Received: 30 March 2023 | Accepted: 29 September 2023

DOI: 10.1002/uar2.20048

Urban Agriculture & Regional Food Systems OPEN ACCESS

ORIGINAL ARTICLE

Integrated use of organic amendments increased mungbean (*Vigna radiata* (L.) Wilczek) yield and its components compared to inorganic fertilizers

André A. Diatta[1,2] | César Bassène[1] | Anicet G. B. Manga[1] | Ozzie Abaye[3] | Wade Thomason[4] | Martin Battaglia[5] | Emre Babur[6] | Ömer Uslu[7] | Doohong Min[8] | Mahmoud Seleiman[9] | Jose F. D. C. Leme Filho[10] | Cheikh Mbow[2]

[1]Département Productions Végétales et Agronomie, UFR des Sciences Agronomiques, de l'Aquaculture et des Technologies Alimentaires (S2ATA), Université Gaston Berger, Saint Louis, Senegal

[2]Centre de Suivi Ecologique, Dakar, Senegal

[3]School of Plant and Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA

[4]Department of Plant and Soil Sciences, Oklahoma State University, Stillwater, Oklahoma, USA

[5]Center for Sustainability Science, The Nature Conservancy, Arlington, Virginia, USA

[6]Faculty of Forestry, Kahramanmaraş Sutcu Imam University, Kahramanmaraş, Turkey

[7]Department of Field Crops, Kahramanmaras Sutcu Imam University, Kahramanmaraş, Turkey

[8]Department of Agronomy, Kansas State University, Manhattan, Kansas, USA

[9]Plant Production Department, College of Food and Agriculture Sciences, King Saud University, Riyadh, Saudi Arabia

[10]College of Agricultural, Life and Physical Sciences, Southern Illinois University, Carbondale, Illinois, USA

Correspondence
André A. Diatta, Département Productions Végétales et Agronomie, UFR des Sciences Agronomiques, de l'Aquaculture et des Technologies Alimentaires (S2ATA), Université Gaston Berger, Saint-Louis, BP 234 Saint Louis, Senegal.
Email: andre-amakobo.diatta@ugb.edu.sn

Assigned to Associate Editor Muhammad Waqas.

Abstract

Rainfall variability, low soil organic matter content, and costly inorganic fertilizers are the major agricultural constraints in Sub-Saharan Africa. Integrated use of compost and manure is essential for sustaining soil fertility and increasing crop productivity. This study was conducted to evaluate the combined effects of compost and animal manure on mungbean growth and yield. The 12 treatments consisted of control, recommended dose of nitrogen, phosphorus, and potassium (NPK), 5 ton ha^{-1} of compost, 10 ton ha^{-1} of poultry, 10 ton ha^{-1} of cattle, and 10 ton ha^{-1} of sheep manure, and six combinations of organic amendments with 50% of their applied rate alone. These treatments were laid out in a randomized complete block design with six replications. Application of cattle manure at 10 ton ha^{-1} significantly increased mungbean seed yield by 66% and 84% compared to the recommended rate of NPK

Abbreviations: CNRA, National Center for Agronomic Research; NPK, nitrogen, phosphorus, and potassium; OM, organic matter; SOM, soil organic matter; SPAD, soil plant analysis development.

and control treatments, respectively. Similar observations were made on stem diameter, total pod weight, and number of seeds per pod. Plants amended with compost had the highest number of ramifications and number of pods than NPK fertilized plants, which recorded (9±) ramifications and (27±) pods per plant. On average, integrated use of 5 ton ha^{-1} of poultry manure + 5 ton ha^{-1} of cattle manure had the highest soil plant analysis development values, though not significantly different from NPK fertilizers. These results suggest that application of organic amendments could be an alternative to costly and inaccessible inorganic fertilizers for improving mungbean productivity under low-input agriculture systems.

1 | INTRODUCTION

Mungbean (*Vigna radiata* (L.) Wilczek) is one of the major food crops grown in South and East Asia (Kang et al., 2014). It is usually grown on marginal lands under rainfed conditions, but it is well adapted to arid and semiarid conditions (Diatta et al., 2020; Kassa et al., 2018; Raina et al., 2016). However, it grows best in subtropical regions with average annual rainfall ranging between 600 and 900 mm and at altitude not exceeding 2000 m on well-drained loams or sandy loam soils (Nair et al., 2019). The nutritional and functional contribution of mungbean for human health is important because of its high levels in carbohydrates, proteins, vitamins, and minerals as well as secondary metabolites such as phenolic acids and isoflavones (Dahiya et al., 2015). Mungbean is well suited to many cropping systems due to its short growth cycle (60–65 days), low water and nitrogen (N) requirements, ability to improve soil fertility through N fixation, and sustain productivity of subsequent crops in subsistence agriculture (Dey et al., 2016; Diatta et al., 2020; Keatinge et al., 2011; Manga et al., 2022; Senaratne et al., 1995). Nevertheless, the yield and quality of mungbean can be enhanced by the proper use of organic amendments. Therefore, with the prevalence of low soil carbon (C) in Sub-Saharan Africa and the high and unfordable cost of fertilizer inputs for smallholder farmers, application of organic fertilizers could help in improving mungbean growth and yield under low soil fertility conditions.

Frequent drought periods and soil degradation are major agricultural problems in Sub-Saharan Africa and are responsible for recurrent food shortages in the region (Diatta et al., 2021; Harris, 2002; Mbow et al., 2019; Sileshi et al., 2017). Similarly, soils in Senegal are inherently low in organic matter (OM), limiting the ability of the soils to retain moisture for crop uptake and activation of nutrient-mineralizing microbial populations (Ginting et al., 2003; McClintock & Diop, 2005). It is well documented that soil organic matter (SOM) plays a key role in the soil system and can enhance soil physical, chemical, and biological properties (Figure 1), thus contributing to increased crop productivity (Du et al., 2020; Lal, 2006, 2020; Oldfield et al., 2019).

In the early development of human agricultural activities, animal manure was used as the main source of nutrient inputs for crop production before the widespread manufacturing of inorganic fertilizers (Zhongqi et al., 2016b). In Senegal, the animal stock is estimated at 108 million in 2020 (FAOSTAT, 2022), corresponding to 190% increase compared to head stock in 2000 (Figure 2). This growth in head stock has resulted in increased N addition to soils through manure application, with an estimated N application of 23,037 tons in 2020 (FAOSTAT, 2022). In Sub-Saharan Africa, application of organic materials such as poultry, cattle, and sheep manure by farmers is a traditionally and commonly used practice for improving soil fertility (Harris, 2002; Sileshi et al., 2017). However, the development of high-yielding varieties with higher nutrient requirements has led to a decrease in the addition of organic materials and increase in use of synthetic fertilizers. Although significant increases in crop production were observed due to the use of mineral fertilizers, their ever-increasing cost, mainly as a result of their high production costs, is a major constraint for increased usage in Africa (Brunelle et al., 2015). In addition, there is an ample body of research showing that sole and continuous application of inorganic fertilizers may increase soil compaction, decrease soil porosity and total organic C content, enhance soil nutrient depletion, and reduce soil microorganism population, which could ultimately limit crop yield and nutritional quality (Choudhary et al., 2018; Diatta et al., 2020; Ginting et al., 2003; Obi & Ebo, 1995; Steiner et al., 2007). Thus, future use of organic amendments to supply nutrients to plants and improve crop yields and overall soil health for smallholder and resource-limited farmers should be a central component in their nutrient management plans (Adegbite et al., 2021; Diatta et al., 2020; Massah & Azadegan, 2016). Greenhouse and field research has shown that higher and sustainable crop yields can be obtained with combined application of manure and compost compared to inorganic fertilizers (Cobb et al., 2018). However, it is essential to identify the optimum manure-compost combination for meeting nutrient requirements for increased crop yields, reduced environmental pollution, and enhanced food security.

Animal manure is composed primarily of excreta (urine and feces), but could also contain bedding materials, dropped feed, scurf, and other farming wastes (Zhongqi et al., 2016a). Manure is rich in plant nutrients such as N, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) and is usually applied to soils as a fertilizer for agricultural production in many regions, including semi-arid regions of Africa (Lal, 2006; Sileshi et al., 2017; Zhongqi et al., 2016a). Manure application has been demonstrated to account for 15% of the N inputs to cropland in Sub-Saharan Africa (Liu et al., 2010). According to Sileshi et al. (2017), 1 ton of manure on a dry weight basis applied to soils in Sub-Saharan Africa can add 325.4 kg of C, 16.9 kg of N, 8.3 kg of P, 11.2 kg of K, 6.9 kg of Ca, 4.4 kg of Mg, and 0.7 kg of S on average. Compared to plant residues and manure, compost releases nutrients more slowly and has longer lasting effects (Ciaccia et al., 2017; Ouédraogo et al., 2001). Slow decomposition is more effective in increasing SOM, which plays a key role in soil fertility by retaining water and nutrients and maintaining soil structure. Other benefits include the disposal and recycling of municipal solid waste, thereby reducing the amount of material going to landfill (McClintock & Diop, 2005). Therefore, reduction in the total dependence on synthetic fertilizers using compost and animal manure has the potential to transform current mungbean into more sustainable production systems (Cai et al., 2019; Edmeades, 2003).

