Biochar Can Enhance Potassium Fertilization Efficiency and Economic Feasibility of Maize Cultivation

by Widowati; Asnah

Journal of Agricultural Science; Vol. 6, No. 2; 2014
ISSN 1916-9752 E-ISSN 1916-9760
Published by Canadian Center of Science and Education

Biochar Can Enhance Potassium Fertilization Efficiency and Economic Feasibility of Maize Cultivation

Widowati[1] & Asnah[1]

[1] Tribhuwana Tunggadewi University, Malang, Indonesia

Correspondence: Widowati, Tribhuwana Tunggadewi University, Jl. Telaga Warna Blok C, Malang, Indonesia. E-mail: widwidowati@gmail.com

Received: November 13, 2013 Accepted: December 9, 2013 Online Published: January 15, 2014

doi:10.5539/jas.v6n2p24 URL: http://dx.doi.org/10.5539/jas.v6n2p24

Abstract

Field experiments were conducted to study the effect of biochar on potassium fertilizer leaching and uptake, efficiency and effectiveness of K fertilization, and economic feasibility of farming maize. Thirty tons ha^{-1} of biochar prepared from organic waste was applied to an Inceptisol. The experiment was arranged in a randomized block design with 7 treatments, namely control (without biochar and KCl), K1 (200 kg ha^{-1} KCl), BK0 (biochar, without KCl), BK1/4 (biochar + 50 kg ha^{-1} KCl), BK 1/2 (biochar + 100 kg ha^{-1} KCl), BK 3/4 (biochar + 150 kg ha^{-1} KCl), and BK1 (biochar + 200 kg ha^{-1} KCl) and three replicates for each treatment. The results suggest that biochar could replace and reduce KCl fertilizer. Biochar application increased the availability of nutrients by 69-70% for K^+, 61-70% for Ca^{++}, 39-53% for N total, 179-208% for P, and 14-184% for K.The results showed that the sole application of biochar increased maize production (6.24 Mg ha^{-1}) by 14% compared sole application of KCl fertilizer (5.45 Mg ha^{-1}). In contrast, dual application of biochar and 75% lower dosage of K fertilizer application increased maize production by 29%. Application of biochar and KCl fertilizer at the rate of 50 kg ha^{-1} resulted in the highest relative agronomic effectiveness (137%) and K fertilizer efficiency (18%). This application rate was also superior both technically and economically as assessed in terms of production (7.02 Mg ha^{-1}), value of sales (revenue; IDR 19,305 million ha^{-1}), income (IDR 8,663 million ha^{-1}), and economic feasibility (R/C, 1.8).

Keywords: biochar, leaching, uptake, efficiency, effectiveness, economic feasibility

1. Introduction

Potassium (K) is an essential nutrient for plant growth and cannot be replaced by other elements. The function of K is associated with increased root growth and tolerance to drought, cellulose formation, enzyme activity, photosynthesis, transportation of sugar and starch, increase protein content of plants, maintain turgor, reduce water loss, and to protect plants against diseases and nematodes (Thomson, 2008). The high mobility of K results in its loss through leaching due to heavy rainfall. Cooke (1985) showed that high amounts of K are lost (172 kg ha^{-1}) followed by N (260 kg ha^{-1}) and P (46 kg ha^{-1}) in maize cultivation.Nutrition content in maize plant yielding maize at 9.45 Mg ha^{-1} were 3.9 kg ha^{-1} (seed) and 157 kg ha^{-1} (cob) (Cooke, 1985). Fertilization is an effort to improve crop yield. The use of inorganic and organic fertilizers can increase soil fertility. In tropical regions with high rainfall, the soils are low in K due to the rapid mineralization of organic matter (Jenkinson & Ayanaba, 1977). The weakness of inorganic fertilizer is the accessibility for poor farmers is low (Garrity, 2004) and fertilization efficiency is low (Baligar & Bennett, 1986). One of cause the low fertilization efficiency is not all fertilizer put into the soil can be absorbed by the plant. The plant absorb potassium at 50 to 70% (Tisdale & Nelson, 1975).

