Plant Growth and Oil Yield Response of Lemon Grass (*Cymbopogon citratuc* L.) to Biochar Application

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የሰዉ ሰራሽ ማዳበሪያ ዋጋ ከጊዜ ወደ ጊዜ ከመጨመሩም ባሻገር በአከባቢ ሁኔታ ላይ የሚያስከትለዉ ተጽዕኖም ሌላዉ ችግር ነዉ። እነዚህን ችግሮች ለማቃለል ሰዉ ሰራሽ ማዳባሪያን በኣካባቢዉ በቀላሉ ከሚገኙ ካርቦናማ ቁስአካል ከሚዘጋጁ ባዮቻርን ከመሳሰሉ አፈር አሻሻይ ጋር በማዋሐድ መጠቀም በዘላቂነት የግብርና ምርታማነትን ለማሻሻልና የምግብ ዋስትናን ለማረጋገጥ ይረዳል። ይህ የምርምር ሥራ በወንዶ ገነት ግብርና ምርምር ማዕከል እንደ አዉሮፓዉያን አቆጣጠር በ2013 እና በ2014 የመኸር ወቅት የተካሄደ ሲሆን ዓላማዉም የተለያየ መጠን ባዮቻር በመጨመር በአፈር ባሕርይ፣ በሎሚ ሳር ዕድገትና ምርታማነት ላይ ያላቸዉን ዉጤት ለመገምገም ነዉ። ጥናቱ ከቡና ሽለፈትና ከሸንኮራ አገዳ ተረፈ ምርት የተዘጋጁ የባዮቻር ዓይነቶችን ያካተተ ሲሆን ለእያንዳንዳቸዉ 0፣ 5፣ 10፣ 15 እና 20 ቶን በሄ/ር መጠን በማዘጋጀትና ትክለኛዉን የመስክ ዲዛይን በመጠቀም ተከናዉኗል። የጥናቱ ዉጤት እንደሚያሳየዉ ሁለቱም የባዮቻር ዓይነቶች በተለያየ መጠን በመጨመራቸዉ ምክንያት የአፈር ኮምጣጣነት፣ የአፈር ካርቦናማ ቁስአካል፣የናይትሮጅን፣ የፎስፎረስ፣ የካታዮን ልዉዉጥ ብቃትና የአፈር ካታዮን ይዘት ተሻሽሏል። እንደዚሁም ባዮቻርን በመጨመር የሎሚ ሳር ለምለምና ደረቅ ግዝፈ ሕይወት፣ የቅጠል ብዛት እና ዋና የዘይት ምርት በአመርቂ ሁኔታ ለመጨመር ተችሏል። ከፍተኛ የሎሚ ሳር ግዝፈ ሕይወት፣ የዕጽዋት ቅጠል ብዛትና የዉሀ ይዘት መጠን የተገኘዉ 15 ቶን በሄ/ር የቡና ሽለፈት ባዮቻር በመጨመር ነዉ። ሆኖም ከፍተኛ የዋና ዘይት ምርት የተገኘዉ 15 ቶን በሄ/ር የሸንኮራ አገዳ ተረ ፈምርት ባዮቻር በመጠቀም ነዉ። ከዚህ ጥናት ዉጤት በመነሳት 15 ቶን በሄ/ር የቡና ሽለፈት ባዮቻር መጨመር ለሎሚ ሳር ምርትና ምርታማነት የመጀመሪያ ተመራጭ ሲሆን የሸንኮራ አገዳ ተረፈ ምርት ባዮቻርን ደግሞ በአማራጭነት መጠቀም ይቻላል። በአጠቃላይ ባዮቻር መጨመር የአፈርን ለምነትና የሰብል ምርታማነት ለማሻሻል በጣም ጠቃሚ ነዉ።