Previous studies have demonstrated the adaptation of mungbean genotypes to the Senegalese environment (Abaye et al., 2018; Cisse et al., 2011), and their potential for increasing cereals yields in intercropping systems (Diatta et al., 2020; Trail et al., 2016) and enhancing the nutritional security of rural populations (Abaye et al., 2015; Vashro et al., 2018). However, no study has investigated the potential of organic amendments for increasing mungbean yields in Senegal, to our knowledge. The present study was conducted to evaluate the effects of integrated application of compost and animal manure on growth, yield, and yield components of mungbean in comparison to the recommended dose of nitrogen, phosphorus, and potassium (NPK) fertilizers.

Core Ideas

- Integrated use of organic amendments is essential for increasing crop productivity and sustaining soil fertility.
- Mungbean yield was significantly enhanced by compost or cattle manure compared to inorganic fertilizer treatments.
- Use of organic amendments can be a sustainable management alternative to expensive synthetic fertilizers.

2 | MATERIALS AND METHODS

2.1 | Soil description

A greenhouse experiment was conducted using soils collected from the Faculty of Agronomy, Aquaculture, and Food Technology's farm of Gaston Berger University, Saint-Louis Senegal (16°03′19.0″N 16°25′39.0″W). The site has been under permanent fallow with predominantly sandy loam soils (Table 1). The soils are classified as sandy loam and have

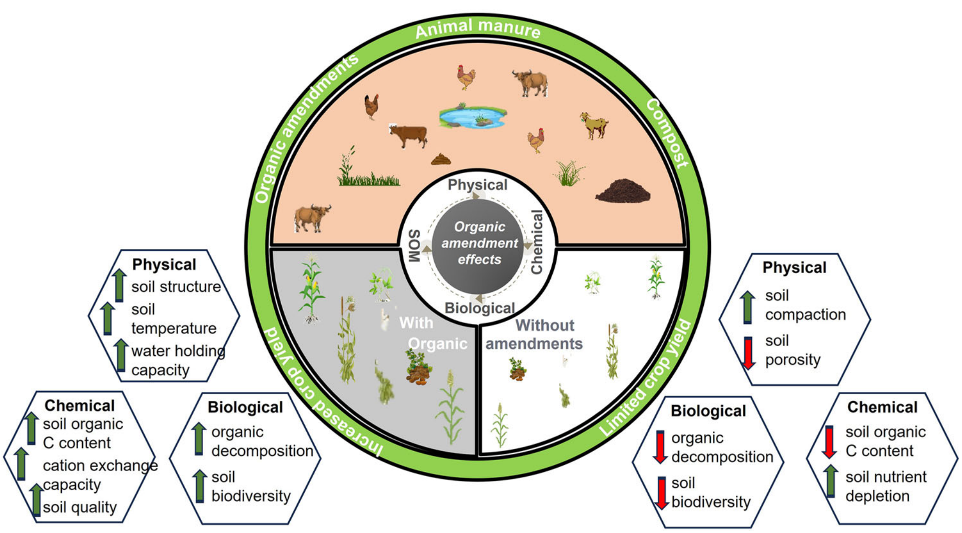

FIGURE 1 Potential benefits of organic amendments in agriculture. SOM, soil organic matter.

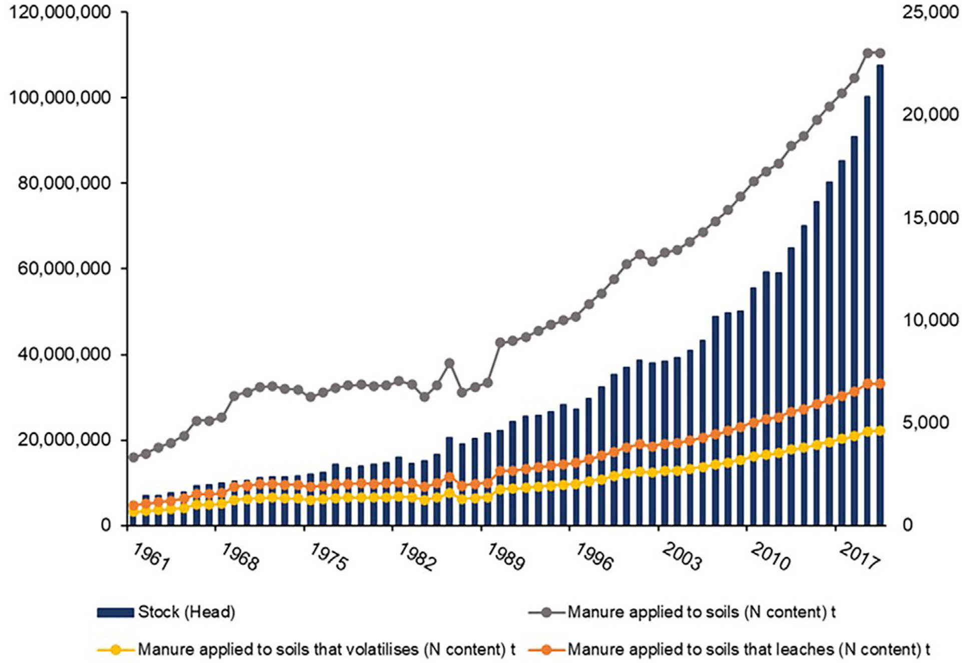

FIGURE 2 Estimates of animal stocks, nitrogen (N) inputs to agricultural soils from livestock manure and corresponding losses via volatilization and leaching in Senegal from 1961 to 2020 (*Source*: Food and Agriculture Organization of the United Nations, FAO).

TABLE 1 Physical and chemical properties of the soil, compost, and animal manure.

Properties	Soil	Compost[a]	Poultry manure	Cattle manure[a]	Sheep manure[a]
Clay (%)	8.25	–	–	–	–
Sand (%)	75.00	–	–	–	–
Silt (%)	16.75	–	–	–	–
Bulk density	1.526	–	–	–	–
Field capacity (cm^3 water/cm^3 soil)	0.156	–	–	–	–
pH (1/2.5)	8.23	7.03	7.24	7.12	7.62
Electrical conductivity (1/2.5) (mS cm^{-1})	0.269	5.920	6.530	3.340	6.470
C (%)	0.793	16.113	7.890	5.897	10.257
N (%)	0.124	5.755	4.006	1.766	2.861
C/N	6.395	2.800	1.970	3.339	3.585
OM (%)	1.364	–	–	–	–
Available P (mg kg^{-1})	34.740	–	–	–	–
Exchangeable Ca (mg kg^{-1})	525.00	1500.00	1200.00	1200.00	750.00
Exchangeable Mg (mg kg^{-1})	90.00	180.00	450.00	135.00	450.00
Exchangeable Na (mg kg^{-1})	35.65	29.90	35.65	12.08	34.50
Exchangeable K (mg kg^{-1})	28.39	46.41	26.75	8.74	18.56

Abbreviations: C, carbon; Ca, calcium; C/N, carbon/nitrogen ratio; K, potassium; Mg, magnesium; N, nitrogen; Na, sodium; OM, organic matter; P, phosphorus.
[a]pH and electrical conductivity of compost, cattle, sheep manure (1:5) materials: deionized water mixture on a volumetric basis.

low water holding capacity, high permeability, and are very sensitive to drought (Herrick et al., 2013). The climate of the area is of the Sudano-Sahelian type and marked by two seasons: a longer dry season (November–June) and a shorter rainy season (July–October). The study area is characterized by an average annual rainfall of 450 mm with a mean maximum temperature of 37˚C and mean minimum temperature of 16˚C.

2.2 | Soil sampling and analysis

The soil was collected randomly to a depth of 20 cm from fields and composite soil samples were air-dried in a dust-free glasshouse and then sieved to pass a 5-mm particle size diameter. The physical and chemical properties (Table 1) of the soil samples were analyzed at the soil-plant and water testing laboratory of the National Center for Agronomic Research-Senegalese Institute of Agricultural Research (CNRA–ISRA) at Bambey (Senegal). Soil texture was determined by measuring the fine fractions (clays and silts) by sedimentation and the coarse fractions (coarse, medium, and fine sands) by sieving on standardized screens. Field capacity and soil bulk density were determined as described by Gupta and Larson (1979) and Chopart (1980), respectively. Soil pH and electrical conductivity were determined (Mathieu et al., 2003), while soil total C, total N, and available P were determined using modified methods of Walkley and Black (1934), Olsen and Sommers (1983), and Kjeldahl (1883), respectively. The SOM was calculated using the formula SOM = carbon content × 1.72 (with 1.72 being the adapted van Bemmeln coefficient of cultivated soils) (Nelson & Sommers, 1996).

The compost used in this experiment was prepared by the CNRA using peanut (*Arachis hypogaea* L.) shells, domestic waste, animal dung, and crop residues (millet straw [*Pennisetum glaucum* (L.) R. Br.] and maize [*Zea mays* L.]). Animal manure was collected from farms near the faculty's farm and applied 1 week before planting. The recommended dose of NPK at 150 kg ha^{-1} of 6-20-10 was applied as a basal dose. Plastic pots were filled with 2.750 kg of soil, on which the corresponding nutrient source was uniformly applied and incorporated at approximately 15 cm in each pot as per fertilization treatment. Each plastic pot was lined with a polythene bag to prevent loss of soil.