According to study conducted by Brady (1992), most potassium added to the soil will be fixed in the spaces between clay lattice and plants can utilize only 1-2%. Meanwhile, organic fertilizers can increase fertilization efficiency. However, in tropic organic fertilizers are decomposition rapidly. In contrast, black carbon (C) or biochar is much more stable. One way to overcome problems of soil fertility and K availability is by adding biochar. Biochar is produced from biomass pyrolysis. Biochar is a material containing hydrocarbon aromatic polycyclic carbon with functional groups (Schmidt & Noack, 2000; Preston & Schmidt, 2006; Krull et al., 2009; Chintala et al., 2013). Biochar has surface area and porosity which are significant in improving water holding capacity, adsorption, and nutrient retention (Downie et al., 2009; Sohi et al., 2010; Chintala et al., 2013). Biochar can affect soil structure, texture, porosity, particle size distribution, and density so it can improve *aerase*, water storage capacity and microbes, and nutrient availability in the root zone of plants (Amonette & Joseph, 2009). Application of biochar leads to changes in pH, electrical conductivity (EC), cation exchange capacity (CEC), and nutrient availability (Liang et al., 2006; Gundale & DeLuca, 2007; Warnock et al., 2007). Biochar can reduce N leaching and improve N use efficiency (Chintala et al., 2013; Steiner et al., 2008; Widowati et al., 2012). The problem is whether biochar can reduce or replace KCl fertilizer so it can streamline potassium fertilization on maize plants. Based on the problem mentioned, a research was conducted to study the effect of biochar and potassium rate application, toward the efficiency and effectivity of fertilization, and also economic feasibility of maize cultivation business. It is hoped that biochar can reduce or replace the usage of KCl fertilizer that the need of potassium fertilizer can be reduced, therefore increasing the revenue of the cultivation business.

2. Method

Biochar was prepared by pyrolysis method in Bioenergy Laboratory of Tribhuwana Tunggadewi University from organic waste. The raw materials for biochar preparation were obtained form of organic waste (mostly consist of plant materials) of UPTD of Hygiene Waste Department of Malang City. These materials were sun dried to reach water content of about 17% and then heated in the pyrolysis reactor at temperature of 500°C for 2 hours 5 minutes. The characteristics city waste and biochar are presented in Widowati et al. (2011). Biochar pH was determined by the method of Amedna et al. (1977), total C by ASTM method (2000), and for N, P, K, Ca, Mg was employed the method described by Masulili et al. (2010). Prepared biochar was applied to the field at the rate of 30 Mg ha^{-1} after 2 weeks of incubation. The experimental design used was randomized block design. All treatments received urea and SP_{36} fertilizer at the rate of 90 kg N/ha and 100 kg P_2O_5/ha. Fertilization was done 6 days after planting (DAP), namely for the SP_{36} and KCl, whereas, urea applied twice *i.e.* 1/3 part on 6 DAP and 2/3 part on 4 weeks after planting (WAP). Potassium fertilizer was given at 1 and 4 WAP and the treatments included an appropriate control, K1 (KCl 200 kg/ha), BK0 (biochar, without KCl), BK 1/4 (biochar + KCl 50 kg ha^{-1}), BK 1/2 (biochar + KCl 100 kg ha^{-1}), BK 3/4 (biochar+ KCl 150 kg ha^{-1}), and BK 1 (biochar + KCl 200 kg ha^{-1}). Each treatment was replicated three times. In all there were 21 plots measuring 3 x 4 m^2. Two weeks after biochar application maize (variety *Bisi* 12) was planted with an interplant distance of 80 x 25 cm resulting in a plant density of 50,000 plants ha^{-1}.Maize was harvested when the cob was dry while the seeds already glisen and reddish yellow, at the age of 110 days. At harvest (110 days after planting) soil samples were collected for analysing soil properties at the end of the experiment. Analysis of soil properties included soil organic matter (Walkley and Black wet oxidation method) (Soil Survey Laboratory Staff, 1992), N (Kjedahl), P available (Bray 1), K available NH_4OAC (buffered at pH 7.0), K unavailable (HCl 25%), and soil texture (sedimentation). Further analysis conducted on plant height, stem diameter (using caliper), leaf area (using leaf area meter), cob length and diameter, dry weight of: (stems, leaves, total above-ground plant, and maize), K (HNO_3 + $HClO_4$) level in leaves and stems at maximum vegetation (10 mst), K level inseeds at harvest and K uptake efficiency. The efficiency of K fertilization is calculated from the dry weight increase of crop yields for each weight unit of K, provided in the fertilizer material (Witt & Dobermann, 2006). To measure the effectiveness of organic fertilizer it is used the calculation of Relative Agronomic Effectiveness (RAE) *i.e.* the ratio between the increase in results using a certain fertilizer to the increase in results using standard fertilizer multiplied by 100 (Ghosal et al., 2003). Observation of dry weight was made by drying the plant material in an oven at 70 °C for 2 x 24 hours. K uptake of maize plants was determined by the weight of dry biomass and K levels.

