Short term effects of Municipal Solid Waste compost, Khat-Derived Biochar and Co-composted Biochar on Soil quality and Faba bean Yield and Protein content

Zewdu Abebe Tessfaw (zewdutessfaw@gmail.com)
Jimma University
Abebe Beyene
Jimma University
Amsalu Nebiyu
Jimma University
Krzysztof Pikoń
Silesian University of Technology
Marcin Landrat
Silesian University of Technology

Research Article

Keywords: co-composted biochar, biochar, compost, soil quality, faba bean yield, grain quality

Posted Date: April 27th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-424999/v1

Abstract

The effects of organic fertilizer to improve soil fertility and crop yield depend on the quality of organic fertilizer. The aim of this study was to test the short-term effects of the applications of municipal solid wastes (MSW) compost, co-composted biochar and biochar on soil quality and faba bean (Vicia faba L.) grain yield and protein content compared with mineral fertilizer. The study was conducted in a field experiment prepared in randomized complete block design with three replicates of each treatment from February 2019 to June 2019. The eight treatments were; control compost, 5%, 15% and 25% w/w co-composted biochars, recommended rate of mineral N & P fertilizer (NPF), biochar, compost + 50% NPF, and control soil. Results showed that the soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable K+, Ca + 2 and Mg + 2 CEC and moisture in the residual soil were significantly increased in the municipal solid waste compost, co-composted biochar and khat-derived biochar amendments compared to the mineral NPF and control soil treatments. The faba bean grain yield was increased significantly ($p < 0.05$) by 34.2%, 33.7% and 30.% compared to the control soil and by 11.3%, 10.9% and 7.8% compared to the mineral NPF for the 5% co-composted biochar, compost + 50% NPF and control compost respectively. The organic fertilizer amendments with or without NPF applications were better than NPF alone with promoting nutrient concentrations, faba bean grain yield and protein contents. Thus, MSW compost and co-composted biochars are recommended because of their easy availability, sustainability and sufficient for proper growth of faba bean.

1. Introduction

Faba bean (*Vicia faba L.*) is the third most important legume crop which grows in many parts of the world after soybean (Glycine max L.) and pea (Pisum sativum L.). It is an important and sustainable source of nutrients for human diet, particularly carbohydrates and proteins [1,2]. Moreover, faba beans contain bioactive substances, such as phenolic compounds, which are essential for their antioxidant activity and healthy feature [1,3]. Due to its nitrogen fixing capacity, it is used in crop rotation with important cereal crops like wheat, barley and other.

Faba bean is ranked first in its production land area among pulse crops cultivated in Ethiopia and it is valued as the cheap source of protein in most Ethiopian diet [4–6]. Even though it is the leading pulse crop in the country, the yield in the country in general is below the world average production yield which is less than 2 ton ha^{-1} [7]. Several biotic and abiotic factors contributed to low productivity of faba bean in the Ethiopia.

Soil fertility associated with low availability of nutrients is a major abiotic factor affecting the growth and yield of crops [8]. Ethiopian soils are recently reported to exhibit multi-nutrient deficiency [9]. Hence, soil acidity and fertility problems are main constrains for low yield of faba bean production in Ethiopia [7]. Soil acidity affects the availability of important plant nutrients in the soil. Approximately 50% of the worlds' arable soils and about 41% of Ethiopians is covered by acid soil [9,10]. Acidic soil can inhibit plant nutrients and biological nitrogen fixation (BNF) potential by legumes. Soil acidity is one of a biotic factor that globally known to reduce nodulation and faba bean yield. Therefore, it is crucial to maintain soil fertility by simple and sustainable methods.

Different soil fertility management practices are favorable to enhance soil fertility and to optimize crop yields including faba beans. But, a possible and sustainable tool is the use of organic amendments such as compost, manure and biochar [11]. Many studies have shown that the addition of organic fertilizers to agricultural soils can effectively improve soil quality and crop yield [12–14]. Soil fertility is a functions of different soil parameters such as water holding capacity, soil organic matter level (SOM), cation exchange capacity (CEC) and clay content [15]. The most important of these factors is SOM as it improves other variables such as nutrient and water storage, intact filter capacity, aeration and CEC and habitat for soil organism.

Organic fertilizers are derived from animal or plant matter, and their application can modify soil physicochemical conditions due to the abundance of organic matter and balancing of nutrient levels [16]. Both compost and biochar are organic fertilizers which can be applied to the soil either in combination or alone to sustainably improve soil fertility [17–19]. But, many studies have shown that the combined application of compost and biochar had more positive synergistic effects on soil nutrient contents, water-holding capacity, soil microbial activities and crop yield [15,17–20]. Co-composted biochar is an organic fertilizer in which biochar can be mixed with composting feedstocks during the composting process [21]. Co-composted biochar is also rich in organic matter, nutrients and microorganisms which have a high agronomical value, but the value depends largely on the soil it is applied to and on the kind of crops produced on that soil [22]. Although, a few studies have investigated the effects of co-composted biochar on soil fertility and crop growth and yield, the mechanisms of the synergic effects are not clear until now. So, more investigations on the characteristics and mechanisms of the synergic effects of biochar and compost on soil fertility and plant growth are needed [17].