2.3 | Experimental design

The experimental pots were laid out in a randomized complete block design with six replicates per treatment. Berken is a hybrid, medium-large seeded mungbean cultivar and was obtained from Oklahoma Foundation Seed Stocks (Stillwater, OK, USA). The fertilization treatments consisted of the control treatment with no fertilizer, inorganic fertilizer (recommended dose of NPK: 6-20-10), compost, animal manure, and the combination of organic amendments (Table 2). The proposed rates for the compost and animal manure are based on the previous research conducted in Senegal on soil improvement, yield increase, and farmers' adoption (Faye et al., 2021). The organic amendments (compost, poultry manure, cattle manure, and sheep manure) were equilibrated in the pots for 7 days, irrigated with river water, and maintained at 80% of field capacity prior to sowing. The river water is characterized by pH (1/2.5) of 6.35, electrical conductivity (1/2.5) (μs cm^{-1}) of 8.41, exchangeable Ca (mg kg^{-1}) of 105.00, exchangeable Mg (mg kg^{-1}) of 18.00, exchangeable Na (mg kg^{-1}) 24.15, and exchangeable K (mg kg^{-1}) of 3.82. In each pot, two seeds were sown on September 3, 2021, at Gaston Berger University's greenhouse. A standardized gravimetric approach of daily pot weighing (twice a day) was followed during the experiment to control watering regimes to gradually attain 80% of field capacity. After 1 week of seedling emergence, the mungbean plants were thinned to one plant per pot. The crop cultural practices were similar in all treatments throughout the growth cycle, except for the compost, animal manure, and fertilizer treatments.

TABLE 2 Experimental treatments and application rate used in each treatment.

No.	Treatment	Application rate
T1	Control	0 ton ha^{-1}
T2	Recommended NPK: 6-20-10	150 kg ha^{-1}
T3	Compost	5 ton ha^{-1}
T4	Poultry manure	10 ton ha^{-1}
T5	Cattle manure	10 ton ha^{-1}
T6	Sheep manure	10 ton ha^{-1}
T7	Compost + poultry manure	2.5 ton ha^{-1} + 5 ton ha^{-1}
T8	Compost + cattle manure	2.5 ton ha^{-1} + 5 ton ha^{-1}
T9	Compost + sheep manure	2.5 ton ha^{-1} + 5 ton ha^{-1}
T10	Poultry manure + cattle manure	5 ton ha^{-1} + 5 ton ha^{-1}
T11	Poultry manure + sheep manure	5 ton ha^{-1} + 5 ton ha^{-1}
T12	Cattle manure + sheep manure	5 ton ha^{-1} + 5 ton ha^{-1}

Abbreviation: NPK, nitrogen, phosphorus, and potassium.

2.4 | Data collection

Soil plant analysis development (SPAD)-502 chlorophyll meter (Konica Minolta Sensing Americas Inc.) readings on the third leaf from the top were taken at sowing, during vegetative growth, at flowering, during pod development, and at maturity stages to help determine foliar chlorophyll concentration differences between fertilization treatments. Leaf chlorophyll content and N content are closely related and are quickly and non-destructively assessed through spectral reflectance, specifically between the red and infrared wavelengths (Gitelson et al., 2003). The SPAD values have been used as a vegetative index in mungbean and is positively correlated to chlorophyll content, growth, and grain yield (Dhakal et al., 2015; Diatta et al., 2020). Plant height, stem

TABLE 3 Effects of compost, animal manure, compost–manure combination, and inorganic fertilizers on stem diameter and number of branches of mungbean.

Treatments	Stem diameter (cm)	Number of branches
T1	0.50[a]cd[b]	9.50cd
T2	0.45d	9.00d
T3	0.55bcd	14.50a
T4	0.70ab	14.00a
T5	0.80a	12.50ab
T6	0.55bcd	13.00ab
T7	0.65abc	12.50ab
T8	0.50cd	10.50bcd
T9	0.55bcd	13.00ab
T10	0.65abc	12.00abc
T11	0.65abc	12.50ab
T12	0.60bcd	11.00bcd

Note: Control (T1), inorganic fertilizer (Recommended NPK: 6-20-10 at 150 kg ha^{-1}) (T2), 5 ton ha^{-1} of compost (T3), 10 ton ha^{-1} of poultry manure (T4), 10 ton ha^{-1} of cattle manure (T5), 10 ton ha^{-1} of sheep manure (T6), 2.5 ton ha^{-1} of compost + 5 ton ha^{-1} of poultry manure (T7), 2.5 ton ha^{-1} of compost + 5 ton ha^{-1} of cattle manure (T8), 2.5 ton ha^{-1} of compost + 5 ton ha^{-1} of sheep manure (T9), 5 ton ha^{-1} of poultry manure + 5 ton ha^{-1} of cattle manure (T10), 5 ton ha^{-1} of poultry manure + 5 ton ha^{-1} of sheep manure (T11), and 5 ton ha^{-1} of cattle manure + 5 ton ha^{-1} of sheep manure (T12).

[a]Each value is the mean of six replicates.

[b]Means within column, followed by different letter are significantly different (Fisher's protected least significant difference, $p = 0.05$).

diameter, and number of branches were determined at maturity stage. After these measurements, mungbean pods were hand-harvested weekly until all mature pods were collected from the plants. Number of pods per plant, pod length, number of seeds per pod, and number of seeds per plant were recorded at harvest. Seed yield was calculated as dry matter of seeds from each plant at harvest, and seed yield per plant was computed.

2.5 | Statistical analyses

Mungbean plant growth, yield, and yield components were statistically analyzed using 2022 JMP Statistical Discovery LLC SAS JMP Pro version 15.0.0 statistical software (SAS Institute Inc.). Analysis of variance (Gomez & Gomez, 1984) was used to test the effects of fertilization treatments on plant height, stem diameter, number of branches, SPAD values, number of pods per plant, pod length, number of seeds per pod, number of seeds per plant, and seed yield. When treatment differences were found at $\alpha = 0.05$ significance level, Fisher's protected least significant difference was used for mean separation.

3 | RESULTS AND DISCUSSION

3.1 | Plant growth

There were significant ($p < 0.05$) effects of fertilizer treatments on mungbean growth parameters (Table 3). Organic amendments and their combinations significantly ($p < 0.05$) increased plant height (Figure 3), stem diameter, and number of branches compared to NPK and control treatments (Table 3). Application of compost + sheep manure (T9) significantly increased plant height by 13% and 25% over recommended rate of NPK and control, respectively. Similarly, stem diameter was significantly increased by 78% and 60% due to the sole application of cattle manure (T5) compared to synthetic fertilizer (T2) and control treatments (T1), respectively. Consistent with previous results, organic amendments resulted in a higher number of branches compared to inorganic fertilizer application and control treatments. Mungbean plants amended with poultry manure (T4) produced 56% and 47% more branches than NPK and control plants, respectively.

The results from this study suggest that plant growth was enhanced by the application of organic amendments when compared to mungbean growth with the recommended rate of inorganic fertilizers. This is in line with other studies where application of organic amendments increased growth of mungbean (Islam et al., 2021), cowpea [*Vigna unguiculata* (L.) Walp.] (Adegbite et al., 2021), peanut (Du et al., 2020), soybean [*Glycine max* (L.) Merr.] (Tagoe et al., 2010), maize (Zhong et al., 2010), rice (*Oryza sativa* L.) (Steiner et al., 2007), and wheat (*Triticum turgidum* L.) (Choudhary et al., 2018). The increase in plant growth following organic amendments could be attributed to the high contents of manure in N, P, K, and other beneficial plant nutrients such as S, Ca, and Mg and trace elements (iron, manganese, copper, and zinc). The high nutrient contents could result in better plant nutrition, thereby enhancing plant growth (Javaid & Bajwa, 2011; Steiner et al., 2007). Jones et al. (2004) reported that SOM promotes the proliferation and development of beneficial microorganisms that play a role in the decomposition of OM, making SOM a major source of plant nutrients. It also improves the physical properties of the soil, such as its porosity, structure, and water holding capacity (Choudhary et al., 2018; Lal, 2006). The management of SOM is, thus, important for the development of a sustainable low-input farming system and for the improvement of soil fertility. The ability of organic amendments to act as a slow-release fertilizer and continuously promote soil physical, chemical, and biological properties could also contribute toward enhanced plant growth (Sutrisno & Yusnawan, 2018). However, Sutrisno and Yusnawan (2018) studied the effects of manure and inorganic fertilizers on mungbean growth, yield, and yield components and reported that NPK fertilizers significantly increased plant growth due to enhanced intake of N

