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GROWTH, YIELD AND NITROGEN USE EFFICIENCY OF GREEN BEAN (*Phaseolus vulgaris* L.) AS INFLUENCED BY RATE OF BIOCHAR AND NITROGEN FERTILIZER AT JIMMA, SOUTHWESTERN ETHIOPIA

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ABSTRACT

Based on the national soil database, most of the southwest Ethiopian soils are deficient in macronutrients (Nitrogen) and affected by ongoing acidification problems. This has affected growth, yield and NUE of legumes in general and that of green beans in particular. However, studies on the combined application of inorganic and organic fertilizer or amendments to improve the growth yield and NUE of green bean is scant. Therefore, a pot experiment was conducted to determine the rate of biochar and nitrogen fertilizer on growth, yield and NUE of green bean on the acidic soil of Jimma in 2017/2018. The treatments consisted of four biochar rates (0, 2, 4 and 6 t ha^{-1}) and four nitrogen fertilizer rates (0, 23, 46 and 69 kg ha^{-1}) and laid out using 4x4 factorial arrangements in a randomized complete block design with three replications. ANOVA show that combined application of biochar and Nitrogen fertilizer highly significantly ($P<0.001$) total pod yield, nitrogen use efficiency and soil pH, total nitrogen and organic carbon. The highest pod yield (48.72g $plant^{-1}$), NUE (12.69 gg^{-1}) was obtained from the combined application of 6 t biochar and 23 kg N fertilizer ha^{-1} , The highest total number of nodules (121.33) at 2 t ha^{-1} BC +23 kg ha^{-1} N fertilizer and the highest soil pH (6.01) resulted when the pots received of 6 t biochar ha^{-1}alone. Therefore, The improved soil chemical properties, pod yield, and nitrogen use efficiency through combined use of biochar and N fertilizer suggests the importance of integrated use of biochar with N fertilizer to ensure that green bean crops are adequately supplied with N for NUE and total pod yield in tropical acid soils for sustainable green bean production in the long term.

Keywords: Acidic soil, Amendment, Coffee husk, Feedstock, Pod yield, Pyrolysis, Soil fertility

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1. INTRODUCTION

Green bean is one of the most cultivated leguminous vegetables in the world and highly valued as sources of many vitamins and minerals and provides more vitamin A and C, calcium, starch and protein (Negash, 2007). It is produced worldwide for export and canning industries. In 2014/2015, world production of green bean was 21.7 million tons from the total area of 1.5 million ha and 7 million tons from the total area of 75,885 ha in Africa. While in Ethiopia, its production was 6,486 tons from a total area of 1,576 ha. With average productivity of 4.12 tons ha^{-1} which is very low as compared to the world average productivity of 14.22 t ha^{-1} (FAOSTAT, 2017).

In Africa, the crop has low yield and quality due to both biotic (disease and pests, lack of improved varieties) and abiotic factors (soil related problems, including N deficiency) are the most common problems (Katungi *et al*., 2010). Similarly, In Ethiopia, the low yield of the crop is attributed to declining of soil fertility, rainfall variability, pest pressure, poor agronomic practices and poor accessibility to quality seed (Katungi *et al.,* 2010). Especially the problem associated with soil acidity is one of the problems constraining green bean productivity (Abebe, 2007). On the other hand, the problem may be attributed to a limited utilization of input for its production as it is taking place on smallholder farms (Dessalegn, 2003, Ferris and Kaganzi, 2008). However, the N fertilizer requirement for the green bean is high due to its weak fixation capacity of atmospheric N compared to other legumes in addition; protein and mineral concentrations of green bean can be affected by poor agronomic practices, including N fertilizer utilization (Abubaker, 2008; Ahmed *et al.,* 2010).

Generally, in Ethiopia soil fertility management is limited and the application of fertilizer by smallholder farmers mainly depends on the blanket recommendation (i.e. 46 kg N ha^{-1}) for the green bean in which it was practiced regardless of the production area, soil type and fertility status (MoANR, 2016). Soil studies in Jimma area indicated that decline of total N which is below the critical level due to N leaching problems as the area receives high rainfall and farmers have a limited cultural practice to integrate chemical N fertilizer with organic amendments in their farmlands. On the other hand, soil acidity problems due to the presence of toxicity of (Al) and (Mn) and poor availability of essential plant nutrients such as P and N were also reported by different authors (Kochian *et al.,*2004; Nigussie *et al.,* 2013).