Abstract

The impact and cost of mineral fertilizers as well as their associated risks on the environmental safety is becoming unaffordable. To alleviate these problems, integrating mineral fertilizers with easily available and an environmental friendly soil amendment, such as biochar is of paramount importance towards meeting our goal of increasing agricultural production and ensuring food security. The experiment was conducted at Wondo Genet Agricultural Research Center in 2013 and 2014 cropping seasons to investigate the effects of biochar application rate on selected soil properties, growth, and yield of lemon grass (Cymbopogon citratuc L.). The treatments consisting of coffee husk and bagasse derived biochars were applied at the rates of 5, 10, 15 and 20 tons ha^{-1} each, and a control treatment without amendment, with 9 treatments. The treatments were laid out in randomized complete blocked design with three replications. Application of both biochars at different rates improved soil pH, soil organic carbon (OC), total nitrogen (N), available phosphorus (P), cation exchange capacity (CEC) and exchangeable cations. Fresh biomass, dry matter yield, number of leaf per hill and essential oil yield of lemon grass were significantly increased due to the application of biochars. Over two years, the highest mean fresh biomass and total dray matter, number of leaf per hill and moisture content were obtained by the application of 15 t ha^{-1} coffee husk biochar followed by the same rate of bagasse biochar. However, the highest mean essential oil yield was obtained from the application of 15 t ha^{-1} bagasse biochar *followed by the same rate of coffee husk biochar. To conclude, coffee husk biochar at the rate of 15 t ha^{-1} could be recommended as the best treatment followed by bagasse biochar with the same rate to achieve optimum lemon grass yield in Wondo Genet and similar areas. Therefore, application of biochar is very imperative to improve soil fertility and crop yield.*

Introduction

Lemon grass (*Cymbopogon citratuc* L.) belongs to the family of Poaceae (Graminae). Lemon grasses grow well in a variety of soils with good drainage under sunny, warm and humid conditions. The oil yield is correlated to the rainfall, a well distributed rainfall, which is native to southern India, Ceylon, Indonesia and Malaysia (Delek, 2008). Lemongrass oil has a wide range of applications in the cosmetic, perfume, pharmaceutical and food industry. Local people use lemon grass oil to subdue toothache. Lemon grass oil can help to accelerate the healing of scratches and cuts. However, when pure lemon grass oil comes into direct contact with the skin, it causes a burning sensation. In Asia, such as Thailand, Indonesia and Vietnam, lemon grass is frequently used as a spice to flavor meat dishes and soups (Delek, 2008).

Nutrient deficiency is prevalent in many crop production systems of the tropics. Farmers need better technologies, more sustainable practices, and fertilizers to improve and sustain the productivity of their crops. Fertilizers play a vital role in raising agricultural productivity in Ethiopia over a period of time *(*Zeleke *et al*., 2010). However, the cost of chemical fertilizers and their associated risks on the environmental safety was becoming unaffordable (Mahajan *et al*., 2008). To alleviate these problems, locally available and environmental friendly soil amendments, such as biochar are of very high significance to improve the overall soil biophysical and chemical properties and enhance agricultural productivity. Biochar is a fine grained highly porous charcoal (carbon) that can be formed as a result of the pyrolysis of biomass in a complete or absence of oxygen and it is different from other charcoals for intended use as a soil amendment (Gaunt and Lehmann, 2008).

Currently, biochar has widely been accepted and given great attention not only due to its contribution in mitigating climate change but also as a desirable soil amendment that can improve soil quality and reduce greenhouse gas emissions in tropical agricultural soils (Agegnehu, 2017; Lehmann and Joseph, 2015). Previous studies suggest that an integrated soil fertility management approach may have more sustainable agronomic and economic impact than a focus on chemical fertilizer alone (Agegnehu and Amede, 2017; Vanlauwe *et al*., 2010). Biochar serves as a catalyst that enhances plant uptake of nutrients and water. Compared to other soil amendments, the high surface area and porosity of biochar enable it to adsorb or retain nutrients and water and also provide a habitat for beneficial microorganisms to flourish (Warnock *et al*., 2007).