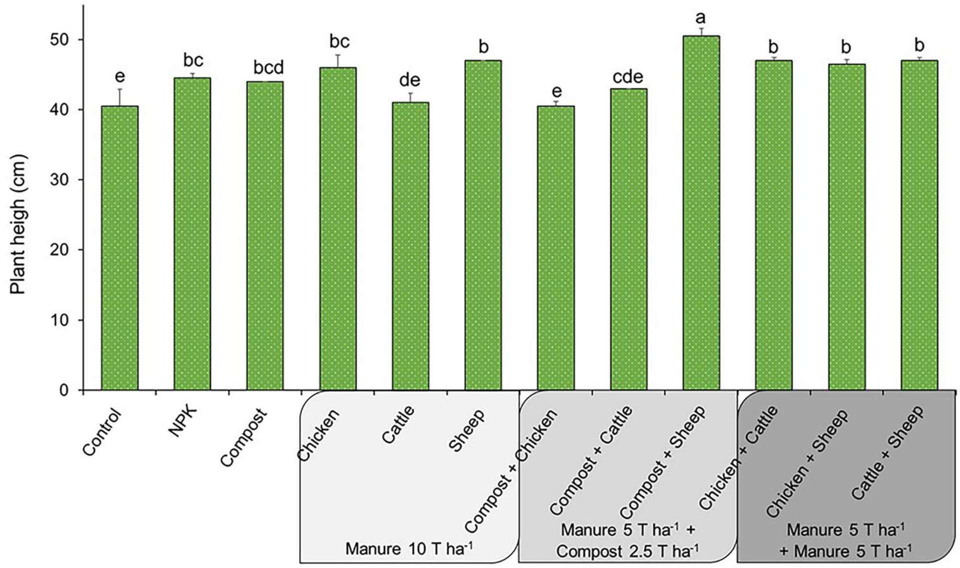

FIGURE 3 Effects of compost, animal manure, compost–manure combination, and inorganic fertilizers on plant height of mungbean. Treatments connected by dissimilar letters are significantly different at $\alpha = 0.05$ according to Fisher's protected least significant difference and error bars represent standard error of the mean ($n = 72$).

and P. It is well documented that application of inorganic NPK increases the availability of macronutrients such as N, P, and K and can make these nutrients readily absorbed by the crops. The utilization of these nutrients in crop metabolism such as carbohydrate synthesis, cellulose, proteins, hormones, and enzymes trigger plant growth. Others have found that combining manure and NPK fertilizers resulted is similar or faster growth than the sole application of NPK (Manna et al., 2007; Wei et al., 2016).

3.2 | Yield components

Application of compost (T3) to mungbean produced 64% and 74% more pods than plants fertilized with NPK and control treatments, respectively, but was not significantly higher than plants amended with cattle manure (T5) (Table 4). As a result, total pod weight of mungbean plants amended with organic amendments, particularly 10 ton ha^{-1} of cattle manure (T5), recorded the highest value (27.43 g) compared to NPK (16.6 g) and control (14.4 g) treatments (Table 4). Unlike the number and weight of pods, NPK fertilizers gave the longest mungbean pods (8.88 cm) compared to unfertilized plants (8.04 cm) but were not significantly different than plants amended with poultry manure + cattle manure (T10), compost (T3), and cattle manure (T5) (Table 4).

The increased number of pods and weight after applying compost (T3) and cattle manure (T5) could be due to the availability of primary growth elements and an efficient utilization of soil resources by mungbean plant, resulting in better plant development (Naeem et al., 2006). The analysis of compost and animal manure amendments shows that compost and cattle have the lowest electrical conductivity values (5.92 and 3.34 dS/m, respectively) compared to other organic amendments and high content in exchangeable bases. As reported by Du et al. (2020), organic amendments can increase soil organic C accumulation and total N, P, and K contents, indicating a sustainable supply of essential elements for plant growth. The greater plant growth under organic amendments compared to NPK fertilized plants could also be related to the effective transport and storage of gases, heat, water, and nutrients due to improved aggregate size, stability, and soil structure (Guo et al., 2019; Peng et al., 2015). Manure application can thus positively influence soil physical and chemical indicators and promote cycling and availability of soil nutrients and soil health (Choudhary et al., 2018).

There was a significant ($p < 0.05$) influence of compost, animal manure, their combinations, and NPK fertilizers on mungbean number of seeds per pod. The mungbean plants fertilized with organic amendments produced the highest number of seeds compared to inorganic fertilizers (Figure 4). Specifically, cattle manure + sheep manure (T12) had the greatest number of seeds per pod with 11.67 seeds per pod, on average, representing 19% more than the control treatment. However, the number of seeds per pod in T12 was not statistically different from inorganic fertilizer NPK (T2) and cattle manure (T5) with 11.17 and 10.50 seeds per pod, respectively (Figure 4). The increase in number of seeds per pods for cattle manure + sheep manure (T12) and cattle manure (T5) is largely attributed to improved SOM content, soil physical, chemical, and biological properties. However, Naeem et al. (2014) recorded a higher number of seeds per pod for NPK

TABLE 4 Effects of compost, animal manure, compost–manure combination, and inorganic fertilizers on number of pods, pod length, and pod weight of mungbean.

Treatments	No pods	Pod length (cm)	Pods weight (g)
T1	25.0[a]def[b]	8.04cdef	14.40cde
T2	26.5def	8.88a	16.60bcde
T3	43.5a	8.39abcde	19.79b
T4	36.0abcd	7.53f	15.70bcde
T5	39.0abc	8.45abcde	27.43a
T6	32.0bcde	8.05bcdef	17.04bcd
T7	21.0ef	8.55abcd	12.89e
T8	35.0abcd	7.79ef	18.80b
T9	31.0cdef	7.93def	17.39bc
T10	42.5ab	8.82a	16.66bcde
T11	20.5f	8.77abc	13.05de
T12	23.0ef	8.79ab	17.83bc

Note: Control (T1), inorganic fertilizer (Recommended NPK: 6-20-10 at 150 kg ha^{-1}) (T2), 5 ton ha^{-1} of compost (T3), 10 ton ha^{-1} of poultry manure (T4), 10 ton ha^{-1} of cattle manure (T5), 10 ton ha^{-1} of sheep manure (T6), 2.5 ton ha^{-1} of compost + 5 ton ha^{-1} of poultry manure (T7), 2.5 ton ha^{-1} of compost + 5 ton ha^{-1} of cattle manure (T8), 2.5 ton ha^{-1} of compost + 5 ton ha^{-1} of sheep manure (T9), 5 ton ha^{-1} of poultry manure + 5 ton ha^{-1} of cattle manure (T10), 5 ton ha^{-1} of poultry manure + 5 ton ha^{-1} of sheep manure (T11), and 5 ton ha^{-1} of cattle manure + 5 ton ha^{-1} of sheep manure (T12).

[a]Each value is the mean of six replicates.

[b]Means within column, followed by different letters are significantly different (Fisher's protected least significant difference, $p = 0.05$).

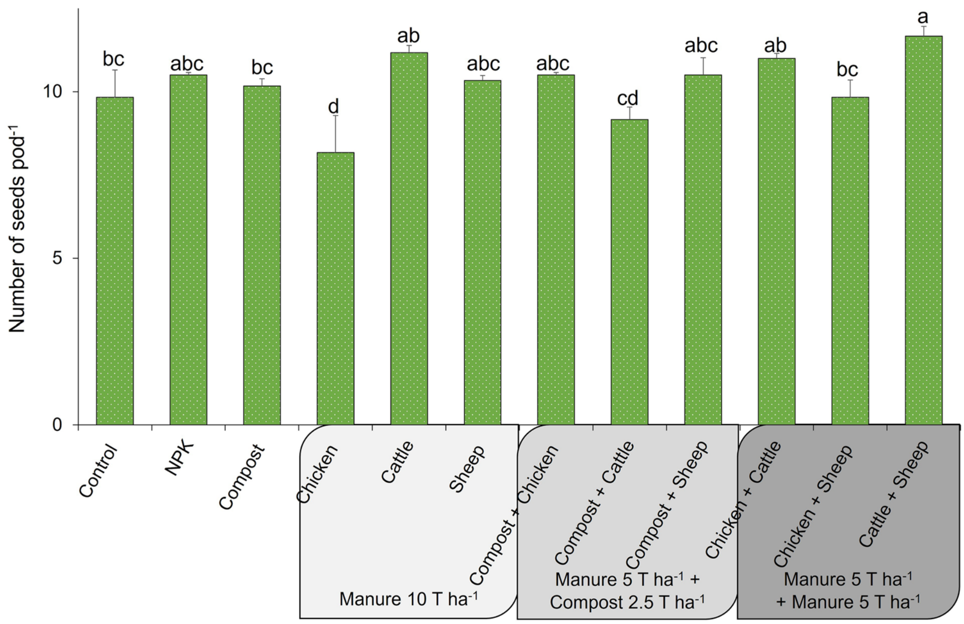

FIGURE 4 Effects of compost, animal manure, compost–manure combination, and inorganic fertilizers on number of seeds per pod of mungbean. Treatments connected by dissimilar letters are significantly different at $\alpha = 0.05$ according to Fisher's protected least significant difference and error bars represent standard error of the mean ($n = 72$).