Many studies showed that increasing N levels of application improved the plant growth, yield and pod quality (Mahmoud *et al.,* 2010). However, the increased cost of inorganic fertilizers and application of recommended dose is difficult to be afforded by the smallscale farmers. Even application of recommended mineral fertilizers does not improve the negative nutrient balance due to the high nutrient removal from the soils (Eichler *et al.,* 2007). Hence, easily accessible and low-cost sources of plant nutrients for supplementing and enhancing chemical fertilizers should be substituted. In this context, integrated nutrient management would be a viable strategy for efficient use of chemical fertilizers with matching addition of organic soil amendments (Eichler *et al.,* 2007). Biochar is recently well known organic component of an integrated nutrient

supply system, which improves soil health, increase productivity and releases some amount of macro and micronutrients (Bass *et al.,* 2016).
Studies reported that positive interactions were observed when N fertilizer and biochar were applied together and more N fertilizer remained in the biochar-amended soil than not amended (Chan and Steiner, 2008). Furthermore, the ability of biochar to retain N and prevent its leaching can increase N fertilizer use efficiency, thereby maintains crop yield under smaller nitrogen inputs (Zhang *et al*., 2015). There is also evidence that showed use inefficiency of applied N fertilizer due to N losses from leaching is widespread. But this problem is alleviated by using biochar due to its specific properties like an ability to increase soil pH, CEC, nutrient recycling and carbon sequestration (Liu *et al.,* 2012). More importantly, biochar has the tendency to inhibit NO_3^- N transformation from applying N fertilizers and hence the use efficiency of applied N could be enhanced particularly under acidic soil conditions. Moreover, the use of inorganic fertilizers with organic fertilizers or amendments is not well understood by smallholder farmers and appropriate rate of inorganic and organic fertilizer sources for enhanced green bean production under Jimma condition is lacking. Therefore, this study was done to investigate the effect of coffee husk biochar and N fertilizer on soil chemical properties and pod yield, N use efficiency of green bean.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The pot experiment was conducted at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM), Horticulture and Plant Science Department research lath-house. The site is located at 7^0 42'N Latitude, 36^0 47' E longitude and altitude of 1710 meters above sea level. The area receives an annual rainfall of 1819.8 mm. The maximum and minimum temperature of the area is 31.8^0 C and 8.5^0 C, respectively. The soil of the area was characteristically reddish brown clay soil with pH from 5.5 to 6.0 (NMA, 2015).

2.2 Biochar Production

Biochar from coffee husk was prepared at JUCAVM by using pyrolysis unit at temperature of 500^0 C with 3 hours of retention time as suggested by Lehmann (2007) and Bayu *et al.* (2015). After the pyrolysis, it was watered to cool down, air dried, put into sacks, took required amounts, grounded to small granules and passed through a 2 mm sieve in order to have the same particle size as that of the soil (Bayu *et al.*, 2015). Finally, it was subjected to laboratory analysis to determine some selected chemical properties.

2.3 Treatments, Experiment Design and procedures

The pot experiment was laid out in randomized complete block Design (RCBD) in 4x4 factorial arrangement with combinations of four levels of biochar (0, 2, 4 and 6 t ha^{-1}) and four levels of nitrogen (0, 23, 46 and 69 kg N ha^{-1}) with three replications. One hundred kilogram (100 kg) urea (blanket recommendation) was used as a reference to

set the N treatments. Totally, there were 16 treatment combinations, which were randomly assigned to each pot.

The experiment was conducted with 96 pots and each pot was tagged for identification purpose. The plastic pots having five kg capacity with upper (28 cm) and lower (25 cm) surface diameter and height (30 cm) were filled with five kg of dry soil with different levels of biochar before planting and nitrogen levels at planting. Before the pots were filled with soil, the soil was air dried for 72 hours, crushed finely and weighted as required.

The lath house used for this experiment did not have the required facilities to control weather conduction inside (have open spaces at a number of places so there was difference in rain droplet and sunlight).

Finally, green bean variety B.C4.4 seed were obtained from Melkasa Agricultural Research Center and four seeds were sown per pot and when the seedling had trifoliate leaves, one poorly established seedling per pots were removed to avoid excessive competition among plants (leave six total number of plants per experimental unit) and other agronomic management practices were held as recommended.