Biochar has agronomic as well as environmental impact for it is a good soil amendment. Evidence shows that the application of biochar can play a significant role in improving soil organic carbon (Agegnehu *et al*., 2016; Glaser *et al*., 2002), water holding capacity (Abel *et al*., 2013; Agegnehu, 2017), soil aeration, increased soil base saturation, nutrient retention and availability and reducing nutrient leaching (Agegnehu *et al*., 2015; Lehmann *et al*., 2003), enhancing plant growth and productivity, reducing greenhouse gas emission and increasing carbon sequestration (Lal, 2011). Carbon sequestration in soil is favored for improving soil quality and achieving sustainable use of natural resources (Lal, 2011). It improves water holding capacity and aggregate stability, CEC and soil pH (Agegnehu *et al.*, 2016; Glaser, 2006). Therefore, the objective of this study was to evaluate the effects of two sources of biochar as soil amendments at different rates on growth and yield of lemon grass and soil properties.

Materials and Methods

The experimental site

The experiment was conducted during the main season of 2013 and 2014 cropping seasons at Wondo Genet Agricultural Research Center. It is geographically located at 07° 03' 19.1" to 07° 04' 00.2" N latitude and from 38° 30' 08.4" to 38° 31' 01.8" E longitude. It receives mean annual rain fall of 1128 mm, with minimum and maximum temperature of 11 and 26°c, respectively. The soil textural class of the experimental area is clay loam with a pH of 6.4.

Treatments and experimental design

The feedstock for biochar production was coffee husk derived from coffee pulping industries and bagasse from sugar factory. Biochar was produced through pyrolysis at Wondogenet Agricultural Research Sub-center. Pyrolysis converts easily broken down organic matter into a highly stable form of carbon, which is mainly used as a soil additive to improve nutrient retention and carbon storage (Krull, 2009). The pyrolysis was done using barrel as a kiln. The kiln was mostly sealed, except a few air pockets initially left open for steam and smoke to escape. After cooling, the kilns were opened and the biochar was removed. The biochar was crushed to particle size below 25 mm prior to field application. The biochar mass was approximately 20-30% of the original biomass, which is in accordance with Adam (2009). The efficiency of traditional charcoal production methods is about 10-22% (calculated on using oven-dry wood with 0% water content) while the efficiency of improved charcoal production system (ICPS) is 30-42%. The ICPS reduces emissions to the atmosphere by up to 75% compared with traditional carbonization processes (Adam, 2009).

The treatments included four rates of each biochar at rates of 5, 10, 15 and 20 t biochar ha^{-1} and a control without amendment, with a total of nine treatments. The treatments were laid out in randomized complete blocked design with three replications. The plot size used was 3 m by 3 m (9 m^2). The biochars were applied manually before sowing and thoroughly mixed in the upper 5 cm of soil. Planting lemon grass for better quality and yield of oil was recommended to grow by slips obtained by dividing well-grown clumps at Wondo Genet Agricultural Research Center planting materials multiplication site. Top of clumps was cut off within 20 to 25 cm of the root, the latter should be divided into slips, and panting was done manually with panting distance of 60 cm between plant and 60 cm between rows. Proper hoeing, weeding, and irrigation of the experimental fields were carried out uniformly as per research recommendations.

Data collection and analysis

Data collection was successively done on soil sampling and analysis, plant growth and yield parameters. Soil samples were collected from the experimental site at a depth of 0-20 cm before biochar application and one year after biochar amendment and after harvesting. The samples were prepared following the standard procedures and analyzed for selected soil physico-chemical properties. Soil samples were analyzed for pH using a ratio of 2.5 ml water to 1 g soil (Black, 1965); for available P using Bray-II method (Bray and Kurtz, 1945); for organic C content using Walkley and Black (1934) method; for total N content using Kjeldahl method (Bremner and Mulvaney, 1982); for exchangeable cations and cation exchange capacity (CEC) using ammonium acetate method (Black, 1965) at the soil and plant analysis laboratory of Debre Zeit Agricultural Research Center. Biochar samples were analyzed for chemical properties following the procedures described above.