(25-50-50 kg ha^{-1}) fertilized mungbean than plants receiving poultry manure (3.5 ton ha^{-1}) and farmyard manure (5 ton ha^{-1}). They attributed these differences to the availability of NPK in sufficient and efficient utilization of soil resources by the plant. However, the lower number of seeds for plants amended with manure could be due to the low rate of application (Javaid & Bajwa, 2011). In the present study, the highest number of seeds observed under cattle manure + sheep manure (T12) can be attributed to improved microbial activity in soil which can improve the availably of essential nutrients such as NPK at flowering and seed formation stages (Zhong et al., 2010). Previous research has shown that organic amendments can enhance total organic C and total N contents as well as enzymatic activities, which will ultimately

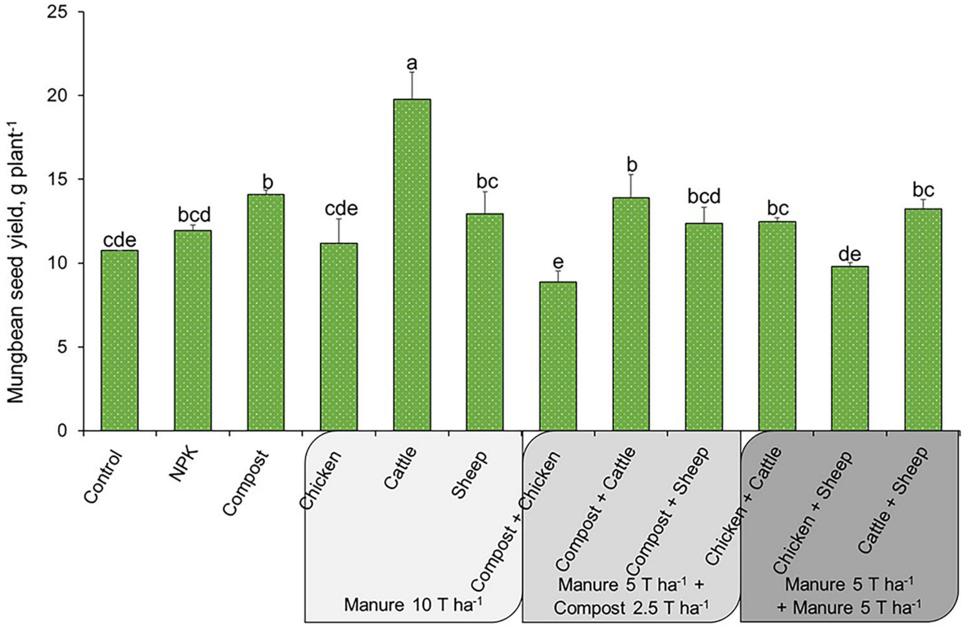

FIGURE 5 Effects of compost, animal manure, compost-manure, and inorganic fertilizer on mungbean seed yield. Treatments connected by dissimilar letters are significantly different at $\alpha = 0.05$ according to Fisher's protected least significant difference and error bars represent standard error of the mean ($n = 72$).

increase mungbean yield parameters (Guo et al., 2019). Ginting et al. (2003) found that manure application increased C and N balances without changes on soil C and N storage and global warming compared to the control plots 4 years after manure application. The 21-year long-term studies of Zhong et al. (2010) and Choudhary et al. (2018) reported that manure application increased soil quality compared to unfertilized control, particularly soil pH; organic C; total N, P, and K; and available N, P, and K content. In another study, Du et al. (2020) found a 8% increase in crop yields due to manure application compared to unamended plots, which is attributable to increase in soil organic C storage, soil pH, and nutrient concentrations, according to Cai et al. (2019). Under Sub-Saharan Africa conditions, Sileshi et al. (2017) observed higher increase (up to 100%) in crop yields following manure application. They attributed the yield increase to improved water holding capacity, increased cation-exchange capacity, and increased soil C. The results from this study suggest that 5 ton ha^{-1} of cattle manure + 5 ton ha^{-1} of sheep manure (T12) and 10 ton ha^{-1} of cattle manure (T5) could potentially provide the required nutrients for the plant to complete the flowering and seed formation stages in comparison to NPK fertilizers.

3.3 | Yield

Mungbean seed yield was significantly ($p < 0.05$) influenced by organic and inorganic fertilizers (Figure 5). Application of cattle manure at 10 ton ha^{-1} (T5) produced significantly higher seed yield than mungbean receiving NPK and no fertilizers, which corresponded to a 66% and 84% increase, respectively. Cattle manure (T5) is followed by compost (T3), compost + cattle manure (T8), and cattle manure + sheep manure (T12), though not statistically different to seed yield from NPK fertilized plants (Figure 5). On average, sole application of animal manures resulted in a seed yield of 14.4 g while their combination produced 11.7 g (Figure 5). The integrated use of compost and animal manure had an average seed yield of 11.8 g. Data on mungbean seed yield also showed that application of poultry manure alone or in combination with compost and other animal manure tended to produce lower seed yield compared to other fertilizer treatments (Figure 5).

Compost and manure and their combinations significantly ($p < 0.05$) increased yield and yield parameters of mungbean, as compared to mungbean plants fertilized with the recommended rate of NPK fertilizers. The results suggest that these soil amendments provided the soil nutrients for enhanced nutrition and production. In our study, cattle manure (T5) significantly ($p < 0.05$) increased mungbean seed yield compared to NPK treatments. Javaid and Bajwa (2011) also reported significant increases in mungbean grain yield following application of farmyard manure at 20 ton ha^{-1} compared to the recommended dose of NPK fertilizers. Similar results were reported following application of organic amendments to cowpea (Badar et al., 2015), peanut (Du et al., 2020), soybean (Choudhary et al., 2018), wheat and maize (Cai et al., 2019), and rice (Steiner et al., 2007). However, Sutrisno and

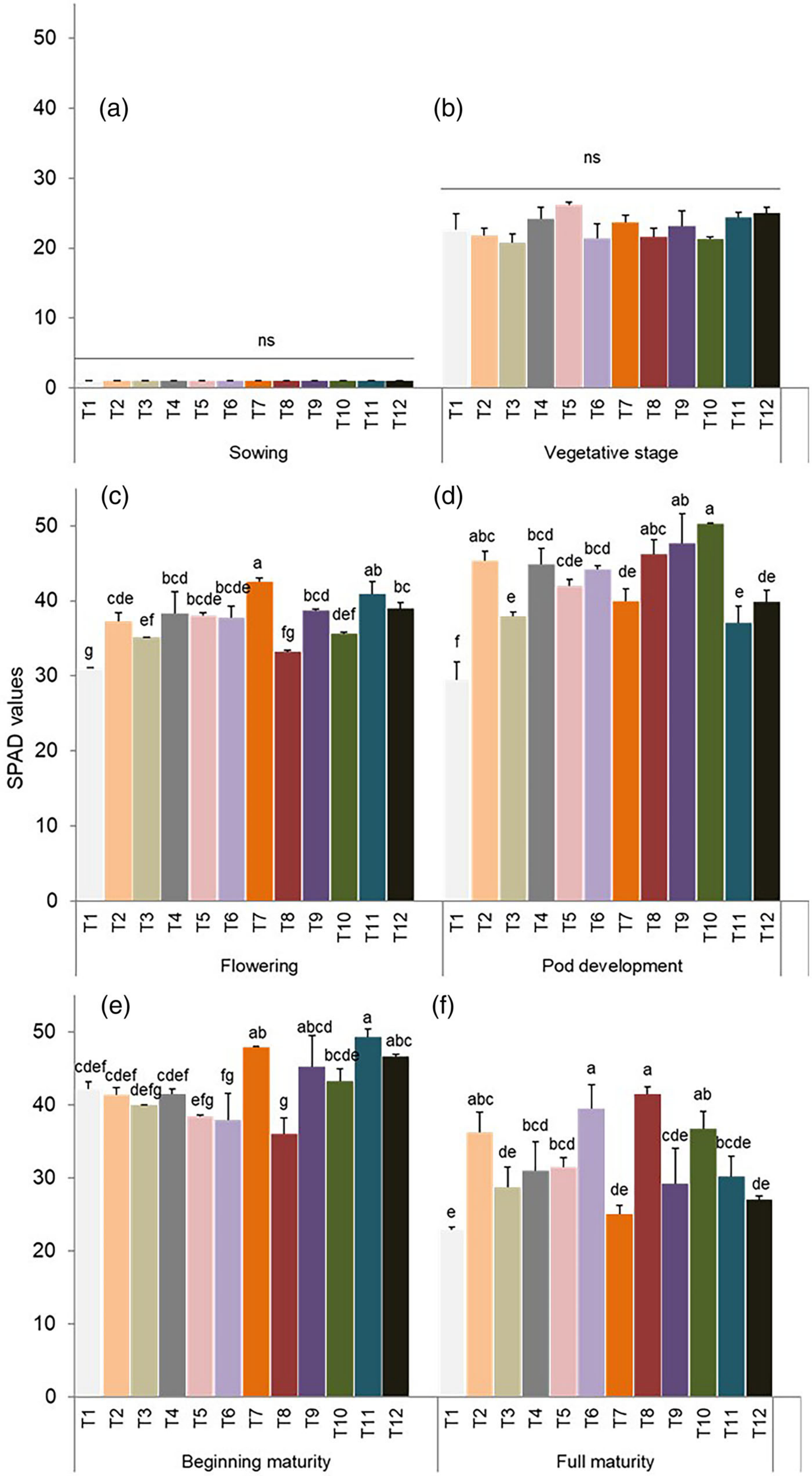

FIGURE 6 Effects of compost, animal manure, compost–manure combination, and inorganic fertilizer on mungbean soil plant analysis development (SPAD) values (S = sowing, V = vegetative stage, F = flowering, P = pod development, M (beg) = beginning maturity, M (full) = full maturity). Treatments with dissimilar letters are significantly different at $\alpha = 0.05$ according to Fisher's protected least significant difference and error bars represent standard error of the mean ($n = 72$). Control (T1), inorganic fertilizer (recommended nitrogen, phosphorus, and potassium [NPK]: 6-20-10 at 150 kg ha^{-1}) (T2), 5 ton ha^{-1} of compost (T3), 10 ton ha^{-1} of poultry manure (T4), 10 ton ha^{-1} of cattle manure (T5), 10 ton ha^{-1}

(Continues)

FIGURE 6 (Continued)
of sheep manure (T6), 2.5 ton ha^{-1} of compost + 5 ton ha^{-1} of poultry manure (T7), 2.5 ton ha^{-1} of compost + 5 ton ha^{-1} of cattle manure (T8), 2.5 ton ha^{-1} of compost + 5 ton ha^{-1} of sheep manure (T9), 5 ton ha^{-1} of poultry manure + 5 ton ha^{-1} of cattle manure (T10), 5 ton ha^{-1} of poultry manure + 5 ton ha^{-1} of sheep manure (T11), and 5 ton ha^{-1} of cattle manure + 5 ton ha^{-1} of sheep manure (T12).