The data were analyzed by using GENSTAT Release 12.2 software. Randomized group design analysis was done and continued with LSD test to see the differences among treatments.Furthermoreregression analysis was done to see the relationship among parameters. The economic feasibility of maize cultivation with biochar and dosage of K fertilizer were done by calculating the cost of production, revenue, income, and the feasibility of the business itself.

3. Results and Discussion

3.1 *Soil and Characteristics of Organic Waste Biochar*

The study was conducted during wet season (January-May, 2012) so there was no irrigation activity. The rainfall data taken from the climatology station of Karangploso Malang were 287 mm (January), 287 mm (February), 422 mm (March), 66.3 mm (April), and 24.12 mm (May). There was no pest and plant diseases encountered during the study. Prior the biochar application the soil had pH (H_2O) 6:37, low organic content (1,46%), low N (0.19%), sufficient P (24.38 mg kg^{-1}), very low K (0.08 cmol kg^{-1}), high Mg (3.81 cmol kg^{-1}), low Ca (4.49 cmol kg^{-1}), and cation exchange capacity (14.02 cmol kg^{-1}). Dusty clay was used from the depth of 0-20 cm. The biochar organic waste came from urban organic waste (consist of the remaining leaves and stems of vegetables and fruits, maize, grass, leaves, trees, and ornamental plants) taken from Solid Waste Management Unit of Sanitation Department of Malang City. Biochar was produced from organic waste with 17-19% water content. The production was done at temperature of 300 °C, within 3-4 days. The organic waste characteristic were pH (H_2O) 9.6, C organic content (31.41%), N (1.67%), P (0.72%), K (0.93%), Mg (0.61 cmol kg^{-1}), Ca (1.08 cmol kg^{-1}), and cation exchange capacity (23.87 cmol kg^{-1}). Biochar was sift with a 10-20 mesh sieve, before application.

3.2 Vegetative Growth of Maize Plants

The plant growth at the maximum vegetative phase does not show any difference among treatments in terms ofplant height and stem diameter. However, there are difference on the leaf area among treatments (Table 1). The application of either biochar without K fertilizer or with low rate of K fertilizer (50 kg ha^{-1}), is better than solely K fertilizer. The biochar application of 30 Mg ha^{-1}, either without K fertilizer (BK0) or with K fertilizer at the rate of (50-150 kg ha^{-1}), yield the same plant height and stem diameter as K fertilizer at the rate of 200 kg ha^{-1}. However, biochar application of 30 Mg ha^{-1} with K fertilizer at the rate of 200 kg ha^{-1} (BK1) yield the lowest leaf area. It also yield the lowest dry weight of leaf, stem, and total plant, which are the same, as K fertilizer addition at the rate of 200 kg ha^{-1} (K1) (Table 2).