Previous studies have shown that the generations of large volume of organic solid wastes from agricultural, industrial and municipal sources lead to the production of organic fertilizer for soil applications [19,23,24]. Agricultural utilization of municipal solid waste (MSW) is become one of the most promising and cost effective options for disposal of MSW. Co-composted biochar derived from municipal organic solid wastes for soil application to enhance crop yield is a current research topic worldwide [21,25–28].

An important issue in use of organic fertilizer is social perception and agricultural acceptance [29]. Currently, the agricultural use of recovered organic fertilizer is limited. The most critical factor that affected the adoption of compost and manure technology was knowledge [29]. Farmers knowledge on co-composting will therefore need to be raised substantially through field observations before appreciable levels of adoption can be expected. Therefore, this study was aimed to assess the effects of the applications of biochar, compost and co- composted biochars derived from municipal organic solid wastes on the quality of acidic soil, yield and protein content of faba bean.

2. Materials And Methods

2.1 Description of the Study area

The study was carried out at Debre Markos University located in north-western, Ethiopia (Fig. 1). Its astronomical location is 10º 21” North Latitude and 37º 43’ East Longitude and an elevation of 2,446 meters. As typical of the elevated portions of Ethiopia the climate is subtropical highland, despite the proximity to the Equator. March is the warmest month with 25.1°C and July the coldest with 18.9°C in the average monthly temperature. The fall of the rain is considerably irregular going from 12 mm in January to 309 mm in July, being therefore still the main differentiator of the seasons of the year.

2.2 Description of organic amendments

The biochar used was prepared by slow pyrolysis of khat (*Catha edulis*) straw at 350ºC. Khat-derived biochar was co-composted with organic fraction of municipal solid waste at Jimma University College of agriculture and veterinary from October to December 2018 (about 88 days). Four co-composted biochars were prepared aerobically from mixed organic municipal solid wastes collected from Jimma city municipal solid waste disposal site with khat straw biochar at rates of 0, 5%, 15% and 25% (w/w). i.e i) control compost mix (no biochar), ii) 5% co-composted biochar (95%w/w organic waste mix + 5% w/w biochar), iii) 15 % co-composted biochar (85% w/w organic waste mix + 15% w/w biochar), iv) 25% co-composted biochar (75% w/w organic waste mix + 25% w/w biochar). The physico-chemical properties of amendments were showed in Table 1 [30].

2.3 Field Experiment Design and Treatments

A Faba bean seed (Vicia faba L.) samples were collected from Adet Agricultural Research Center (AARC) by taking supportive letter from Jimma University. Faba bean is selected as a test crop because of, it is the 3rd most commonly grown within the study area and sensitive in acidic soil. Seeds were sown in solid rows having a depth of 5–7 cm, row to row distance of 40 cm and plant to plant distance of 10 cm [31]. Although, the growth parameters are varied with plant varieties, the dosha faba bean seed variety is used for the study. 120 plants were grown per plot (6 plants horizontally and 20 plants vertically in a line). The field experiment was conducted from February to July, 2019 at Debremarkos University soil and plant science department field research site with irrigation system. The field experiment site was selected based on the information of it’s soil acidity and water availability for irrigation.

The experimental land was divided into triplication unit plots with size of 5 m^2 (2.5m× 2m) in a randomized complete block design for the eight treatments (Fig. 2). Chemical fertilizer and organic materials were added to the excavated fertilization caves between rows according to field management practice. The eight treatments were as follow i) control compost (no biochar), ii) 5% co-composted biochar, iii) 15 % co-composted biochar, iv) 25% co-composted biochar, v) recommended rate N & P fertilizer (100% NPF), vi) 50% NPF + compost, vii) Khat biochar and viii) control soil (soil alone). Compost, biochar and co-composted biochar were added at rate of 10 ton ha^{-1}. The application rate of compost was determined according to [32,33].

Table 1
The physicochemical properties of khat-derived biochar and four different types of co-composted biochar is present below. Results are expressed as mean values ± SD, n = 3.

Parameters	Units	Treatments				
		Khat-derived biochar	control compost	5% co-composted biochar	15% co-composted biochar	25% co-composted biochar
EC	dS/m	1.6 ± 0.02a	0.75 ± 0.01b	0.51 ± 0.02c	0.63 ± 0.01d	0.42 ± 0.04e
pH		8.9 ± 0.01a	8.24 ± 0.33b	8.29 ± 0.34b	8.52 ± 0.36d	8.61 ± 0.15d
Moisture content	%	9.7 ± 0.23a	53.8 ± 1.18b	47.57 ± 0.92c	46.85 ± 0.56c	44.54 ± 0.78c
Organic matter	%	88.4 ± 0.67a	33.32 ± 0.35b	40.26 ± 0.75c	37.09 ± 0.93c	30.77 ± 1.25b
Total organic carbon	%	47.7 ± 0.36a	18.0 ± 0.5bde	21.5 ± 0.8cd	19.38 ± 0.34bcd	16.76 ± 1.08e
CEC	cMole(+)/kg	113.41 ± .5a	105.4 ± 0.7b	177.95 ± 1.1c	121.61 ± 0.7d	112.06 ± 2.7e
C:N ratio		31.8 ± 0.1a	11.26 ± 0.6b	14.97 ± 0.8c	16.07 ± 1.68cd	17.33 ± 0.79d

Tukey HSD ($p < 0.05$; means within a row followed by different letters are significantly different).