Yusnawan (2018) reported that manure application at 5 ton ha^{-1} did not significantly increase mungbean seed yield compared to NPK fertilizers. Although the lack of yield increase was attributed to the low rate of applied manure, Adegbite et al. (2021) found that 12 ton ha^{-1} of cattle manure produced similar seed yield as inorganic N at 20 kg ha^{-1}. Others have attributed the lack in yield response following application of organic materials to the low quantity of readily available N for crop uptake (Chen et al., 2018; Edmeades, 2003; Sileshi et al., 2017). In the present study, differences in seed yields between organic amendments and inorganic fertilizers can be attributed to increased total soil C and N levels, which can last up to 4 years (Ginting et al., 2003). In addition, P, K, Mg, and Ca contents could be increased after applying organic amendments to soils, hence explaining the increased mungbean yield (Adegbite et al., 2021; McClintock & Diop, 2005; Tagoe et al., 2010). Oagile and Namasiku (2010) found significant increase in N, P, and exchangeable bases with the addition of up 20 w/w% manure, suggesting the positive effects of manure in improving soil fertility. Studies investigating the impacts of organic amendments on soil fertility and crop productivity have also reported significantly higher cation exchange capacity for manure and compost-amended soils than non-amended soils, demonstrating the importance of manure in modifying the soil exchange capacities (McClintock & Diop, 2005; Oagile & Namasiku, 2010; Ouédraogo et al., 2001; Steiner et al., 2007). The initial amounts of exchangeable bases were significantly higher for compost (1756 mg kg^{-1}) and animal manure (1440 mg kg^{-1}, on average) than the soil (679 mg kg^{-1}) (Table 1). Greater concentrations in exchangeable Ca were observed for all organic amendments, suggesting that the exchange capacity of the soils is mainly attributed to the Ca from organic materials. In addition, exchange sites in the soil particles could be freed up following organic amendment such as compost and cattle manure through the binding of cations in the soil solution, leading to greater nutrient concentrations (McClintock & Diop, 2005). Higher C levels through application of organic amendments could provide more stable humic complexes and result in increased adsorption capacity of the soil (McClintock & Diop, 2005). A greater stimulation of microbial-mediated release of nutrients can be also induced by the enhanced retention of moisture in the small pore size of more stable humic complexes (Zhong et al., 2010).

Among organic amendments, the significant increase in mungbean seed yield under cattle manure (T5) treatment compared to compost, poultry, and sheep manure could be due to its low electrical conductivity (Table 1). Research on single and combined application of organic and inorganic fertilizers has shown that lower electrical conductivity value for organic amendments improve crop yields through SOM maintenance and microbial activity (Du et al., 2020). This is supported by Oagile and Namasiku (2010) results, which indicated that electrical conductivity values lower than the 4 mS cm^{-1} critical value has no potential threat to soil productivity for crop growth. Therefore, cattle manure with lower electrical conductivity value (3.340 mS cm^{-1}) than the critical value and other organic amendments such as compost (5.920 mS cm^{-1}), poultry manure (6.530 mS cm^{-1}), and sheep manure (6.470 mS cm^{-1}) have lower potential to contribute toward salt buildup, which could explain the greater yield increase observed in our study by cattle manure. The chemical analysis of soil amended with manure showed enhanced cation exchange capacity and increased nutrient contents (K, Mg, and Al) (McClintock & Diop, 2005). In the present study, mungbean plants amended with manure yielded more than those receiving compost, probably due to the higher concentrations of C, N, P, K, Ca, Mg, and Fe in manure compared to compost. The advanced stage of decomposition of the compost has been shown to result in a C drop (up to 20%) and a possible loss of labile nutrients to leaching or volatilization (McClintock & Diop, 2005).

Several studies have shown that manure application could meet most of the N requirement of legume crops and produce higher yield than the only application of synthetic fertilizers (Badar et al., 2015; Choudhary et al., 2018; Du et al., 2020). These findings suggest that the judicious use of organic amendments in mungbean cultivation can produce seed yields equivalent or greater to those obtained with mineral fertilizers. Therefore, organic amendments have the potential to enhance crop yield and decrease the dependence on inorganic fertilizers, thus limiting the risks induced by extensive and inappropriate use of synthetic fertilizers. Research has also shown the positive effects of manure on mungbean tolerance to abiotic stresses and improved nutritional quality (Naeem et al., 2006; Nair et al., 2019; Sutrisno & Yusnawan, 2018). Therefore, research efforts should be encouraged to investigate the effects of separate and combined effects of organic amendments such as compost, manure, and inorganic fertilizers on mungbean productivity in semi-arid regions.

3.4 | SPAD values

Application of organic amendments, their combination and inorganic fertilizers induced significant differences ($p < 0.05$)

for the SPAD values during mungbean growth. On average, SPAD values continuously increased from the vegetative growth stage (23.01; Figure 6b) until the beginning of maturity to reach 42.46 (Figure 6e) and then decreased to 31.60 at full maturity (Figure 6f). However, there were no significant differences between fertilization treatments at sowing (Figure 6a) and vegetative stages (Figure 6). At flowering stage (Figure 6c), the SPAD values of mungbean amended with compost + poultry manure (T7) were 21% higher than values of NPK fertilized plants (35). At the pod development stage, when poultry manure was applied in combination with cattle manure (T10), SPAD values were increased by 33% over SPAD values of NPK treatments (Figure 6d). At the beginning and full maturity (Figure 6e and f), application of poultry manure + sheep manure (T11) and compost + cattle manure (T8) significantly increased SPAD values by 23% and 44% over the recommended rate of inorganic fertilizer (T2), respectively (Figure 6).

Few studies have shown that organic amendments could produce higher SPAD values than those of recommended rates of inorganic fertilizers. However, the results from this study indicate that application of organic amendments could reduce N losses by conserving soil N through the formation of organo-mineral complexes (Lal, 2006; McClintock & Diop, 2005; Tiquia et al., 2002), hence ensuring a continuous availability of N to mungbean for higher SPAD values. Other studies investigating the benefits of organic amendments to plant nutrition also attributed the enhanced SPAD values to increased N availability (Badar et al., 2015; Du et al., 2020; Ginting et al., 2003).

4 | CONCLUSION

This study was undertaken to assess the effects of integrated use of compost and animal manure on mungbean growth, yield, and yield components. Our results demonstrated that application of cattle manure at 10 ton ha^{-1} (T5) significantly increased mungbean seed yield by 66% compared to inorganic fertilizer treatments due to improved soil properties. There were also significant effects of organic amendments on mungbean growth and yield components. The higher yield obtained with the application of cattle manure can be attributed to the enhanced nutrient availability, resulting in greater plant height, stem diameter, number of branches, number of seeds per pod, number of pods, and pod weight. The results suggest that compost or cattle manure application can be a potential source of plant nutrients and soil conditioner. Future research could focus on the impacts of organic amendments on soil nutrient availability as well as the interactions between soil microorganism, OM, and nutrient dynamics. Research efforts can be directed toward promoting use of compost and animal manure as a sustainable management alternative to expensive and inaccessible synthetic fertilizers and support farmers' determination to adapt to increasingly challenging and unstable environment.

AUTHOR CONTRIBUTIONS

Andre Diatta: Conceptualization; data curation; formal analysis; methodology; writing—original draft. **César Bassène**: Methodology; supervision; validation. **Anicet Manga**: Methodology; supervision; validation. **Ozzie Abaye**: Conceptualization; methodology; writing—review and editing. **Wade Thomason**: Validation; writing—review and editing. **Martin Battaglia**: Formal analysis; writing—review and editing. **Emre Babur**: Writing—review and editing. **Omer Uslu**: Writing—review and editing. **Doohong Min**: Writing—review and editing. **Mahmoud Seleiman**: Writing—review and editing. **Jose Leme**: Writing—review and editing. **Cheikh Mbow**: Methodology; validation; writing—review and editing.

ACKNOWLEDGMENTS

The authors are grateful to the Département Productions Végétales et Agronomie, UFR des Sciences Agronomiques, de l'Aquaculture et des Technologies Alimentaires (S2ATA), Université Gaston Berger, for their support and technical assistance. The authors would also like to thank the anonymous reviewers for their valuable comments.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

REFERENCES

Abaye, A. O., Archibald, T. G., Vaughan, L., Thompson, T. L., Thomason, W. E., Mbaye, D. F., Mamadou, L., Abdoulaye, S., Gueye, F., & Snyder, G. (2018). *Internationalizing the land grant mission: Lessons from Senegal* (CSES-207P). Virginia Cooperative Extension.