Plant growth and yield data were collected by sampling five plants randomly from central rows of each plot. Plant height, fresh biomass, total dry matter yield, and number of leaves per hill, essential oil content and oil yield were collected and analyzed. Essential oil content was determined by taking 300 g fresh leaves of composite samples using hydro-distilled in a Clevenger apparatus according to Guenther (1972). The data were subjected to analysis of variance using the general linear model procedure (PROC GLM) of SAS statistical package version 9.1 (SAS Institute, 2004). The total variability for each trait was quantified using the following model:

$$Y_{ij} = \mu + R_i + T_j + e_{ijk} \qquad (1)$$

Where Y_{ij} is the measured value, μ = grand mean, R_i is effect of the ith replication, T_j is effect of the jth treatment, and e_{ijk} is the variation due to random error. Means for the treatments (n = 9) were compared using the MEANS statement with the least significant difference (LSD) test at the 5% probability level. Linear regression analysis was performed between plant parameters, and biochar rate and plant parameters following the SAS REG procedure.

Results and Discussion

Biochar chemical properties

The results of biochar properties are indicated in Table l. The organic carbon, total N and the available P contents of biochar were high. Exchangeable K, Ca, and Mg concentrations of the biochars were medium to high. However, coffee husk biochar had higher carbon and total N content than sugarcane bagasse biochar, but the contents of exchangeable cations and CEC in sugarcane bagasse biochar were higher than in coffee husk biochar (Table 1). Both boichars contained plant nutrients in addition to its action as soil conditioners. However, it is better to apply biochar together with additional nutrients to enhance its function (Steiner *et al.*, 2008). Other studies indicated that biochar has been shown to retain nutrients against leaching (Agegnehu *et al.*, 2015; Lehmann *et al.*, 2003), potentially improving the efficiency of nutrients applied alongside biochar (Major *et al.*, 2010). The chemical properties of biochar vary based on the type of feedstock used for charring, the charring environment (e.g. temperature, air) and additions during pyrolysis process (Glaser *et al.*, 2002). The source of biochar material strongly affects the content and availability of nutrients in the soil after amendment. The soil chemical properties after amendment will strongly be affected by source of biochar applied.

Table 1. Selected chemical characteristics of the experimental soil and biochars used for the study

Parameter	Element concentration	Parameter	Element concentration
Experimental soil		Coffee husk biochar	
pH-H_2O	6.4	Exchangeable K (cmol/kg)	-
Organic C (%)[a]	1.81	Exchangeable Na (cmol/kg)	0.77
Total N (%)	0.20	Exchangeable Ca (cmol/kg)	6.47
Available P (mg/kg)	9	Exchangeable Mg (cmol/kg)	2.37
CEC (meq/100g)	19.8	**Bagasse derived boichar**	
Exchangeable K (cmol/kg)	-	Organic C (%)	29.6
Exchangeable Na (cmol/kg)	0.08	Total N (%)	0.25
Exchangeable Ca (cmol/kg)	9.15	Available P (ppm)	50
Exchangeable Mg (cmol/kg)	2.51	CEC (meq/100g)	33.15
Coffee husk biochar		Exchangeable K (cmol/kg)	-
Organic C (%)	45.0	Exchangeable Na (cmol/kg)	8.49
Total N (%)	0.59	Exchangeable Ca (cmol/kg)	3.82
Available P (ppm)	36	Exchangeable Mg (cmol/kg)	0.62
CEC (meq/100g)	15		

