaching ambient temperature. At maturity, the compost no longer emitted ammonia or urine-like odours and developed an earthy smell. The pH ranged between 6 and 8, and the C/N ratio was 23.32.

Preparation of liquid organic compost. The liquid organic fertiliser was prepared using cattle manure and fresh neem (*Azadirachta indica*) leaves. Cattle manure was collected from grazing areas where urine and solid excreta were naturally mixed. Approximately 50-60 kg of dried cattle manure and 15-20 kg of fresh neem leaves were introduced into a 200 L metal barrel. The dried cattle manure was mixed with fresh neem leaves, wood ash, biologically active soil, and water to produce a liquid extract. The addition of wood ash and biologically active soil helped moderate acidity and promote microbial activity (Bernal *et al*., 2009).

The barrel was sealed hermetically during the first three days of fermentation and then kept partially covered for the remainder of the fermentation period. The mixture was stirred daily for 15 days to ensure homogenisation and stimulate microbial activity. After fermentation and filtration, a liquid organic fertiliser suitable for field application was obtained.

Crop settings. In each experimental unit plot, 30-day-old eggplant seedlings produced in the nursery were transplanted in six rows under both cropping systems (mono-cropping and inter-cropping). Eggplant plants were spaced at 60 cm × 50 cm, corresponding to a planting density of 33,000 plants ha^{-1}.

In the inter-cropping system, cowpea was sown 15 days after eggplant transplanting in order to reduce early-stage interspecific competition and allow proper establishment of eggplant plants. Cowpea spacing was 25 cm x 30 cm, corresponding to a planting density of 133,000 plants ha^{-1}.

Application of fertilisers. Solid organic compost was applied as a basal dressing at a rate of 10 t ha^{-1} (equivalent to 6 kg per unit plot) for treatments T1 (solid compost), T4 (solid compost + half mineral fertiliser), and T6 (solid compost + liquid compost + half mineral fertiliser).

Liquid compost was used as a foliar fertiliser after filtration to remove residues. Before application, it was diluted by mixing 0.4 L of liquid compost with 9.6 L of water to avoid salt injury to seedlings. The diluted solution was applied at a rate of 10 L per unit plot for treatments containing liquid organic fertiliser using a Tropica 16 L knapsack sprayer. Applications were carried out at the vegetative stage (10 days after planting) and at the flowering stage (30 days after planting). Mineral fertilisers were applied at the recommended rate of 400 kg NPK ha^{-1} and 200 kg calcium nitrate ha^{-1} for treatment T3,

and at half rate (200 kg NPK ha^{-1} and 100 kg calcium nitrate ha^{-1}) for treatments T4, T5, and T6.

Mineral fertiliser application was split, with two-thirds applied as basal dressing (267 kg NPK ha^{-1} and 134 kg calcium nitrate ha^{-1}) and the remaining one-third (133 kg NPK ha^{-1} and 66 kg calcium nitrate ha^{-1}) applied at the flowering stage. All fertilisers (organic and mineral) were uniformly applied over the entire unit plot area to ensure homogeneous nutrient distribution within the eggplant-cowpea intercropping system and maintain comparable conditions among treatments. This approach was adopted to reflect local farmer practices commonly used under smallholder farming conditions in the study area.

Soil and compost analysis. The chemical properties of the experimental soil and organic fertilisers (solid and liquid compost) were determined before implementation of the experiment (Table I).

Soil samples were collected at a depth of 0-20 cm before plot demarcation, using an auger, along the diagonals of the experimental field. Composite soil samples were air-dried at room temperature (25-30 °C), ground, and sieved through a 2 mm mesh before analysis. The processed samples were prepared according to the operational procedures of the Institut National Polytechnique Félix Houphouët-Boigny (INP-HB).

Soil and plant analyses were performed using standard laboratory procedures. Soil organic carbon and total nitrogen were determined by dry combustion using a carbon–nitrogen analyser.

For solid compost and cowpea residues, organic carbon and total nitrogen were determined using the methods of Walkley and Black (1934) and Kjeldahl (1883), respectively; whereas mineral elements were analysed using a portable X-ray fluorescence spectrometer (pXRF).