Abaye, O., Trail, P., Gueye, T., Gueye, F., Mbaye, D., & Guisse, B. (2015). *Mungbean as an alternative high protein source food legume for Senegal*. Spanish Association for Legumes.

Adegbite, E. A., Atere, C. T., & Olayinka, A. (2021). Growth, nitrogen fixation and yields of cowpea (*Vigna unguiculata* L. Walp) and chemical properties of an acid Alfisol in response to applications of organic amendments and inorganic N. *Journal of Plant Nutrition*, *44*(5), 692–703.

Badar, R., Khan, M., Batool, B., & Shabbir, S. (2015). Effects of organic amendments in comparison with chemical fertilizer on cowpea growth. *International Journal of Applied Research*, *1*(45), 66–71.

Brunelle, T., Dumas, P., Souty, F., Dorin, B., & Nadaud, F. (2015). Evaluating the impact of rising fertilizer prices on crop yields. *Agricultural Economics*, *46*(5), 653–666.

Cai, A., Xu, M., Wang, B., Zhang, W., Liang, G., Hou, E., & Luo, Y. (2019). Manure acts as a better fertilizer for increasing crop yields than synthetic fertilizer does by improving soil fertility. *Soil and Tillage Research*, *189*, 168–175.

Chen, Y., Camps-Arbestain, M., Shen, Q., Singh, B., & Cayuela, M. L. (2018). The long-term role of organic amendments in building soil nutrient fertility: A meta-analysis and review. *Nutrient Cycling in Agroecosystems*, *111*(2), 103–125.

Choudhary, M., Panday, S. C., Meena, V. S., Singh, S., Yadav, R. P., Mahanta, D., Mondal, T., Mishra, P. K., Bisht, J. K., & Pattanayak, A. (2018). Long-term effects of organic manure and inorganic fertilization on sustainability and chemical soil quality indicators of soybean-wheat cropping system in the Indian mid-Himalayas. *Agriculture, Ecosystems & Environment*, *257*, 38–46.

Chopart, J. L. (1980). Etude au champ des systèmes racinaires des principales cultures pluviales au Sénégal (Arachide Mil-Sorgho-Riz pluvial); Thèse I.N.P.: Toulouse, France.

Ciaccia, C., Ceglie, F., Tittarelli, F., Antichi, D., Carlesi, S., Testani, E., & Canali, S. (2017). Green manure and compost effects on NP dynamics in Mediterranean organic stockless systems. *Journal of Soil Science and Plant Nutrition*, *17*(3), 751–769.

Cisse, M., Diouf, M., Gueye, T., & Fall, A. (2011). Linking policy, research, agribusiness and processing enterprise to develop mungbean (*vigna radiata*) production as export crop from Senegal River Valley. In A. Bationo, B. Waswa, J. M. Okeyo, F. Maina, & J. M. Kihara (Eds.), *Innovations as key to the green revolution in Africa* (pp. 905–912). Springer.

Cobb, A. B., Wilson, G. W. T., Goad, C. L., & Grusak, M. A. (2018). Influence of alternative soil amendments on mycorrhizal fungi and cowpea production. *Heliyon*, *4*(7), e00704.

Dahiya, P. K., Linnemann, A. R., Van Boekel, M. A. J. S., Khetarpaul, N., Grewal, R. B., & Nout, M. J. R. (2015). Mung bean: Technological and nutritional potential. *Critical Reviews in Food Science and Nutrition*, *55*(5), 670–688. https://doi.org/10.1080/10408398.2012.671202

Dey, S. K., Chakrabarti, B., Prasanna, R., Mittal, R., Singh, S. D., & Pathak, H. (2016). Growth and biomass partitioning in mungbean with elevated carbon dioxide, phosphorus levels and cyanobacteria inoculation. *Journal of Agrometeorology*, *18*(1), 7–12.

Dhakal, Y., Meena, R. S., De, N., Verma, S. k., & Singh, A. (2015). Growth, yield and nutrient content of mungbean (*Vigna radiata* L.) in response to INM in eastern Uttar Pradesh, India. *Bangladesh Journal of Botany*, *44*(3), 479–482.

Diatta, A. A., Abaye, O., Thomason, W. E., Lo, M., Thompson, T. L., Vaughan, L. J., Gueye, F., & Diagne, N. (2020). Evaluating pearl millet and mungbean intercropping in the semi-arid regions of Senegal. *Agronomy Journal*, *112*(5), 4451–4466.

Diatta, A. A., Fike, J. H., Battaglia, M. L., Galbraith, J. M., & Baig, M. B. (2020). Effects of biochar on soil fertility and crop productivity in arid regions: A review. *Arabian Journal of Geosciences*, *13*(14), 595.

Diatta, A. A., Min, D., & Jagadish, S. K. J. A. I. A. (2021). Drought stress responses in non-transgenic and transgenic alfalfa—current status and future research directions. *Advances in Agronomy*, *170*, 35–100.

Diatta, A. A., Thomason, W. E., Abaye, O., Thompson, T. L., Battaglia, M. L., Vaughan, L. J., Lo, M., & Filho, J. F. D. C. L. (2020). Assessment of nitrogen fixation by mungbean genotypes in different soil textures using 15N natural abundance method. *Journal of Soil Science and Plant Nutrition*, *20*(4), 2230–2240.

Du, Y., Cui, B., Zhang, Q., Wang, Z., Sun, J., & Niu, W. (2020). Effects of manure fertilizer on crop yield and soil properties in China: A meta-analysis. *Catena*, *193*, 104617.

Edmeades, D. C. (2003). The long-term effects of manures and fertilisers on soil productivity and quality: A review. *Nutrient Cycling in Agroecosystems*, *66*(2), 165–180.

FAOSTAT. (2022). *Livestock manure. Inputs. land, inputs and sustainability*. https://www.fao.org/faostat/en/#data/EMN

Faye, A., Stewart, Z. P., Diome, K., Edward, C.-T., Fall, D., Ganyo, D. K. K., Akplo, T. M., & Prasad, P. V. V (2021). Single application of biochar increases fertilizer efficiency, C sequestration, and pH over the long-term in sandy soils of Senegal. *Sustainability*, *13*(21), 11817.

Ginting, D., Kessavalou, A., Eghball, B., & Doran, J. W. (2003). Greenhouse gas emissions and soil indicators four years after manure and compost applications. *Journal of Environmental Quality*, *32*(1), 23–32.

Gitelson, A. A., Gritz , Y., & Merzlyak, M. N. (2003). Relationships between leaf chlorophyll content and spectral reflectance and algorithms for non-destructive chlorophyll assessment in higher plant leaves. *Journal of Plant Physiology*, *160*(3), 271–282. https://doi.org/10.1078/0176-1617-00887

Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research*. John Wiley & Sons.

Guo, Z., Zhang, J., Fan, J., Yang, X., Yi, Y., Han, X., Wang, D., Zhu, P., & Peng, X. (2019). Does animal manure application improve soil aggregation? Insights from nine long-term fertilization experiments. *Science of The Total Environment*, *660*, 1029–1037.

Gupta, S., & Larson, W. J. W. (1979). Estimating soil water retention characteristics from particle size distribution, organic matter percent, and bulk density. *Water Resources Research*, *15*(6), 1633–1635.

Harris, F. (2002). Management of manure in farming systems in semi-arid West Africa. *Experimental Agriculture*, *38*(2), 131–148.

Herrick, J. E., Urama, K. C., Karl, J. W., Boos, J., Johnson, M.-V. V., Shepherd, K. D., Hempel, J., Bestelmeyer, B. T., Davies, J., Guerra, J. L., Kosnik, C., Kimiti, D. W., Ekai, A. L., Muller, K., Norfleet, L., Ozor, N., Reinsch, T., Sarukhan, J., & West, L. T. (2013). The global Land-Potential knowledge system (LandPKS): Supporting evidence-based, site-specific land use and management through cloud computing, mobile applications, and crowdsourcing. *Journal of Soil and Water Conservation*, *68*(1), 5A–12A.

Islam, M. R., Jahan, R., Uddin, S., Harine, I. J., Hoque, M. A., Hassan, S., Hassan, M. M., & Hossain, M. A. (2021). Lime and organic manure amendment enhances crop productivity of wheat–mungbean–t. aman cropping pattern in acidic piedmont soils. *Agronomy*, *11*(8), 1595.

Javaid, A., & Bajwa, R. (2011). Field evaluation of effective microorganisms (EM) application for growth, nodulation, and nutrition of mung bean. *Turkish Journal of Agriculture and Forestry*, *35*(4), 443–452.

Jones, D. L., Hodge, A., & Kuzyakov, Y. (2004). Plant and mycorrhizal regulation of rhizodeposition. *New Phytologist*, *163*(3), 459–480.

Kang, Y. J., Kim, S. K., Kim, M. Y., Lestari, P., Kim, K. H., Ha, B. o-K., Jun, T. H., Hwang, W. J., Lee, T., Lee, J., Shim, S., Yoon, M. Y., Jang, Y. E., Han, K. S., Taeprayoon, P., Yoon, N. A., Somta, P., Tanya, P., Kim, K. S., … Lee, S.-H. (2014). Genome sequence of mungbean and insights into evolution within *Vigna* species. *Nature Communications*, *5*, 5443. https://doi.org/10.1038/ncomms6443

Keatinge, J. D. H., Easdown, W. J., Yang, R. Y., Chadha, M. L., & Shanmugasundaram, S. (2011). Overcoming chronic malnutrition in a future warming world: The key importance of mungbean and vegetable soybean. *Euphytica*, *180*(1), 129–141. https://doi.org/10.1007/s10681-011-0401-6

Kjeldahl, J. (1883). A new method for the determination of nitrogen in organic matter. *Zeitschrift Fur Analytische Chemie*, *22*, 366–382.