[a] *C = carbon; N= nitrogen; P = phosphorous; CEC = cation exchange capacity*

Soil properties

Soil pH and organic C content were markedly increased one year after biochar application (Table 2). Similar trends were observed for total N, available P, CEC, and exchangeable bases; such increases were attained due to biochar application. The improvement in available P and CEC was particularly significant after biochar application (Table 2). The increase in soil pH due to application of biochar could be because of the porous nature of biochar and its high surface area and which in turn increased the CEC of the soil. Studies indicated that application of biochar in acid soils has also shown a liming effect (Agegnehu *et al.*, 2016; Lehmann and Rondon, 2006). Other studies also indicated that Al and soluble Fe were decreased in biochar amended soils due to the increase in CEC (Lehmann and Rondon, 2006; Masulili *et al.*, 2010). The increase in organic C and total N due to addition of biochar could be resulted from the presence of high amount of C and N in the biochars. Higher values of organic C in biochar treated soils indicate the recalcitrance of organic C in biochar (Agegnehu, 2017).

The increase in available P could be due to the presence of high P in the biochar and the increase in soil pH and CEC due to biochar application (Table 2), which may reduce the activity of Fe and Al. Previous studies also indicated the increase in available P after the application of biochar (Chan *et al*., 2008; van Zwieten *et al.*, 2010). The increase in CEC due to application of biochar could be resulted from the inherent characteristics of biochar, such as high surface area, and porosity, and variable charge organic material that has the potential to increase soil CEC, surface sorption capacity and base saturation when added to soil (Glaser et al., 2002). In general, soils amended with biochar had high CEC (Agegnehu *et al*., 2016; Chan *et al*., 2008; Masulili *et al*., 2010). Higher values of exchangeable bases with biochar treated soils might be attributed to the presence of ash in the biochar. The ash content of biochar helps the immediate release of the occluded mineral nutrients, such as Ca, K and N for crop use (Scheuner *et al*., 2004). The results of the present study also agree with Lehmann et al. (2003) who reported the highest exchangeable bases in biochar amended soils.

Table 2. Chemical properties of soil samples before and after one-year amendment in 2013 and 2014 cropping season

Soil property	Before amendment	After one year amendment
pH-H_2O	6.4	6.8
Organic C (%)	1.8	2.0
Total N (%)	0.20	0.27
Available P (ppm)	9.0	24.7
CEC (meq/100g)	19.8	29.9
K (Cmol/kg)	-	1.32
Na (Cmol/kg)	0.08	0.63
Ca (Cmol/kg)	9.1	9.5
Mg (Cmol/kg)	2.5	6.0

Yield and yield components

In 2013 cropping season, statistically significant differences were not observed among biochar rates for all parameters (Table 3). Numerically higher lemon grass leaf number per hill (112 kg ha^{-1}), dry matt yield (1264 kg ha^{-1}) and fresh biomass (5695 kg ha^{-1}) were obtained from the application of 15 t ha^{-1} coffee husk biochar, while greater moisture content (78.3%) and essential oil yield (28.2 kg ha^{-1}) were recorded from bagasse biochar with the same rate compared to the other biochar rates. However, in 2014 cropping season, application of biochar had significant ($p < 0.01$) effect on lemon grass fresh biomass and number of leaves per hill, plant dry matter and essential oil yield ($p < 0.05$), but not on moisture content (Table 3). The highest lemon grass leaf number per hill (207 kg ha^{-1}) was obtained from the addition of 15 t ha^{-1} coffee husk biochar, while the highest essential oil yield (72.2 kg ha^{-1}) and fresh biomass (10,845 kg ha^{-1}) were obtained from bagasse derived biochar with the same rate (Table 3).

On average, both total dry matter and essential oil yield were significantly higher in 2014 than in 2013, perhaps because of differences in the rainfall amount and growing conditions in the two seasons. However, the significant difference in biochar rates in 2014 growing season may be because of the positive effect of biochars on soil properties through time, which agrees with the findings of other studies (Major *et al.*, 2010; Topoliantz *et al*., 2005). For example, Major et al. (2010) reported the absence of difference in yield between 8 and 20 t ha^{-1} biochar application after one year of cropping on an Oxisol in Colombia. But, maize yield in biochar amended plots increased up to 140% compared to the control throughout the following three years, indicating a longer-term beneficial impact of biochar on crop productivity and soil fertility. Steiner et al. (2008) also indicated that application of biochar and fertilizer improved plant growth and doubled grain yield in comparison to fertilizer alone. In the first year of biochar application, there may be immobilization of nutrients such as nitrogen. The results were in agreement with previous studies (Agegnehu, 2017; Chan et al., 2008; Major et al., 2010), indicating that positive effects of biochar application on crop yields with application of 5-50 t ha^{-1} biochar, with appropriate nutrient management. Since biochar is recalcitrant, single application of it can provide beneficial effects for several years in the field *(*Lehmann and Rondon, 2006; Major *et al.*, 2010; Steiner *et al*., 2008).