2.4 Soil and Plant sample collection

Soil samples were taken before treatment application and after faba bean harvesting stage from each of the plots of the 8 treatments. Soil samples were collected from a depth of 15–20 cm. The physical and chemical property of the studied soil is presented in Table 2.

The necessary field management practices were carried out as per the practices followed by the farming community around the study area. In addition, all the field experiments involving were conducted according the guideline written in [34]. Plant samples were collected according to the procedures described in [35] for aboveground growth parameters analysis. The faba bean plants, about 10% (12 plants) were collected per plot. Sampling was done when the pods became brown to black in color. From the inner rows, all plant samples from each treatment were randomly sampled and marked with a sample card. From these sampled plant growth data, such as plant height, number of pods $plant^{-1}$, number of seeds pod^{-1}, 100- seed weight (g) and grain yield (kg ha^{-1}) were recorded.

2.5 Analytical procedure for Soil Sample analysis

Bulk density (BD) was determined on the undisturbed soil sample using the core method, in which the samples were dried in an oven set at 105°C to constant weight [36]. Soil texture was determined using Bouyoucos hydrometer method [37]. The pH in the soil was determined potentiometrically by weighing 10 gm of air dried soil (< 2 mm) sample with 1:2.5 soil/water suspension [38]. Organic carbon was determined following the Walkley wet digestion method and total nitrogen was determined by Kjeldahl digestion, distillation and titration procedures as described by [38]. Potassium (K), calcium (Ca), and magnesium (Mg) were determined from 1 gm of air dry soil sample extracted with 10 mL of 1 N ammonium acetate kept for overnight and filtered using Whatman paper number 42 and final volume was diluted up to 50 mL deionized water. Ammonium acetate extract of the soil samples was determined by atomic absorption spectroscopy (AAS) [39]. Available Phosphorus in the soil samples was determined by leaching the soil with 0.002N H_2SO_4 (1 soil : 200 H_2SO_4 suspension, w/v) and shaken for at least 30 minutes and filtered through Whatman filter paper No. 42 to get a clear solution. The amount of phosphorus in the extract was estimated by chlorostannous reduced phosphomolybdate blue colour method using spectrophotometer at wavelength of 690 nm [38,40] and CEC by using an ammonia electrode [41]. The crude proteins content (N × 6.25) of the seeds was determined by Kjeldahl nitrogen, according to the AOAC method 979.09 [40]. Moisture content in soil was determined from weight loss by placing 10 g of air dried raw soil in beaker and heating with oven at 105^0 C until constant weight obtained. Quality control was based on the use of blank solvents and internal standards.

2.6 Statically analysis

The effects of organic fertilizers amendments on soil parameters and faba bean growth parameters and grain protein contents were determined using one-way analysis of variance (ANOVA) followed by Tukey HDS test (at the 0.05 significance level) between treatments [42]. Statistical analysis was performed using the statistical package SPSS (IBM version 21).

3. Result And Discussions

3.1 Soil physicochemical properties before treatment

The data in the Table 2 showed that the physical and chemical parameters of the soil samples from the study site. Soil pH (H_2O) analyses showed that the studied soil was classified as acidic (5.25 ± 0.5) in 1:2.5 soil: water ratio. Soil pH affects the availability of soil nutrients for plants in the soil solutions. In more acidic soil or at low pH, the availability of crop nutrients is low, and at higher pH or more alkaline soil media, there is an increasing in the likelihood of nutrients to tie up in the soil. The optimum soil pH range for most crops is 6.0–7.5 and for faba bean and other alkaline preferring crops 6.0–8.0 [43,44], which crop nutrients are available. Liming is required for faba bean cultivation as the pH of the study soil was less than 6.0. The soil had a clay characteristic which is 4 % of sand, 30 % silt and 66% of clay texture classes with bulk density of 1.04 g/cm^3. The exchangeable base concentrations in the soil with unit of Cmole/kg were 9.8 of Ca, 1.0 of Mg and 4.2 of K. The soil had moderate value of cation exchange capacity (26.64 Cmole/kg). The total nitrogen and phosphorous contents were 0.21% and 35.49 mg/kg respectively. The soil having low organic carbon contents (1.50%). This confirmed that the Ethiopian cultivated soil has low organic carbon contents.

Table 2
Some physicochemical properties of studied soil before amendments is presented below. Results are expressed as mean values ± SD, n = 3.