Liquid compost was analysed at the ENVAL laboratory using standardised ISO and NF analytical methods. The C/N ratio of soil and compost was calculated to assess nitrogen availability.

TABLE I. Chemical properties of soil (0-20 cm) and applied organic fertilisers prior to implementing the study

Chemical parameters	Soil	Solid compost	Liquid compost
pH	5.0	6.24	8.21
C	0.70 %	431.1 g kg^{-1}	9.0 g L^{-1}
N	0.06 %	18.1 g kg^{-1}	0.8 g L^{-1}
C/N	11.7	23.82	11.25
P	4.1 mg kg^{-1}	1.1 g kg^{-1}	10.2 mg L^{-1}
K	0.078 cmol kg^{-1}	2.5 g kg^{-1}	3.7 g L^{-1}
Ca	0.442 cmol kg^{-1}	8.4 g kg^{-1}	0.06 g L^{-1}
Mg	0.346 cmol kg^{-1}	0.5 g kg^{-1}	0.6 g L^{-1}
Na	0.136 cmol kg^{-1}	-	0.2 g L^{-1}
CEC	6.56 cmol kg^{-1}	-	-
Cu	28.50 mg kg^{-1}	21.0 mg kg^{-1}	0.005 mg L^{-1}
Fe	25.00 mg kg^{-1}	12.2 g kg^{-1}	0.05 mg L^{-1}
Mn	88 mg kg^{-1}	0.3 g kg^{-1}	0.005 mg L^{-1}
Mo	1.868 mg kg^{-1}	4.0 mg kg^{-1}	-
Zn	25.6 mg kg^{-1}	14.0 mg kg^{-1}	-

Parameter assessment

Yield and system productivity. Eggplant determinations included mean fruit weight per plant and total fruit yield; whereas cowpea measurements included grain yield and total biomass yield.

In addition, system productivity was assessed using the Area Equivalent Yield (AEY), cowpea total biomass production, and estimated nitrogen input. The AEY was calculated based on the local market prices of the two crops, estimated at approximately US$ 0.50 kg^{-1} for eggplant fruits and US$ 1.30 kg^{-1} for cowpea grains, following the method of Mead and Willey (1980):

$$AEY = (Ye \times Pe + Yc \times Pc) / Pe$$

Where:

Ye = eggplant fruit yield (t ha^{-1}),
Yc = cowpea grain yield (t ha^{-1}),
Pe = price of eggplant fruits (US$ kg^{-1}), and
Pc = price of cowpea grains (US$ kg^{-1}).

AEY was used as an integrated indicator of system productivity by expressing the yields of the component crops as eggplant yield equivalents using market price-based conversion factors. AEY was preferred over the Land Equivalent Ratio (LER) because it accounts not only for biological productivity, but also for the economic value of the component crops. This was considered more appropriate in the present study because eggplant and cowpea differ in market value and end use, making AEY a more relevant indicator of system performance under smallholder farming conditions.

Statistical analysis. Parametric data were subjected to analysis of variance (ANOVA) at the 5% significance level using IBM SPSS Statistics version 27. Where significant differences were detected, treatment means were separated using Tukey's Honestly Significant Difference (HSD) test.

RESULTS

Eggplant fruit weight and yield

Eggplant fruit weight. Eggplant fruit weight was significantly affected by fertiliser treatments under both mono- and inter-cropping systems ($P < 0.001$; Table 2). Integrated soil fertility management (ISFM) treatments combining organic and mineral fertilisers generally produced higher fruit weights than sole organic fertilisation, mineral fertiliser alone, and the unfertilised control. Under mono-cropping conditions, the combined application of solid compost, liquid compost, and half the recommended mineral fertiliser rate (T6) produced the highest fruit weight; whereas the control treatment, consistently recorded the lowest values. Under inter-cropping conditions, fruit weight also increased markedly, with integrated fertilisation treatments. The treatment combining solid organic fertiliser with half the recommended mineral fertiliser rate (T4) produced the highest fruit weight, while the unfertilised control treatment showed the lowest performance. Across all fertiliser treatments, eggplant fruit weight remained consistently higher under mono-cropping than under inter-cropping conditions.