Table 3. Effect of biochar application on yield and yield components of lemon grass

Treatment	2013				
	FBM (kg ha^{-1})	DM (kg ha^{-1})	NLPH	MC (%)	EOY (kg ha^{-1})
0 (control)	4674	1080	90.9	76.9	21.9
5 t ha^{-1} CHB	4944	1122	100.9	77.3	24.7
10 t ha^{-1} CHB	5059	1128	98.0	77.7	25.5
15 t ha^{-1} CHB	5695	1264	111.7	77.8	26.0
20 t ha^{-1} CHB	5459	1201	97.2	78.0	27.0
5 t ha^{-1} SBB	5236	1157	96.6	77.9	26.0
10 t ha^{-1} SBB	5093	1120	92.0	78.0	23.7
15 t ha^{-1} SBB	4951	1074	95.2	78.3	28.2
20 t ha^{-1} SBB	4611	1001	99.0	78.3	23.0
Significant level	NS	NS	NS	NS	NS
$LSD_{0.05}$	NS	NS	NS	NS	NS
CV (%)	19.0	15.2	18.9	2.2	22.0
	2014				
Treatments	FBM kg ha^{-1}	DM (kg ha^{-1})	NLP	MC (%)	EOY kg ha^{-1}
0 (control)	8564^{d}	2458d	190.5^{bc}	71.3	57.0^{c}
5 t ha^{-1} CHB	8975^{cd}	2513c	188.8^{bc}	72.0	$63.8a^{bc}$
10 t ha^{-1} CHB	9979^{ab}	2864ab	194.7^{bc}	71.3	61.7^{bc}
15 t ha^{-1} CHB	10298^{ab}	2801abc	207.22^{a}	72.8	66.96^{ab}
20 t ha^{-1} CHB	9063^{c}	2538c	183.5^{c}	72.0	63.3^{bc}
5 t ha^{-1} SBB	9986^{ab}	2816ab	191.9^{bc}	71.8	67.0^{ab}
10 t ha^{-1} SBB	9686^{bc}	2770bc	190.35^{bc}	71.4	62.2^{bc}
15 t ha^{-1} SBB	10845^{a}	3026a	200.4^{ab}	72.1	72.2^{a}
20 t ha^{-1} SBB	10186^{ab}	2883ab	200.4^{ab}	71.7	68.9^{ab}
Significant level	**	*	**	NS	*
$LSD_{0.05}$	876.8	245.5	12.3	NS	8.73
CV	9.3	5.7	6.9	2.6	14

*,**,****Significant at p<0.05, p<0.01 and p<0.001, respectively; NS= not significant. Means with the same letter in column are not significantly different at p<0.05; LSD: Least Significant Difference; CHB: from Coffee husk biochar; SBB: Sugarcane bagasse biochar; FBM: Fresh biomass, NLPH: Number of leaves per hill; MC: moisture content: EOY: Essential oil yield.*

Analysis of variance over two years indicated that lemon grass fresh biomass and number of leaves per hill significantly ($p < 0.05$) differed among biochar rates (Table 4). The highest fresh biomass, number of leaves per hill and moisture content were obtained from application of 15 t ha^{-1} from coffee husk biochar followed by the application of bagasse biochar with the same rate (Table 4). Lemmon grass fresh biomass and number of leaves per hill increments of 20 and 13% were obtained from the application 15 t ha^{-1} biochar, respectively compared to the control. Malisa *et al.* (2011) also showed that application of 10 t ha^{-1} biochar increased yield of Kenaf (*Hibiscus cannabinus* L.) and soil physico-chemical properties in Malaysia. Several studies demonstrated crop yield improvements due to biochar application on acidic and highly weathered tropical soils (Agegnehu *et al*., 2015; Lehmann *et al*., 2003).