2.4 Soil Sampling and Analysis

The soil sample for this experiment was collected from Jimma Agricultural Research Center (JARC) whose pH has been determined to be strongly acidic (pH_w = 4-5). Five soil samples were collected in a diagonal pattern from a depth of 0 to 30 cm by using an auger and bulked to obtain one sample. The sample was air dried, ground using a pestle and mortar and allowed to pass through a 2 mm sieve. Before commencement of the experiment the soil sample (1kg) and the biochar were analyzed for physical and chemical properties using standard laboratory procedures at Jimma Agricultural Research Center Soil and Plant tissue Chemistry Laboratory.

2.5 Plant Sampling for Nitrogen Content Analysis

The shoot part of the plant was collected from each pot at harvesting stage, washed by distilled water, dried using oven dried (70^0 C for 48 hours at constant weight) then grounded to pass 1 mm sieve size and subjected to wet digestion and analyzed for total N content by Kjeldahl procedure.

2.6 Data Collection

2.6.1 Growth and yield Parameters

1. Total Pod Yield (kg/plant): - Total weight of pods was determined from pods harvested from each plant per pot at harvesting time and weighed using sensitive balance (CTG-6H+).

2. Nitrogen use efficiency (NUE) is the efficiency with which soil nitrate-N is converted into grain N. The NUE in plants was calculated in terms of the nutrient efficiency ratio (NER), as reported by Baligar *et al.,* (2007) and expressed as total nitrogen use efficiency in gram $gram^{-1}$.

Nutrient Efficiency Ratio (NER) = $\frac{Units\ of\ yield\ (g)}{Units\ of\ nutriens\ in\ plant\ tissue\ (g) due\ to\ applied}$ gg^{-1}

2.7. Data Analysis

Before analysis, all the data's collected were checked for its normality and then, subjected to analysis of variance (ANOVA) using general linear model in SAS software version 9.3 (SAS Institute Inc. 2012). For parameters showing significant differences, mean separation between treatments were carried out using least significant difference (LSD) test at 5% level of significance.

3. RESULTS AND DISCUSSION

3.1 Effect of Biochar and Nitrogen Fertilizer Rate on pod yield and NUE Parameters

3.1.1 Total Pod Yield per Plant (g)

The main effects of BC and N fertilizer rates and their interaction had highly significant ($P<0.001$) effect on total pod yield per plant (Appendix Table 1). The highest total pod yield per plant (48.72 g) resulted from application 6 t BC with 23 kg N ha^{-1} which was statistically in parity the yield obtained from 6 t BC with 46 kg N ha^{-1} (Table 1). On the other hand, the lowest total pod yield per plant (24.90 g) was recorded from the control treatment.

The possible reasons for the maximum pod yield per plant observed from the higher combined application of BC and N fertilizer could be due to the quick response of green bean and character of BC has large surface area, high cation exchange capacity and high pH this enable BC to has the potential to control the rates of nitrogen cycling by enhancing the soil content of NH_4^+ and NO_3^- through direct adsorption or reducing the emission of N_2O and losses of N leaching or increasing the population of nitrifying soil bacteria for biological N retention (Clough and Condron, 2012). These results are in agreement with the works of Van Zwieten *et al.* (2010) who reported that the combined application of BC and N fertilizer highly increases crop yield. Songkrit *et al.* (2017) also reported that the addition of 5 and 10% (w/ w) cassava steam BC to the soil increased the total pod yield of green bean.

3.1.2 Nitrogen Use Efficiency (NUE)

The main effects of BC and N fertilizer rates and their interaction had highly significant ($P< 0.001$) difference on NUE of green bean (Appendix Table 2). The highest NUE (12.69 gg^{-1}) was resulted from BC rate of 6 t ha^{-1} + 23 kg ha^{-1} N fertilizers (Table 1). On the other hand, the lowest (7.33 gg^{-1}) from 23 kg ha^{-} N fertilizers. The possible reasons for the highest NUE was due to the physicochemical properties of biochar including high surface area and porous structure, high surface functional groups, mineral components (Yao *et al*., 2012; Zheng *et al*., 2013b) which could results in the high adsorbing capacity of the BC and make available the applied N to the plant. In addition, BC has the potential to control the rates of N cycling due to enhancing the soil content of NH_4^+ and NO_3^- through direct adsorption, reducing losses of N leaching

and increased the population of nitrifying soil bacteria for biological N retention (Clough and Condron, 2012).

These results are in agreement with the work of (Chan *et al*., 2008) who reported that that the application of BC with N increases the radish yield. They, indicating that biochar could efficiently improve plant N utilization. Zhang *et al*. (2010) indicated that a BC amendment of 40 t ha^{-1} increased the agronomic N use efficiency from 2.3 kg kg^{-1} with no BC to 5.3 kg kg^{-1} with the BC application (40 t ha^{-1}).