Table 1. Plant height mean, stem diameter, leaf area, leaf dry weight, stem and total plant at maximum vegetative growth

Treatment	Plant Height (cm)	Stem Diameter (cm)	Leaf area (cm^2)	Leaf BK ($Mg\ ha^{-1}$)	BK Trunk ($Mg\ ha^{-1}$)	BK Total Plant ($Mg\ ha^{-1}$)
K1	177.33	2.53	6104.44 ab	2.02 a	2.60 a	4.62 a
BK0	184.00	2.70	6485.57 c	2.33 b	3.23 c	5.56 c
BK1/4	184.00	2.83	6579.11 c	2.31 b	3.72 d	6.03 d
BK1/2	184.67	2.77	6462.45 bc	2.28 b	3.11 bc	5.39 c
BK3/4	177.00	2.73	6218.29 bc	2.22 b	2.82 ab	5.04 b
BK1	176.33	2.50	5836.09 a	1.99 a	2.55 a	4.54 a

Means followed by the same letters in the same column are not significantly different (p=0.05).

Biochar with K fertilizer at the rate of 50 kg ha^{-1}, yields the highest dry weight of stems and total weight. According to Baronti et al. (2010), the highest dry matter increase (120%) is obtained on biochar application at the rate of 60 Mg ha^{-1}, any higher rate would decreases biomass. The biochar application and K fertilizer with increased rate (100, 150, 200 kg ha^{-1}), lowers the dry weight of stem as well as total plant weight. The biochar application without K fertilizer (BK0) yields better dry weight of leaves, stems, and total plant, compared to the application of K fertilizer only (K1) (Table 1).

3.3 Uptake and Efficiency of Potassium Fertilization in Maize Plants

K uptake in seeds did not show any differences among treatments, however there were differences found in leaves and stems. Biochar application without K fertilizer (BK0) results in higher K uptake in the leaves, than other treatments (Table 2). K uptake in the leaves increases 128% with biochar application only. Higher K uptake in the seeds and stems meanshigher efficiency of K fertilizer, with the value of R^2 in successive was 0.703 and 0.926. However, when biochar was combined with K fertilizer (100-200 kg ha^{-1}) then there was decrease in K uptake in the stems by 4-92%. Biochar without K fertilizer and biochar with K fertilizer at the rate of 50 kg ha^{-1}, yields the same K uptake in the stems. K uptake increases since biochar can reduce leaching and increase nutrient availability (Chan et al., 2007; Yamato et al., 2006; Widowati et al., 2011). The addition of higher rate K fertilizer (100, 150, 200 kg ha^{-1}) will reduce the K uptake both in the leaves and stems (Figure 1).

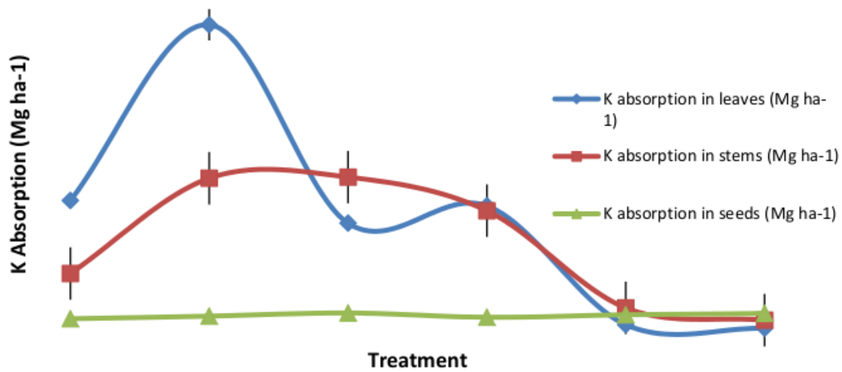

Figure 1. Potassium uptake in leaves and stems when vegetative growth maximally and potassium uptake in seeds at harvest time