Table 4. Effect of biochar application on yield and yield components of lemon grass combined over years

Treatment	FBM (kg ha^{-1})	DM (kg ha^{-1})	NLPH	MC (%)	EOY (kg ha^{-1})
0 (control)	6620^{c}	1769c	140.8^{b}	74.0	39.5
5 t ha^{-1} CHB	6960^{bc}	1818cd	144.9^{b}	74.7	44.3
10 t ha^{-1} CHB	7611^{ab}	1996ab	146.4^{b}	74.7	43.6
15 t ha^{-1} CHB	7996^{a}	2033a	159.5^{a}	75.3	46.8
20 t ha^{-1} CHB	7261^{abc}	1869abc	140.3^{b}	74.9	45.8
5 t ha^{-1} SBB	7611^{ab}	1987ab	144.9^{b}	74.8	46.7
10 t ha^{-1} SBB	7390^{abc}	1945abc	141.3^{b}	74.7	43.0
15 t ha^{-1} SBB	7898^{a}	2050a	147.9^{b}	75.2	49.7
20 t ha^{-1} SBB	7398^{abc}	1942abc	149.7^{ab}	75.0	46.1
Significance level	*	*	*	NS	NS
LSD (5%)	887.3	191.7	11.4	NS	NS
CV (%)	18.2	9.7	11.8	2.2	20.8

**Significant at p<0.05; NS: Not significant. Means with the same letter in column are not significantly different at p<0.05; LSD: Least Significant Difference; CHB: from Coffee husk biochar; SBB: Sugarcane bagasse biochar; FBM: Fresh biomass, NLPH: Number of leaves per hill; MC: moisture content: EOY: Essential oil yield.*

The linear regression analysis indicated that essential oil yield was positively and significantly ($p < 0.01$ and $p < 0.05$)) correlated with coffee husk biochar ($R^2 = 0.72^{**}$) and sugarcane bagasse biochar ($R^2 = 0.42^{*}$) (Fig. 1). The correlation between essential oil yield and coffee husk biochar was stronger than the correlation between essential oil yield and sugarcane bagasse biochar. This difference was also reflected in the essential oil yield and total dry matter yield where both parameters resulted in higher production from the application of coffee husk biochar than sugarcane bagasse biochar. Studies have shown that different biochar types differed in their agronomic effectiveness in increasing crop growth and yield (Agegnehu *et al*., 2015; Spokas *et al*., 2012).

The application of coffee husk biochar resulted in significantly higher correlations of essential oil yield and dry matter yield with number of leaves per hill (0.77** and 0.44*, respectively) in comparison to the correlations of oil yields and total dry matter from the application of sugarcane bagasse biochar (0.37** and 0.27, respectively) (Fig. 2). A possible reason for higher relationship of essential oil yield and total dry matter yield of lemon grass with number of leaves per hill due to the application of coffee husk biochar is that the organic amendment has the capacity to improve the soil condition and nutrient content that can be available to the growing plants. The direct effect of coffee husk biochar as soil amendment exceeded the direct effect of sugarcane bagasse biochar on the growth of lemon grass. Previous studies have also shown linear correlations between yield and yield components of maize and barley as a result of application of biochar and co-composted-biochar mixture (Agegnehu, 2017; Agegnehu *et al*., 2016; Solaiman *et al*., 2012).