Soil parameter	Unit	Value
Sand	%	4
Clay	%	66
Silt	%	30
Texture class		Clay
Bulk density	$g\ cm^{-3}$	1.04
pH (H_2O)		5.25
Exchangeable Ca^{2+}	Cmole/kg	9.8
Exchangeable Mg^{2+}	Cmole/kg	1
Exchangeable K^{+}	Cmole/kg	4.20
CEC	Cmole/kg	26.64
Available P	ppm	35.49
Total N	%	0.21
Organic carbon (OC)	%	1.50

3.2 Effects of Amendments on Soil Residual physicochemical properties

The findings in the present study have shown that, there is an increasing in the residual physico-chemical properties of a soil with the application of MSW compost, co-composted biochar and khat biochar and combined application of compost and mineral NPF, but decreased in the control soil and mineral 100% NPF in the short term applications (Table 3). The residual soil pH increased by 0.33–0.55 units after amending of acidic soil with biochar, compost and co-composted biochars and reduced by 0.2 units for control soil and mineral NPF from the value before harvesting. The reduction in the soil acidity or the increasing of pH in the MSW organic fertilizer amended soils is due to the organic amendments are alkaline which can directly increase the soil pH during applications. Moreover, the higher cation exchange capacity of the strong conjugated bases (COO^{-}) of the weak humic acid of these amendments, which have the capacity of binding Al, Mn and Fe with the negative charge sites. The increasing in the pH of studied soil due to the application of compost, biochar and co-composted biochar is in line with the findings in [20,45]. Many studies have reported that organic amendments such as biochar, manure and compost increase soil residual pH [20,46,47]. Unlikely, [11] observed that the soil pH was reduced under mineral fertilizer treatments. According to [15], lone compost application has a liming effect due to its richness in alkaline cations such as Ca, Mg, and K, which are liberated from organic matter faster mineralization.

The moisture contents of residual soils were lower in 100% NPF, while higher in the compost, co-composted biochars and khat-derived biochar treatments, than in the control soil (Table 3). The highest residual moisture content (11.5%) was observed in the 5% co-composted biochar treated soil. This study confirmed that application biochar during composting process improved water holding capacity of the co-composted biochar treated soil. But, inorganic fertilizer application decreased water retention capacity of the residual soil due to the deceasing in organic matter content. [48] observed the increasing in the moisture of biochar-amended composts with beneficial effects on the composting process. Similar reports by [49] showed that the organic soil amendments increased water retention potential of a soil, which is attributed to a significant increase of soil organic matter and specific surface area.

The results showed that there were significant differences ($p < 0.05$) in the residual soil total organic carbon (TOC) contents between the MSW compost, co-composted biochars and biochar amendments and the control soil or 100% NPF (Table 3). The residual total organic carbon (TOC) decreased both in the control soil and 100% NPF after harvesting by 1.33%, while it was increased by 7.3% – 43.3% for control compost, 5%, 15%, 25% w/w co-composted biochars, khat biochar and 50% NPF + compost amended soils compared to the initial soil TOC value. An observation showed that the applications of compost, biochar-blended compost and biochar from treated organic waste sources increased soil organic carbon by 11%, 20% and 36% respectively with respect to the control [19]. The increasing in TOC of soil with compost, biochar and biochar-blended compost amendments is in lined with the report in [22].

The total nitrogen and available phosphorous in residue soil also increased due to the organic amendments, but decreased for the 100% N & P fertilizer and in the control soil (Table 3). Recent studies have shown that the co-composting result in the formation of hydrophilic organic coating on the surfaces of biochar which is enriched in N mainly as NO_3^- [50]. According to the report by [51], there is a significant increasing in the N content after the applications of different organic amendments such as dairy cattle manure, fresh white clover, vegetable, fruit, and yard waste compost, and poplar tree compost as a result of mineralization of organic nitrogen in the organic amendments. Some studies also reported that reduced N (nitrate) leaching when biochar was applied to soil combined with mineral or organic N fertilizer [52]. Our results also showed that soil residual available P content was increased in the control compost, 5% co-composted biochar, 15% co-composted biochar, 25% co-composted biochar, khat biochar and 50% NPF + compost by 3.1% – 12.7%, while in the 100% NPF and control soil residual available P reduced by 6.2% and 2.8% respectively compared to the value before harvesting. The highest residual soil available P was observed in the 5% co-composted biochar treatment. Similarly, [53] reported a synergistic effect between biochar and organic fertilizer in increasing the soil available P. The increases in the soil available P observed in the soils could be attributed to reduced Fe and Al activity due to increase in the soil pH (5.25–5.8). In acid soils, soluble inorganic phosphorus is fixed by aluminum and iron [54]. The available phosphorous content in the amendments were also significantly increased which might be due to the rapid degradation of organic phosphorus by indigenous microorganisms [55].

As it was presented in Table 3, that the application of MSW compost, co-composted biochar, khat biochar, and combination mineral NPF and compost to acidic soil increased CEC and the exchangeable Ca, Mg and K contents in the residual soils compared to the control and 100% NPF. The highest residual (Cmole(+)/kg) contents of Ca^{+2}, Mg^{+2}, K^+ and CEC were observed in control compost amended soils and the lowest for the control soil and 100% NPF. Our results showed that compared to the biochar, the compost used had greater proportions of exchangeable bases and CEC, this may be due to the compost used in the experiment decomposed faster than the other amendments and released soluble cations (K^+, Ca^{+2} and Mg^{+2}) and increase the overall CEC. The finding by [11] showed that the soil K^+, Ca^{+2} and Mg^{+2} contents were decreased significantly by mineral N and K fertilizers treatments, while increased by organic amendments (compost and co-composted biochars).

Table 3
Some physicochemical properties of amended soil at the end of faba bean harvesting is presented below.