Eggplant total fruit yield. Eggplant total fruit yield was significantly influenced by fertiliser treatments under both mono-cropping and inter-cropping systems ($P < 0.001$; Table 3). Integrated soil fertility management treatments combining organic and mineral fertilisers, generally produced higher yields than sole organic fertilisation, mineral fertiliser alone, and the unfertilised control. Under mono-cropping conditions, the treatment combining solid compost, liquid compost, and half the recommended mineral fertiliser rate (T6) produced the highest yield, whereas the control treatment consistently recorded the lowest yield values. Under intercropping conditions, integrated fertilisation treatments also resulted in improved yields compared with

TABLE 2. Effects of fertiliser treatments on eggplant fruit weight under mon-ocropping and inter-cropping systems

Treatments	Fruit weight (g plant^{-1})	
	Mono-cropping system	Inter-croppings ystem
Control - no fertiliser	122.7 ± 4.4 d	52.0 ± 2.1 e
Solid compost	283.5 ± 21.8 c	114.1 ± 8.4 d
Liquid compost	299.6 ± 13.3 c	133.5 ± 13.8 d
Mineral fertiliser	319.3 ± 12.6 c	181.6 ± 3.6 c
Solid compost + half mineral fertiliser	383.7 ± 11.6 b	257.7 ± 19.9 a
Liquid compost + half mineral fertiliser	392.8 ± 6.5 b	226.8 ± 5.1 b
Solid + liquid compost + half mineral fertiliser	475.0 ± 7.8 a	218.4 ± 15.6 b
P-value	<0.001	<0.001
Significance	HS	HS

Values are means ± standard deviation (n = 3). Means followed by the same letter within a column are not significantly different at P<0.05

TABLE 3. Eggplant total fruit yields (t ha^{-1}) for different fertiliser treatments and cropping systems

Treatments	Yields (t ha^{-1})	
	Mono-cropping system	Inter-cropping system
Control - no fertiliser	3.88 ± 0.28 d*	1.82 ± 0.22 e
Solid compost	9.30 ± 0.74 c	3.77 ± 0.28 d
Liquid compost	9.00 ± 0.44 c	4.41 ± 0.51 d
Mineral fertiliser	10.62 ± 0.41 c	5.86 ± 0.43 c
Solid compost + half mineral fertiliser	12.72 ± 0.30 b	8.55 ± 0.63 a
Liquid compost + half mineral fertiliser	12.86 ± 0.48 b	7.54 ± 0.17 ab
Solid + liquid compost + half mineral fertiliser	15.57 ± 0.65 a	7.27 ± 0.51 b
P-value	<0.001	<0.001
Significance	HS	HS

Values are means ± standard deviation (n = 3). Means followed by the same letter within a column are not significantly different at P<0.05

sole organic fertilisation and the unfertilised control. Treatments combining solid compost with half the recommended mineral fertiliser rate (T4) produced the highest yield under inter-cropping conditions, while the control treatment recorded the lowest performance. Mineral fertiliser alone produced intermediate yield values compared with the integrated fertilisation treatments.

Across all fertiliser treatments, eggplant yields remained consistently higher under mono-cropping than under inter-cropping conditions. Yield gaps between the two cropping systems varied significantly among treatments ($P < 0.001$), with the largest gap observed under the treatment combining solid compost, liquid compost, and half the recommended mineral fertiliser rate (T6).

Cowpea grain yield. Cowpea grain yield was significantly influenced by fertiliser treatments ($P < 0.001$; Table 4). Integrated soil fertility management (ISFM) treatments combining organic and mineral fertilisers generally produced higher grain yields than sole organic fertilisation, mineral fertiliser alone, and the unfertilised control. The treatment combining solid compost, liquid compost, and half the recommended mineral fertiliser rate (T6) produced the highest grain yield; whereas the control treatment consistently recorded the lowest performance. Sole organic fertilisation and mineral fertiliser alone produced intermediate and statistically comparable grain yields.