Table 1: Interaction Effects of Biochar and Nitrogen Fertilizer Rate on Total Pod per Plant

Factors		Parameters studied	
Biochar (t ha^{-1})	N fertilizer (kg ha^{-1})	Total pod yield per plant (g)	NUE(g/g)
0	0	24.90^{k}	-
	23	29.73^{j}	7.33^{c}
	46	32.57^{i}	8.76^{cd}
	69	34.57^{h}	8.96^{c}
2	0	33.27^{i}	8.09^{cd}
	23	36.02^{g}	7.71^{c}
	46	39.23^{e}	10.69^{b}
	69	41.50^{d}	12.31^{a}
4	0	35.46^{g}	12.14^{a}
	23	38.67^{e}	9.57^{b}
	46	40.97^{d}	7.36^{d}
	69	43.36^{c}	7.34^{d}
6	0	37.32^{f}	11.96^{a}
	23	48.72^{a}	12.69^{a}
	46	48.33^{a}	11.40^{a}
	69	44.77^{b}	9.80^{b}
LSD (5%)		**1.53**	**1.51**
CV (%)		**1.18**	**2.50**

Means in the column followed by the same letter(s) are not significantly different at 5% level of significance. LSD (0.05) = Least Significant Difference at 5% level; and CV (%) = coefficient of variation in percent; NUE= nitrogen use efficiency.

3.2 Effect of Biochar and Nitrogen Fertilizer Rate on Soil Parameters

3.2.1 Soil pH

Biochar application highly significantly ($P< 0.001$) affects soil pH compared with the control (Appendix Table 1). The highest soil pH (6.01) was resulted from 6 t ha^{-1} alone (Table 2). On the other hand, the lowest soil pH (4.83) was control treatment. The

possible reason for an increase in the pH of the soil was due to high ash content of BC resulted dominated by carbonates of alkali and alkaline earth metals, phosphates and some amounts of organic and inorganic N and due to the rapid proton (H^+) exchange between the soil and the BC. The reduction in exchangeable acidity, exchangeable Al and exchangeable Fe relates to the increase in soil pH because BC has high surface area and contains cations that adsorb the availability of anions (Deal *et al.* (2012).
These results are in agreement with the work of Wang *et al. (*2014) who reported that rice husk biochar increased soil pH by one unit than the control treatment. Martinsen *et al.* (2015) reported that the biochar application to acidic soil caused a significant increase in mean soil pH. In addition Dume *et al.* (2015) reported that biochar application significantly affects soil pH and the highest (6.14) observed from the highest (15 t ha^{-1}) rate of biochar application on acidic soil.

3.2.2 Total Nitrogen (%)

The amount of Total nitrogen in acidic soil was highly significantly ($P<0.001$) affected by main effaces of BC and N and its interaction (Appendix Table 1).The highest total nitrogen (0.34%) was resulted from application of BC rate of 6 t ha^{-1} + 69 N ha^{-1}(Table 2) which is statically similar with total nitrogen obtained from application of BC rate of 6 t ha^{-1} + 46 kg ha^{-1} N. On the other hand, the lowest (0.17%) was recorded from the control treatment. The possible reason for the increased in the amount of total nitrogen in acidic soil with combined application of BC and N could be due some amount of decomposition which might have occurred when BC is added to soil (Liang *et al.,* 2006), which could induce net immobilization of inorganic N already present in the soil solution, high amount of total N present in BC (Tsai *et al.* 2012) and the ability of BC to adsorbed the applied N in the soil (Sohi *et al.,* 2010).
These results are in agreement with the work of Jones *et al.,* (2012) who reported that application of biochar to acidic soil could increase total nitrogen from 0.24 to 0.38 %. Dume *et al*. (2015) reported that the application of coffee husk biochar produced at 500°C temperature and applied at a rate of 15 t ha^{-1} on the acidic soil could increase soil total nitrogen (0.32-0.58 %).