Parameter	Unit	Control soil	Control compost	5% co-composted biochar	15% co-composted biochar	25% co-composted biochar	Khat biochar	100% NPF	50% NPF + compost
pH (H_2O)		5.05a	5.80b	5.76b	5.74b	5.60e	5.58e	5.05a	5.66b
Moisture	%	10.4a	10.8a	11.5b	10.8a	10.7a	10.6a	9.8g	10.8a
OC	%	1.48a	2.08b	2.15b	1.61d	1.93e	1.97be	1.48a	1.87h
TN	%	0.15ad	0.18bce	0.19c	0.16abd	0.17bde	0.18bce	0.15adf	0.17bde
Ava. P	ppm	34.5a	37.7bg	40.0c	37.3beg	36.6bef	38.5bg	33.3a	36.9bef
Exch. K^+	Cmole/kg	3.90a	13.6b	13.2b	11.9d	12.5e	12.2def	3.75a	11.9df
Exch.Ca^{2+}	Cmole/kg	4.81a	9.88b	8.35c	6.84d	6.93de	7.12e	5.71g	10.1b
Exch.Mg^{2+}	Cmole/kg	1.01a	2.24b	2.14b	1.99d	1.74e	1.96d	1.21g	2.46h
CEC	Cmole/kg	23.5a	39.2b	38.7bc	36.0cd	38.4bc	34.7d	25.5a	36.8cd
Tukey HSD ($p < 0.05$; means within a row followed by different letters are significantly different).									

3.3 Effects of Amendments on Faba bean growth parameters

Data on Table 4 showed that the faba bean plant growth parameters (plant height, tiller number per plant, pods per plant, seeds per pod, seed size and g of 100 seeds and yield) were found to be significantly ($p < 0.05$) affected by khat derived biochar, compost and co-composted biochar soil amendments compared to the control. There were also significant differences in faba bean height between control compost, compost + 50% NPF, 5% and 15% co-composted biochars and the 100% NPF. The highest faba bean height (108.50 cm) was observed in the 5% co-composted biochar and the lowest (93.25 cm) was for control soil. Our results were in line with the report in [56], which faba bean stems can grow 90–130 cm tall, mainly depending on the genotype. Similar results by [14], showed that improved soil available nutrients (available P and exchangeable base cations (K^+, Ca^{2+} and Mg^{2+})) were probably the cause of the superior growth effect of co-composted biochar amended maize.

There was a significant difference in the number of branches (tillers) per plant as affected by amendments of khat-derived biochar, compost and co-composted biochar compared to the control soil. The compost + 50% NPF soil amendment had the highest numbers of tillers which was similar with 5% co-composted biochar amended soil and the lowest was recorded for the control soil. There were no significant differences ($P > 0.05$) between control compost, compost + 50% NPF, 5% and 15% co-composted biochars and NPF amendments in number of branches per plant.

The effect of organic amendments was significant ($p < 0.05$) on the number of pods per plant compared to the 100% NPF and control soil (Table 4). The number of pods per plant was the highest (16.5) for 5% co-composted biochar compared to the other amendments. But, the number of pods per plant was comparable in the organic amendments. Similarly, number of pods per plant increased in the order of 5% co-composted biochar > 15% co-composted biochar > compost + 50% NPF, control compost > 25% co-composted biochar > khat biochar > 100% NPF > control soil. [57], in their studies found the amount of pod per plant for faba bean growth on different levels of P and K fertilizers ranged between 10.1–18.7.

All the amendments had a significant effect on number of seeds per pod compared to the control (Table 4). However, the effects between organic amendments and 100% NPF were not significantly differed on number of seeds per pod. The numbers of seeds per pod were highest (3.05) for 5% co-composted biochar and lowest (2.15) for control soil. This result is in line with the report in [43], in which, pods usually contain three to six seeds. [1] also demonstrated that the numbers of seeds per pods of faba bean seed with different categories was ranged from 1.96–2.90.

Although seed size varies greatly among varieties, faba bean seeds are classified as large (> 1.0 g seed $^{-1}$), medium (0.5–1.0 g seed $^{-1}$) and small (< 0.5 g seed $^{-1}$) [43]. The 100 grain seed weights measure the size of faba bean seeds. Seed size was significantly affected by different organic and mineral fertilizers. The seed size of 5%, compost + 50% NPF and 15% co-composted biochar amendments are categorized as large (> 1.0 g seed $^{-1}$), while the seed sizes of the remaining amendments including in the control soil were medium (0.80 to 0.92 g seed $^{-1}$) (Table 4). The current available study showed that large size faba bean seeds have low numbers of pods per plant [58]. Our results revealed that the 100 grains weight was in line with the report demonstrated by [59] (51 g 100 seed^{-1} to 392 g 100 seed^{-1} or 0.51 g seed^{-1} to 3.92 g seed^{-1}) for different varieties of faba bean which grow on soil with adequate nutrient contents. The study by [1] also demonstrated that the size of faba bean seed with different categories was ranged from 0.77–0.83 g. Our results showed that the weights of 100 seeds were greater than the finding (0.56-61.0 g seed^{-1}) reported by [57] for faba bean grown on different levels of mineral (P and K) fertilizers.