Cowpea total biomass. Cowpea total biomass yield was significantly influenced by fertiliser treatments ($P < 0.001$; Table 4). Biomass production increased progressively from the unfertilised control to the integrated fertilisation treatments. The highest biomass yield was obtained under the combined application of solid compost, liquid compost, and half the recommended mineral fertiliser rate (T6); whereas the control treatment produced the lowest biomass values. Integrated fertilisation treatments consistently outperformed sole organic fertilisation and mineral fertiliser alone.

Estimated nitrogen input. Estimated N input was significantly influenced by fertiliser treatments ($P < 0.001$; Table 5). Nitrogen input generally increased from the unfertilised control to the integrated fertilisation treatments. Combined application of solid compost, liquid compost, and half the recommended mineral fertiliser rate (T6) produced the highest nitrogen input, whereas the control treatment recorded the lowest value. Integrated fertilisation treatments consistently resulted in higher nitrogen input than sole organic fertilisation and mineral fertiliser alone.

Area Equivalent Yield. Area Equivalent Yield (AEY) was significantly affected by fertiliser treatments ($P < 0.001$; Table 5). Integrated soil fertility management treatments produced the highest AEY values; whereas the unfertilised control consistently showed the lowest performance. Treatments combining organic fertilisers with reduced mineral fertiliser rates generally outperformed sole organic fertilisation and mineral fertiliser alone,

TABLE 4. Yields of the cowpea intercrop under different fertiliser treatments

Treatments	Yield (t ha^{-1})	
	Dried grains	Total biomass
Control no fertiliser	1.12 ± 0.05 d*	1.96 ± 0.04 e
Solid compost	1.70 ± 0.08 c	2.67 ± 0.19 d
Liquid compost	1.73 ± 0.05 c	3.23 ± 0.12 c
Mineral fertiliser	1.79 ± 0.09 c	3.30 ± 0.06 c
Solid compost + half mineral fertiliser	2.58 ± 0.5 b	4.09 ± 0.08 b
Liquid compost + half mineral fertiliser	2.73 ± 0.16 b	4.29 ± 0.24 b
Solid + liquid compost + half mineral fertiliser	3.24 ± 0.18 a	5.53 ± 0.19 a
P-value	<0.001	<0.001
Significance	HS	HS

* Different letters per column indicate significant difference for treatments at $P<0.05$; HS = Highly significant

TABLE 5. Area Equivalent Yield and estimated N input of the eggplant–cowpea intercropping system under different fertiliser treatments

Treatments	Area Equivalent Yield (t ha^{-1})	Nitrogen input (kg ha^{-1})
Control no fertiliser	4.81±0.22 d*	59.00±1.38 e
Solid compost	9.32±0.46 c	80.30±5.95 d
Liquid compost	9.03±0.57 c	97.00±3.62 c
Mineral fertiliser	10.63±0.51 b	99.20±2.04 c
Solid compost + half mineral fertiliser	15.44±0.70 a	122.70±2.45 b
Liquid compost + half mineral fertiliser	14.82±0.28 a	128.90±7.31 b
Solid + liquid compost + half mineral fertiliser	15.92±0.41 a	166.00±5.71 a
P-value	<0.001	<0.001
Significance	HS	HS

* Different letters per column indicate significant difference for treatments at P<0.05; HS = Highly significant

indicating improved productivity of the intercropping system under integrated fertilisation strategies.

DISCUSSION

General interpretation of ISFM performance. In this study, fertilisation treatments were not standardised on an equivalent nutrient basis, particularly for nitrogen. This approach is consistent with ISFM principles, which promote the combined use of organic and mineral resources under realistic smallholder farming conditions rather than strict nutrient equivalence (Vanlauwe *et al.*, 2015). The aim was therefore to assess the overall agronomic performance of fertilisation strategies rather than isolate the effect of a single nutrient. These results suggest that crop performance in such systems depends not only on nutrient inputs but also on biological and ecological interactions that regulate system functioning. In systems combining organic and mineral inputs, nutrient release dynamics, synchronisation with crop demand, and soil biological processes may play an important role in influencing crop performance and overall system productivity (Chivenge *et al.,* 2011).