Table 2: Interaction Effects of Biochar and Nitrogen Fertilizer Rate on Total Nitrogen and soil pH

Factors		Parameters studied	
Biochar (t ha^{-1})	N fertilizer (kg ha^{-1})	Total nitrogen %	Soil pH
0	0	0.17^{i}	4.83^{j}
	23	0.21^{fg}	5.44^{fe}
	46	0.20^{fhg}	5.11^{i}
	69	0.19^{ihg}	5.14^{hi}
2	0	0.26^{d}	5.45^{fde}
	23	0.18^{ih}	5.42^{f}
	46	0.19^{ihg}	5.23^{hgi}
	69	0.21^{fg}	5.18^{hgi}

4	0	0.29^{dc}	5.78^{b}
	23	0.24^{e}	5.68^{cb}
	46	0.21^{feg}	5.28^{g}
	69	0.22^{fe}	5.25^{hg}
6	0	0.29^{bc}	6.01^{a}
	23	0.30^{bc}	5.58^{c}
	46	0.32^{ba}	5.57^{cd}
	69	0.34^{a}	5.55^{cde}
LSD (5%)		**0.03**	**0.12**
CV (%)		**6.14**	**1.40**

Means in the column followed by the same letter(s) are not significantly different at 5% level of significance. LSD (0.05) = Least Significant Difference at 5% level; and CV (%) = coefficient of variation in percent.

4. SUMMARY AND CONCLUSION

The results of this study showed that growth, yield, NUE and soil parameters in which green bean was grown total pod yield, NUE, soil pH and total nitrogen increased along with increased application rates of biochar with minimal increased N fertilizer. Accordingly, the main effect of biochar and N fertilizer and its interaction highly significantly influenced total pod yield, NUE, soil pH and total nitrogen. The highest total pod yield (48.72 g) and NUE (12.69 g g^{-1}) were recorded from application of 6 t ha^{-1}BC+ 23 kg ha^{-1} N fertilizer; soil pH (6.01) was from 6 t ha^{-1} BC alone while total N (0.34%) from 6 t ha^{-1}BC+69 kg ha^{-1} N fertilizer.

In conclusion, the results of the present study indicated that the combined application of BC and N fertilizer substantially improved growth, yield, NUE of green bean and some soil chemical properties and accordingly all the combination of BC and N fertilizer levels showed better pod yield and NUE parameters as compared to the control treatment and also application of BC levels showed better soil chemical properties as compared to control and N alone. For instance, maximum total pod yield per plant and NUE were obtained from the combined application of 6 t ha^{-1} BC+ 23 kg ha^{-1} N fertilizer and maximum soil pH were obtained from 6 t ha^{-1} BC on acidic soil under Jimma condition. Therefore, on the basis of the results of the present study, it is indicative that green bean can grow well in the study area and farmers can benefit more by practicing the combined application of 6 t ha^{-1} BC+23 kg ha^{-1} N that resulted in better total pod yield and NUE of green bean and soil pH. However, since the data is obtained from pot experiment, only one season and varieties, it will be worth repeating the experiment under field condition, across different season and locations including various varieties and soil type to draw sound conclusions and recommendations.

Future Recommendations

Similar experiment is suggested to be carried out, especially during the main rainy season under field condition, including different types of biochar with different macro and micro fertilizers, varieties and with different soil type and Agro ecology.

Further studies on different types of organic and inorganic fertilizers with different biochar type for the increment of marketable pod yield, NUE and improvement of soil chemical properties are suggested to be conducted.

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APPENDICES

Appendix Table 1: Mean Squares of ANOVA for Analysis of Variance Showing Mean Squares of Total Pod Yield of Green Bean, **Soil pH and Total Nitrogen**

Source of Variation	DF	TPY	pH	TN

REP	2	0.18 ^{NS}	0.01 ^{NS}	0.01 ^{NS}
BIOCHAR	3	141.65**	0.67**	0.04**
NITROGN	3	255.80**	0.22**	0.01**
BC x N	9	11.79**	0.13**	0.02**
ERROR	30	0.89	0.01	0.02

Where; DF = degrees of freedom; TPY=total pod yield; pH=power of hydrogen; TN =Total nitrogen; ^{NS}, * and ** implies non significant, Significant and highly significance differences at 5% level of probability, respectively.

Appendix Table 2: Mean Squares of ANOVA for Analysis of Variance Showing Mean Squares of Shoot Nitrogen Contents of above ground plant tissue (straw and pod) of Green Bean.

Source of Variation	DF	**Nitrogen content**	
		STRAW	POD
REP	2	0.06*	0.02**
BIOCHAR	3	1.34**	4.01**
NITROGEN	3	0.99**	2.13**
BC x N	9	0.91**	0.95**
ERROR	30	0.04	0.01

Where; DF = degrees of freedom, * and ** implies Significant and highly significant differences at 5% level of probability, respectively.