The increase in plant growth parameters of faba bean grew on biochar, compost and MSW co-composted biochars amended soils could be attributed to the increased soil pH and hence higher P availability following application of biochar or compost amendments. The production of more branches in the amended soil was attributed to high supply of additional plant nutrients from the amendments mainly N and P and improving soil acidity and microbial activity which enhance available plant nutrients. This result may be due to the organic amendments released plant nutrients in better extent than NPF and building greater amounts of metabolites to be used in developing new tissues and pods.

3.4 Seed Yield (kg ha^{-1})

Seed yield was significantly affected by co-composted biochar, compost, khat biochar amendments and combined applications of compost and mineral NPF (Table 4). Significantly ($p < 0.05$), higher seed yield (4513 kg ha^{-1}) was observed in the 5% co-composted biochar as compared to control soil which gave the lowest seed yield per hectare (3363 kg ha^{-1}). Similarly, [5,6] reported that faba beans grain yield (kg ha^{-1}) with different varieties were ranged from 3703.7- 4886.8. The 5% co- composted biochar, compost + 50% NPF and control compost amendments increased the faba bean grain yield by 34.2%, 33.7% and 30.% compared to the control soil and by 11.3%, 10.9% and 7.8% compared to the mineral N and P fertilizer respectively. The biochar and compost effects on plant growth and soil factors as reported for two growth periods by [61], have shown that the overall plant growth and soil fertility decreased in the order compost > biochar + compost > mineral fertilizer + biochar > mineral fertilizer > control.

Table 4 Effects of amendments on the faba bean growth properties is presented below.

Treatments	plant height (cm)	tillers (no./plant)	pods/plant	seeds/pod	seed weight (g 100 seed $^{-1}$)	yield (kg/ha)
5% co-composted khat biochar	108.50 ±7.25a	2.70 ±.73a	16.45 ±3.17a	3.05 ± .75a	106.04 ±.79a	4513.33 ±55.48a
15% co-composted khat biochar	106.00 ±9.06b	2.60 ±.94ab	16.25 ±3.86b	3.00 ± .68a	103.26 ±1.69b	4438.20 ±112.80b
25% co-composted khat biochar	103.95 ±9.54c	2.50 ±.82bc	15.12 ±4.05c	3.00 ±.85a	88.87 ±.93c	4019.97 ±65.18c
Control compost /compost mix	105.95 ±10.68b	2.65 ±.82 abde	15.50 ±4.39d	3.00 ±.85a	92.38 ±1.37d	4374.23 ±94.81d
Compost +50% NPF	107.2 ±1.70ab	2.75 ±0.85a	16.10 ±2.87b	3.00 ±0.92a	105.59 ±3.44	4496.71 ±33.22a
100% NPF	103.00 ±5.32f	2.50 ±.69bcg	12.35 ±3.96e	2.85 ±.93e	85.87 ±.52e	4056.51 ±34.13e
Khat biochar + 100% RIF	104.20 ±7.59c	2.55 ±.67bcg	15.15 ±3.15c	3.00 ±1.02a	91.64 ±.60d	4140.33 ±40.67f
Soil alone	93.25 ±8.49g	1.50 ±.88g	10.45 ±4.41g	2.15 ±.82g	80.51 ±.57g	3363.15 ±37.24g

Tukey HSD ($p < 0.05$; means within a column followed by different letters are significantly different).

The seed yield (kg ha^{-1}) is summative effect of the entire plant growth parameters. The enhanced faba bean grain yield due to compost, biochar and co-composted biochar amendments compared to the mineral fertilizer and control was attributed to the addition of the most essential nutrients (N and P) and K, which are much available through mineralization of organic matter. This phenomenon was more explained as compost and co-composted biochar are rich in organic matter, nutrients and microorganisms which released slowly essential plant nutrients like nitrate and phosphate. In addition these amendments are alkaline and have liming effects. Thus, the faster mineralization of the organic matter released basic cations (Ca, Mg and K) and corrected the acidic soil in the study site, which improve the microbial activity as well as plant nutrient availability. In addition, compost and co-composted biochars had enough contents of nutrients and enhanced grain yields compared to biochar as a result of faster decompositions to release available mineral nutrients. According to the report of [62]: the increased in soil N, P and K concentrations under organic amendments were reflected in higher residue N, P and K concentrations in soil which improves growth parameters, grain yield and quality of plants. The superior growth effects, seed yield and quality of plants grow on soil amended with co-composted biochar was also due the optimized in soil C/N ratio which enhance soil microbial activities.

3.5 Effects of Amendments on Grain Protein content

Statistical analysis showed that all amendments significantly ($P < 0.05$) increased crude protein contents of faba bean seeds compared to the control (Table 5). The increment in protein contents (%) was in the order of soil alone < 100% NPF < Khat biochar < 25% co-composted biochar < 15% co-composted biochar < control compost < 5% co-composted biochar < compost + 50% NPF. Our results have shown that the highest protein content was recorded in the compost + 50% NPF (25.27%), while the lowest value (15.30%) for the control soil. The results of this study revealed that the protein contents of the seed in compost + 50% NPF amendment faba bean increased by 65.2% than the control. These results are in line with those of [63], which the faba bean seed protein contents, the highest (20.94%) for organic amendments and the lowest (17.56%) for the control. Similarly, [64] reported that the protein contents of eight faba bean varieties ranged from 16.94%-21.89%. Other report by [31] showed that the protein content of faba bean in dry seeds was varied between 17.6 and 34.5% .