Eggplant fruit weight. The significant increase in eggplant fruit weight under integrated fertilisation treatments indicates that the combined application of organic and mineral fertilisers improved fruit development compared with sole organic fertilisation and the unfertilised control. Fruit weight increased progressively with fertilisation intensity, whereas lower values were consistently recorded under intercropping than monocropping conditions.

This trend may be explained by the complementary roles of organic and mineral nutrient sources within Integrated Soil Fertility Management (ISFM) systems. Organic amendments likely improved soil structure, moisture retention, and microbial activity, thereby enhancing nutrient retention and gradual nutrient release. In contrast, mineral fertilisers provided readily available nutrients required during periods of high crop demand. The improved fruit weight observed under integrated fertilisation may therefore reflect better nutrient synchronisation and enhanced assimilate accumulation during fruit development. The lower fruit weight observed under intercropping conditions may be attributed to interspecific competition between eggplant and cowpea for light, nutrients, and water.

These findings are consistent with reports by Adekiya *et al*. (2019), who observed improved fruit development in vegetable crops under integrated nutrient management. Similarly, Vanlauwe *et al*. (2015) and Chivenge *et al*. (2011) reported that ISFM improves crop performance in tropical farming systems through the complementary use of organic and mineral inputs. Olaniyi and Ojetayo (2011) also reported enhanced fruit growth and nutrient uptake in eggplant under combined fertilisation strategies.

However, some studies conducted under similarly degraded tropical soils have reported weaker responses to integrated fertilisation due to low soil moisture availability, rapid nutrient losses, and limited organic matter mineralisation (Palm *et al*., 2001). Such contrasting results suggest that the effectiveness of ISFM practices may vary according to soil properties and environmental conditions.

Further studies are needed to evaluate the long-term effects of integrated fertilisation on nutrient dynamics, crop competition, and fruit quality attributes such as nutritional composition, organoleptic characteristics, firmness, sugar content, and vitamin concentration in eggplant–cowpea intercropping systems.

Eggplant total fruit yield. The higher eggplant yields obtained under integrated fertilisation treatments indicate improved crop productivity compared with sole organic fertilisation, mineral fertiliser alone, and the unfertilised control. Yield improvement was more pronounced under treatments combining composts with reduced mineral fertiliser rates, whereas yields remained consistently lower under intercropping than monocropping conditions.

This trend may be explained by the complementary effects of organic and mineral nutrient sources within ISFM systems. Organic amendments improve soil structure, increase water-holding capacity, stimulate microbial activity, and enhance nutrient retention, whereas mineral fertilisers provide readily available nutrients during periods of rapid crop growth. The combined application of these inputs likely improved nutrient synchronisation with crop demand throughout the cropping cycle. In contrast, the relatively lower performance observed under sole organic fertilisation may be related to the slower decomposition and mineralisation of organic materials, which may not fully satisfy crop nutrient requirements during periods of high nutrient demand. The lower yields recorded under intercropping conditions probably resulted from interspecific competition between eggplant and cowpea plants for light, water, and nutrients.

These findings agree with reports by Chivenge *et al*. (2011) and Vanlauwe *et al*. (2015), who demonstrated that integrated soil fertility management improves crop productivity in tropical farming systems. Similar positive responses of eggplant yield to combined organic and mineral fertilisation were also reported by Adekiya *et al*. (2019) and Ayeni *et al*. (2012), who observed increased vegetable productivity under integrated nutrient management strategies. In addition, Hinsinger (2001) highlighted that integrated nutrient management may improve phosphorus availability in acidic tropical soils where phosphorus fixation limits crop productivity.

However, some studies conducted under highly weathered tropical soils have reported inconsistent yield responses to integrated fertilisation due to poor synchronisation between nutrient release and crop demand, low rainfall, and rapid nutrient leaching (Moyin-Jesu, 2007). These contrasting findings indicate that the efficiency of ISFM practices may depend on soil characteristics and climatic conditions.

Further long-term studies are required to assess the sustainability of integrated fertilisation strategies and their effects on soil

fertility restoration and productivity stability in eggplant–cowpea intercropping systems.