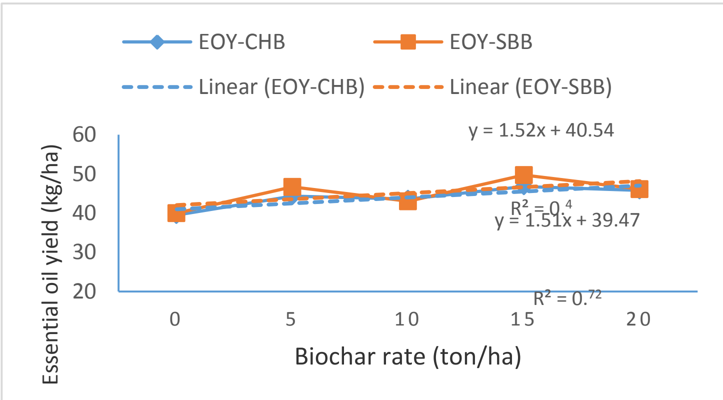

Figure 1. Correlation of essential oil yield (kg ha^{-1}) with two different biochar rates. EOY: Essential oil yield; CHB: Coffee husk biochar; SBB: Sugarcane bagasse biochar.

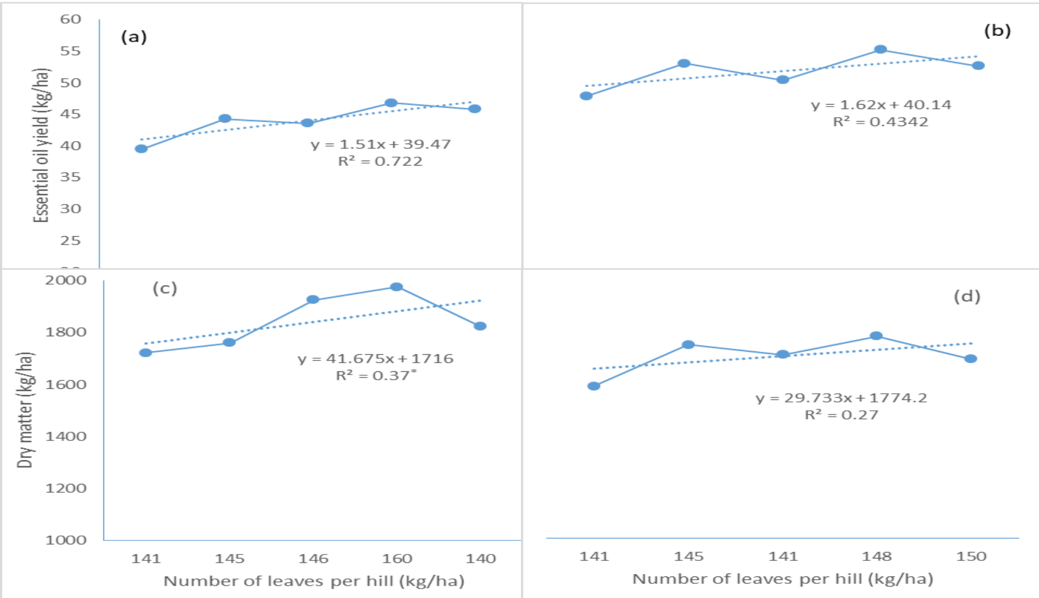

Figure. 2. Correlations of essential oil yield (EOY) and dry matter yield of lemon grass with number of leaves per hill.

Conclusion

Understanding the soil resource in an area and adoptions of management options to improve the productivity of soils is necessary for sustainable use. Use of biochar as a soil amendment with mineral fertilizer and other organic amendments has been proved to enhance agricultural productivity significantly by improving soil properties such as soil pH, electrical conductivity, organic carbon, total nitrogen, available phosphorous, CEC and exchangeable cations. Biochar applications also significantly increased growth and yield of lemon grass. Application of coffee husk biochar at 15 t ha^{-1} could be recommended to achieve optimum yield of lemon grass and improve soil fertility, followed by bagasse biochar with the same application rate. Further research is required on biochar involving different biochar types produced from different feedstock sources, frequency of application and their residual effect on soil fertility and crop yield.

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