Findings show that application of N, P, K and S fertilizers generally increases crop yields and nutrient quality. N, P and S are important constituents of protein and enzymes. Apart from nitrogen and phosphorous which N and P mineral fertilizer had, khat-derived biochar, compost and co-composted biochars also contain other important nutrients, such as K, Ca, Mg and S. The increasing in the protein quality as a result of organic amendments is because of: K nutrient can be attributed to it's involvement as activator in synthesis of protein, Ca is important in N metabolism and protein formulation by enhancing NO_3^- uptake, Mg also helps in the configuration for protein synthesis and Sulfur (S) responsible for the formation of the disulphide bond and stabilized protein tertiary structure. So, the higher increment in protein contents of the organic amendments compared to the mineral NP fertilizer were as a result of additional essential nutrients in the organic fertilizers from decomposition of organic matter in the soil.

Table 5
Protein contents of mean of faba bean seeds as results of different amendments of soil is presented below

treatments	Soil alone	25 % khat biochar + co-composted	Khat biochar + 100% NPF	100% NPF	Control compost	15% co-composted biochar	5%khat biochar + co composted	Compost + 50% NPF
Protein (%)	15.30 ± .52a	20.67 ± .28b	20.29 ± .72bc	19.61 ± .82c	23.25 ± .40e	21.53 ± .53f	23.75 ± .19e	25.27 ± .56g

Tukey HSD ($p < 0.05$; means within a row followed by different letters are significantly different).

In the present study, although a short term effects of municipal solid waste compost, co-composted biochar and khat-derived biochar in residual soil and faba bean yield and grain quality was investigated, the results have shown that positive effects on the soil quality and faba bean yield have been observed. The findings showed that these organic fertilizers improve soil pH, moisture, nutrients, faba bean growth parameters, and yield and protein contents. Studies have reported that, the nutrient from many organic fertilizers often shows little effect on crop growth in the year of application, because of the slow-release characteristics of organic matter [65]. Many literatures have reported on the long term applications of waste organic fertilizer have many advantageous such as lead to improvement in soil microorganism, slow release of nutrients, which increases soil quality, increased crop yield and quality in higher extent than effects in short term applications [66–68].

4. Conclusion And Recommendations

The applications of organic fertilizer amendments to the soil can improve the availability of nutrients directly by release mineral nutrients due to their faster decomposition or indirectly through soil liming, reducing leaching and enhance microbial activity. According our findings, the addition of organic amendments (khat–derived biochar, compost and co-composted biochars) increased the organic matter contents which are important sources of plant nutrients (total organic carbon, total nitrogen, available phosphorus, soluble metallic cations (K^+, Ca^{+2} and Mg^{+2}), CEC and enhance soil pH. So that compost, khat-derived biochar and co-composted biochar amendments were better than mineral fertilizer alone with improving nutrients concentrations and faba bean yield and seed protein contents. Among all the amendments, control compost, compost + 50% NPF and 5% w/w co-composted biochar had better and comparable effects on soil physicochemical properties, faba bean yield and seed protein. Hence municipal solid organic waste compost and co-composted biochars were recommended because of their easy availability, sustainability and sufficient enough for proper growth of faba bean.

Declarations

Author contribution statement

Conceptualization, Z.A., K.P. and M.L.; methodology, Z.A., A.B. and A.N.; investigation, Z.A., A.B. and A.N.; resources, Z.A., A.B., A.N., K.P. and M.L.; data curation, Z.A., A.B., A.N., K.P and M.L.; writing—original draft preparation, Z.A., A.B. and A.N.; writing—review and editing, K.P. and M.L.; project administration, M.L.; funding acquisition, K.P. All authors have read and agreed to the published version of the manuscript.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Additional information

No additional information is available for this paper.

Acknowledgements

The authors wish to thank Jimma University and Debremarkos University for their financial and logistic support. We also thank the staff of Debremarkos soil laboratory and Amhara Design and Supervision Work Enterprise Laboratory Services for providing support to conduct the laboratory determination.

Competing interest statement

This manuscript was written and edited with the participations of all the authors. The authors declare no conflict of interest.