Cowpea grain yield. The significant increase in cowpea grain yield under integrated fertilisation treatments indicates improved crop productivity compared with sole organic fertilisation and the unfertilised control. Grain yield increased progressively with fertilisation intensity, with the highest values recorded under treatments combining organic amendments with reduced mineral fertiliser rates.

This trend may be explained by improved nutrient availability under integrated fertilisation. Organic amendments likely improved soil physical properties, microbial activity, and nutrient retention, whereas mineral fertilisers ensured rapid nutrient availability during critical growth stages. The complementary use of organic and mineral nutrient sources may therefore have promoted better vegetative growth, flowering, and grain formation. In addition, improved soil fertility conditions under ISFM treatments may have favoured biological nitrogen fixation and enhanced nutrient cycling within the cropping system.

These findings are consistent with reports by Adjei-Nsiah *et al*. (2018), who observed increased cowpea productivity under integrated nutrient management. Similarly, Bationo *et al*. (2012) and Vanlauwe *et al*. (2015) reported that combined organic and mineral fertilisation improves legume productivity in tropical agricultural systems. Chivenge *et al*. (2011) also highlighted the importance of integrated soil fertility management in improving crop performance under nutrient-limited tropical conditions.

However, some studies conducted under low-fertility tropical soils have reported variable responses of legumes to integrated fertilisation due to differences in rainfall distribution, soil biological activity, and nutrient mineralisation rates (Abaidoo *et al*., 2007). These contrasting findings suggest that environmental conditions strongly influence the effectiveness of integrated fertilisation practices.

Further studies are needed to evaluate the long-term effects of integrated fertilisation on cowpea productivity, nutrient cycling, and biological nitrogen fixation in tropical intercropping systems.

Cowpea total biomass. The significant increase in cowpea total biomass under integrated fertilisation treatments suggests improved vegetative growth and biomass accumulation compared with sole organic fertilisation and the unfertilised control. Biomass production increased progressively with fertilisation intensity, with the highest values recorded under treatments combining organic and mineral fertilisers.

This trend may be explained by improved nutrient availability and enhanced soil fertility conditions under integrated fertilisation. Organic amendments likely improved soil structure, moisture retention, and microbial activity, whereas mineral fertilisers supplied readily available nutrients during active growth stages. The resulting improvement in nutrient uptake may have promoted greater biomass accumulation. Increased biomass production may also contribute to improved soil organic matter inputs and nutrient recycling within the cropping system.

These findings agree with reports by Giller (2001) and Bationo *et al*. (2012), who highlighted the importance of nutrient availability in improving legume biomass production and soil fertility restoration. Similarly, Chivenge *et al*. (2011) and Vanlauwe *et al*. (2015) reported that integrated soil fertility management enhances crop growth and biomass accumulation through improved nutrient synchronisation and soil fertility improvement.

However, Palm *et al*. (2001) reported that biomass responses to integrated nutrient management may remain limited under degraded soils characterised by low biological activity and poor nutrient mineralisation. Such

contrasting observations indicate that the efficiency of ISFM practices may vary depending on soil quality and environmental conditions.

Further research is required to assess the contribution of cowpea biomass to soil fertility restoration, nutrient recycling, and sustainable productivity in integrated crop management systems.

Estimated nitrogen input. The higher nitrogen input recorded under integrated fertilisation treatments suggests improved nitrogen accumulation and enhanced contribution of cowpea to soil fertility within the intercropping system. Nitrogen input increased progressively with fertilisation intensity, with the highest values obtained under treatments combining organic amendments with reduced mineral fertiliser rates.

This trend may be explained by improved plant growth and biomass production under integrated fertilisation, which likely favoured greater nitrogen accumulation in plant tissues. Organic amendments probably improved soil biological activity and nutrient retention, whereas mineral fertilisers ensured balanced nutrient availability required for plant growth and symbiotic activity. Under such conditions, cowpea integration may have contributed to improved nutrient availability within the cropping system.