Lal, R. (2006). Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural lands. *Land Degradation & Development*, *17*(2), 197–209.

Lal, R. (2020). Soil organic matter content and crop yield. *Journal of Soil and Water Conservation*, *75*(2), 27A–32A.

Liu, J., You, L., Amini, M., Obersteiner, M., Herrero, M., Zehnder, A. J. B., & Yang, H. (2010). A high-resolution assessment on global nitrogen flows in cropland. *Proceedings of the National Academy of Sciences*, *107*(17), 8035–8040.

Manga, A. G. B., Ndiaye, M., Ndiaye, M. A. F., Sané, S., Diop, T. A., Diatta, A. A., Bassene, C., Min, D., Battaglia, M., & Harrison, M. T. (2022). Arbuscular mycorrhizal fungi improve growth and phosphate nutrition of *Acacia seyal* (Delile) under saline conditions. *Soil Systems*, *6*(4), 79.

Manna, M., Swarup, A., Wanjari, R., Mishra, B., & Shahi, D. (2007). Long-term fertilization, manure and liming effects on soil organic matter and crop yields. *Soil and Tillage Research*, *94*(2), 397–409.

Massah, J., & Azadegan, B. (2016). Effect of chemical fertilizers on soil compaction and degradation. *Agricultural Mechanization in Asia, Africa and Latin America*, *47*(1), 44–50.

Mathieu, C., Pieltain, F., & Jeanroy, E. (2003). *Analyse chimique des sols: Méthodes choisies*. Tec & doc.

Mbow, C., Rosenzweig, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., Liwenga, E., Pradhan, P., Rivera-Ferre, M.-G., & Sapkota, T. (2019). Food security. In P. R. Shukla et al. (Eds.), *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. IPCC. https://www.ipcc.ch/srccl/chapter/chapter-5/

Mcclintock, N. C., & Diop, A. M. (2005). Soil fertility management and compost use in Senegal's peanut basin. *International Journal of Agricultural Sustainability*, *3*(2), 79–91.

Naeem, M., Iqbal, J., & Bakhsh, M. (2006). Comparative study of inorganic fertilizers and organic manures on yield and yield components of mungbean (*Vigna radiat* L.). *Journal of Agriculture and Social Sciences*, *2*(4), 227–229.

Naeem, M. A., Muhammad, K., Muhammad, A., & Rashid, A. (2014). Yield and nutrient composition of biochar produced from different feedstocks at varying pyrolytic temperatures. *Pakistan Journal of Agricultural Sciences*, *51*(1), 75–82.

Nair, R. M., Pandey, A. K., War, A. R., Hanumantharao, B., Shwe, T., Alam, A., Pratap, A., Malik, S. R., Karimi, R., Mbeyagala, E. K., Douglas, C. A., Rane, J., & Schafleitner, R. (2019). Biotic and abiotic constraints in mungbean production—Progress in genetic improvement. *Frontiers in Plant Science*, *10*, 1340. https://doi.org/10.3389/fpls.2019.01340

Nelson, D. W., & Sommers, L. E. (1996). Total carbon, organic carbon, and organic matter. In D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston, & M. E. Sumner (Eds.), *Methods of* soil analysis*: Part 3* chemical methods (pp. 961–1010). Soil Science Society of America, Inc., American Society of Agronomy, Inc.

Oagile, D., & Namasiku, M. (2010). Chicken manure-enhanced soil fertility and productivity: Effects of application rates. *Journal of Soil Science and Environmental Management*, *1*(3), 46–54.

Obi, M. E., & Ebo, P. O. (1995). The effects of organic and inorganic amendments on soil physical properties and maize production in a severely degraded sandy soil in southern Nigeria. *Bioresource Technology*, *51*(2–3), 117–123.

Oldfield, E. E., Bradford, M. A., & Wood, S. A. (2019). Global meta-analysis of the relationship between soil organic matter and crop yields. *Soil*, *5*(1), 15–32.

Olsen, S. R., & Sommers, L. E. (1983). Phosphorus. In A. L. Page (Ed.), *Methods of soil analysis: Part 2 chemical and microbiological properties* (pp. 403–430). Soil Science Society of America, Inc., American Society of Agronomy, Inc.

Ouédraogo, E., Mando, A., & Zombré, N. (2001). Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa. *Agriculture, Ecosystems & Environment*, *84*(3), 259–266.

Peng, X., Horn, R., & Hallett, P. (2015). Soil structure and its functions in ecosystems: Phase matter & scale matter. *Soil & Tillage Research*, *146*, (Part A), 1–3.

Raina, S. K., Govindasamy, V., Kumar, M., Singh, A. K., Rane, J., & Minhas, P. S. (2016). Genetic variation in physiological responses of mungbeans (*Vigna radiata* (L.) Wilczek) to drought. *Acta Physiologiae Plantarum*, *38*(11), 263. https://doi.org/10.1007/s11738-016-2280-x

Senaratne, R., Liyanage, N. D. L., & Soper, R. J. (1995). Nitrogen fixation of and N transfer from cowpea, mungbean and groundnut when intercropped with maize. *Fertilizer Research*, *40*(1), 41–48. https://doi.org/10.1007/bf00749861

Sileshi, G. W., Nhamo, N., Mafongoya, P. L., & Tanimu, J. (2017). Stoichiometry of animal manure and implications for nutrient cycling and agriculture in sub-Saharan Africa. *Nutrient Cycling in Agroecosystems*, *107*(1), 91–105.

Steiner, C., Teixeira, W. G., Lehmann, J., Nehls, T., De Macêdo, J. L. V., Blum, W. E. H., & Zech, W. (2007). Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant and Soil*, *291*(1), 275–290.

Sutrisno, S., & Yusnawan, E. (2018). Effect of manure and inorganic fertilizers on vegetative, generative characteristics, nutrient, and secondary metabolite contents of mungbean. *Biosaintifika: Journal of Biology & Biology Education*, *10*(1), 56–65.

Tagoe, S. O., Horiuchi, T., & Matsui, T. (2010). Effects of carbonized chicken manure on the growth, nodulation, yield, nitrogen and phosphorus contents of four grain legumes. *Journal of Plant Nutrition*, *33*(5), 684–700.

Tiquia, S. M., Richard, T. L., & Honeyman, M. S. (2002). Carbon, nutrient, and mass loss during composting. *Nutrient Cycling in Agroecosystems*, *62*(1), 15–24.

Trail, P., Abaye, O., Thomason, W. E., Thompson, T. L., Gueye, F., Diedhiou, I., Diatta, M. B., & Faye, A. (2016). Evaluating intercropping (living cover) and mulching (desiccated cover) practices for increasing millet yields in Senegal. *Agronomy Journal*, *108*, 1742–1752. https://doi.org/10.2134/agronj2015.0422

Vashro, T. N., Farris, A., Kraak, V. I., Hulver, M. W., Gueye, F., & Abaye, A. O (2018). Effects of mung bean consumption on dietary diversity of women and children in Senegal. *Journal of Nutritional Ecology and Food Research*, *5*(1), 40–46. https://doi.org/10.1166/jnef.2018.1181

Walkley, A., & Black, I. A (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, *37*(1), 29–38.

Wei, W., Yan, Y., Cao, J., Christie, P., Zhang, F., & Fan, M. (2016). Effects of combined application of organic amendments and fertilizers on crop yield and soil organic matter: An integrated analysis of long-term experiments. *Agriculture, Ecosystems & Environment*, *225*, 86–92.

Yehuala, K., Daneil, A., Abiro, T., Amsalu, A., & Dejene, M. (2018). Participatory on farm evaluation of improved mungbean technologies in the low land areas of North Shewa Zone Amhara Region, Ethiopia. *Journal of Agricultural Extension and Rural Development*, *10*(8), 158–164. https://doi.org/10.5897/jaerd2018.0962

Zhong, W., Gu, T., Wang, W., Zhang, B., Lin, X., Huang, Q., & Shen, W. (2010). The effects of mineral fertilizer and organic manure on soil microbial community and diversity. *Plant and Soil*, *326*(1), 511–522.

Zhongqi, H., Pagliari, P. H., & Waldrip, H. M. (2016a). Applied and environmental chemistry of animal manure: A review. *Pedosphere*, *26*(6), 779–816.

Zhongqi, H., Pagliari, P. H., & Waldrip, H. M. J. P. (2016b). Applied and environmental chemistry of animal manure: A review. *Pedosphere*, *26*(6), 779–816.

How to cite this article: Diatta, A. A., Bassène, C., Manga, A. G. B., Abaye, O., Thomason, W., Battaglia, M., Babur, E., Uslu, Ö., Min, D., Seleiman, M., Filho, J. F. D. C. L., & Mbow, C. (2023). Integrated use of organic amendments increased mungbean (*Vigna radiata* (L.) Wilczek) yield and its components compared to inorganic fertilizers. *Urban Agriculture & Regional Food Systems*, *8,* e20048. https://doi.org/10.1002/uar2.20048