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Figures

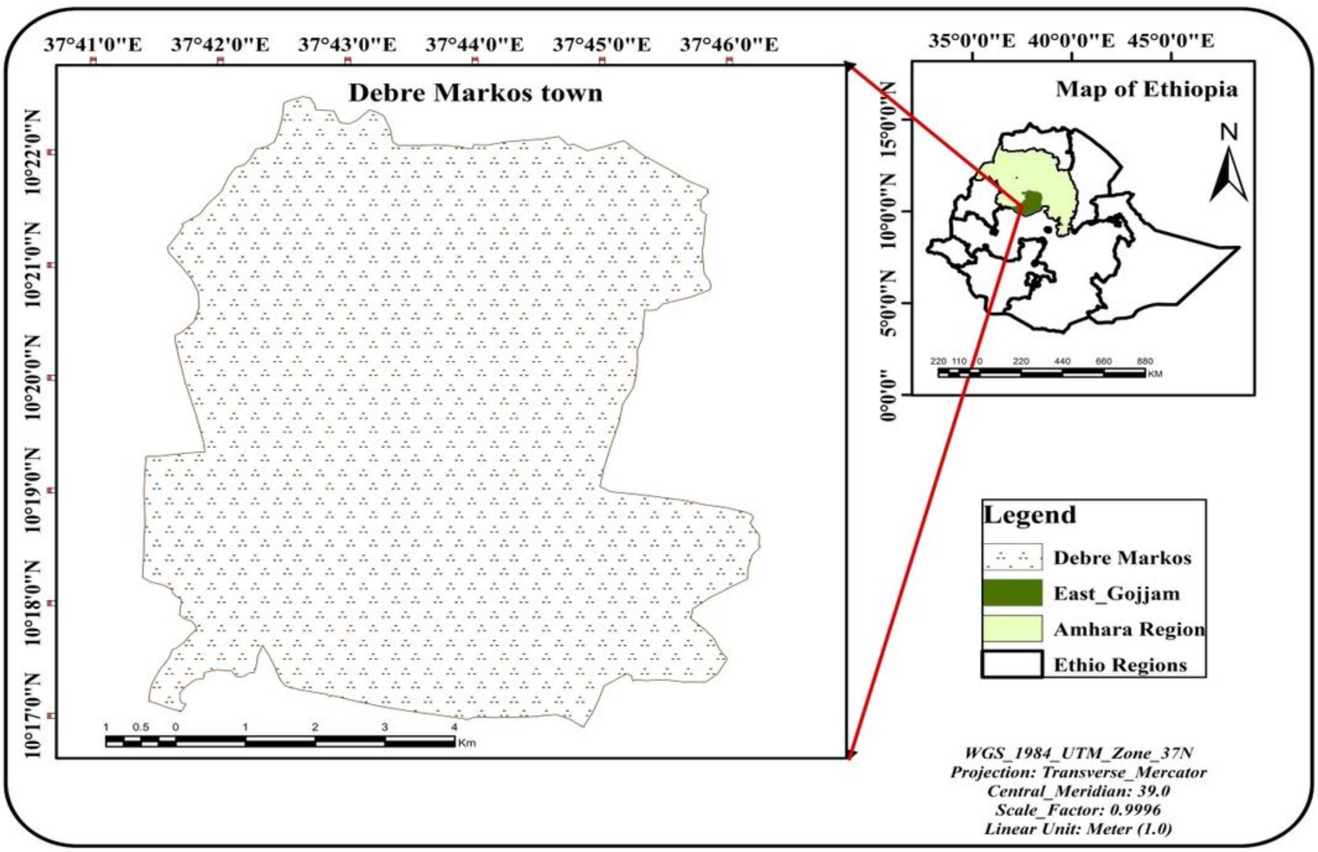

Figure 1

Location map of field experiment site. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

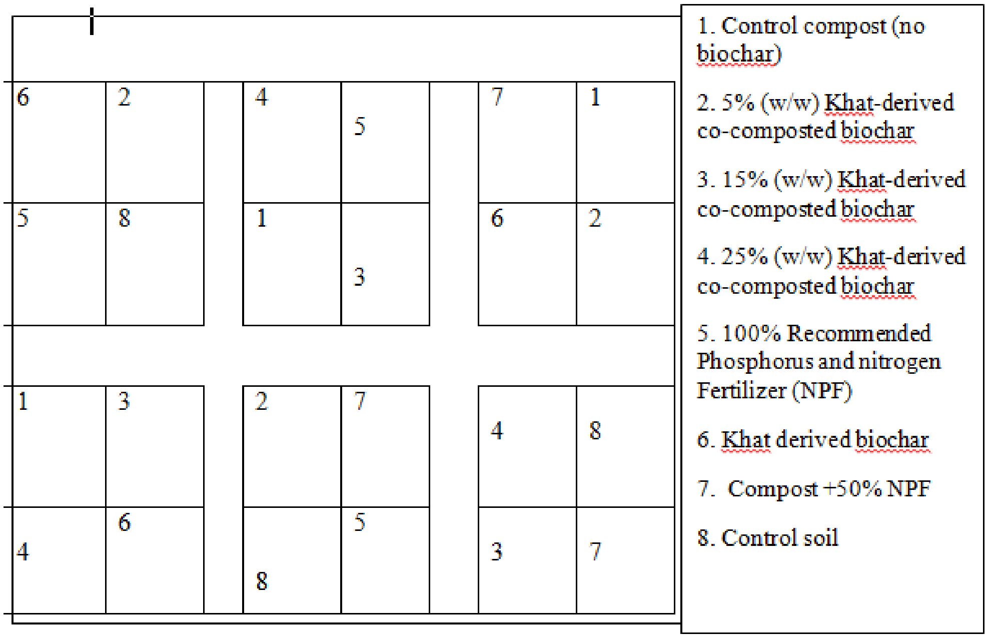

Figure 2

Trial layouts of the field experiment plots receiving treatments

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