These findings are consistent with reports by Dakora and Keya (1997), who highlighted the important contribution of legumes to nitrogen fixation and soil fertility improvement in tropical agricultural systems. Similarly, Peoples *et al*. (2009) and Sanginga *et al*. (2003) reported increased nitrogen contribution by legumes under favourable soil fertility conditions. Vanlauwe *et al*. (2015) and Chivenge *et al*. (2011) also emphasised that integrated soil fertility management improves overall system performance in tropical farming systems.

However, some studies have reported reduced biological nitrogen fixation under excessive mineral nitrogen application due to inhibition of rhizobial activity and symbiotic processes in legumes. Other studies conducted under degraded tropical soils have also reported weak nitrogen fixation responses associated with low microbial activity and poor soil fertility conditions.

Further studies are needed to investigate the interactions between integrated fertilisation, rhizobial activity, nutrient cycling, and biological nitrogen fixation efficiency in eggplant–cowpea intercropping systems.

Area Equivalent Yield. The significant increase in Area Equivalent Yield (AEY) under integrated fertilisation treatments indicates improved productivity of the intercropping system compared with sole organic fertilisation and the unfertilised control. The highest AEY values obtained under treatments combining organic amendments with reduced mineral fertiliser rates suggest better complementarity between eggplant and cowpea within the associated cropping system.

This trend may be explained by improved nutrient availability and more efficient utilisation of environmental resources under integrated fertilisation. Organic amendments likely enhanced soil structure, water retention, and nutrient conservation, whereas mineral fertilisers supplied readily available nutrients during periods of high crop demand. The combined use of these inputs may therefore have improved nutrient synchronisation and reduced competition between associated crops. In addition, cowpea integration likely contributed to biomass production and nitrogen input within the intercropping system.

These findings agree with reports by Mead and Willey (1980), who demonstrated that intercropping efficiency depends largely on resource availability and complementarity between component crops. Similarly, Lithourgidis *et al*. (2011) and Kermah *et al*.

(2017) reported improved intercropping productivity under systems combining legumes with companion crops. Vanlauwe *et al*. (2015) and Chivenge *et al*. (2011) also highlighted the importance of integrated soil fertility management in improving productivity in tropical farming systems.

However, some studies conducted under low-input tropical systems have reported lower intercropping efficiency where nutrient limitations, moisture stress, and poor crop synchronisation reduced crop complementarity and overall system productivity. These contrasting findings indicate that the success of intercropping systems depends strongly on nutrient management and environmental conditions.

Further long-term studies are required to evaluate the stability and sustainability of integrated fertilisation strategies in improving intercropping productivity and soil fertility restoration under tropical smallholder farming conditions.

CONCLUSION

The results indicated that fertilisation strategies combining organic amendments with reduced mineral fertiliser rates significantly improved crop productivity and overall system performance compared with sole organic fertilisation, mineral fertiliser alone, and the unfertilised control.

Integrated fertilisation treatments substantially increased eggplant fruit weight and total fruit yield, indicating improved nutrient availability under ISFM practices. Similar positive responses were observed for cowpea grain yield and total biomass production, highlighting the beneficial effects of combined organic and mineral nutrient sources on legume productivity and biomass accumulation. In addition, integrated fertilisation significantly improved estimated nitrogen input and Area Equivalent Yield (AEY), suggesting improved productivity of the intercropping system.

A contrasting observation was that eggplant yield remained lower under intercropping than monocropping conditions, probably due to interspecific competition between eggplant and cowpea for light, nutrients, and water. However, this reduction at the crop level did not reduce overall system productivity, as reflected by the high AEY values obtained under integrated fertilisation treatments. This finding highlights the importance of evaluating intercropping systems at the system level rather than on the basis of individual crop performance alone.

Overall, the study indicates that combining ISFM with legume-based intercropping can improve crop productivity and nitrogen input under tropical farming conditions. The integration of organic and mineral fertilisers therefore represents a promising strategy for improving crop productivity and soil fertility management in smallholder agricultural systems.

Further long-term studies are needed to evaluate the effects of integrated fertilisation on soil biological processes, nutrient dynamics, biological nitrogen fixation, and fruit quality attributes such as nutritional composition, organoleptic characteristics, firmness, sugar content, and vitamin concentration in eggplant–cowpea intercropping systems.

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