The efficiency of fertilization as the utility to calculate the use of K fertilizer in the plant production. The highest K fertilizer efficiency (18%) is in the biochar application with K fertilizer (50 kg ha^{-1}). Biochar application with increased K rate up to 200 kg ha^{-1} will decrease the fertilization efficiency of K. The efficiency of K fertilization on Biochar with K fertilizer, at the rate of 150-200 kg ha^{-1}, is not different compared to the application of K fertilizer only (200 kg ha^{-1}) (Figure 2). The relationship between biochar with various rate of K fertilizer and K fertilization efficiency is shown in Figure 3. The higher the rate of K fertilizer, the lower efficiency of K fertilizer, with value of R^2 = 0.907. Biochar application can reduce the rate of K fertilizer and increase the efficiency of K fertilizer.

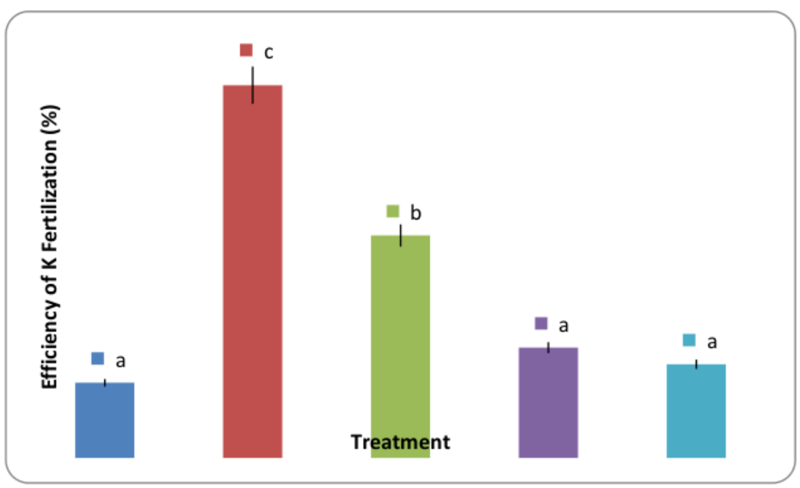

Figure 2. Effects of biochar and dosage of K fertilizer to efficiency of K fertilization on maize result

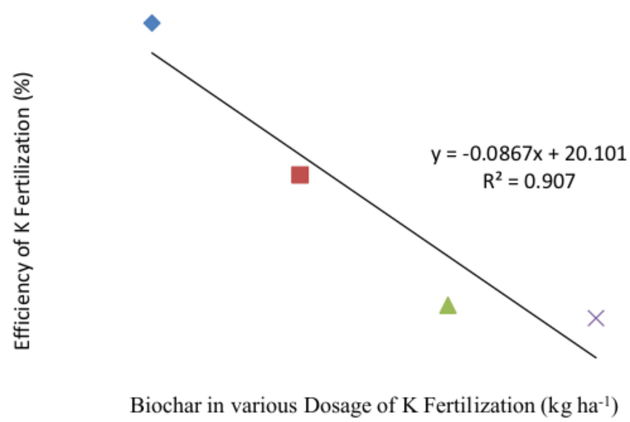

Figure 3. Relationship between Biochar in various Dosage of K Fertilization and Efficiency of K Fertilization

3.4 The Effects of Biochar and Potassium Fertilizer Rate Toward the Result Component, Maize Yield, and Relative Agronomic Effectiveness (RAE)

The components of maize yield and dry maize results show no difference among treatments (Table 2). As observed by Major et al. (2010), during 4 years, maize yield does not increase significantly in the first year after biochar application of 20 Mg ha^{-1} in the Oxisol. In the second, third and fourth year respectively, there is maize yield increase in successive 28%, 30%, 140% compared to controls. Compared to the application without biochar (K1), the biochar application yield increases 11-16% (long-cob), 5-9% (cob diameter), and 2-6% (weight of 1000 grains). There is no difference among treatments on the dry corn yield, However there is an increase of 14% with the application of biochar at 30 Mg ha^{-1} compared to the K fertilizer application at the rate of 200 kg ha^{-1}. Biochar application can enhance the nutrient reserves in the root zone, reduce leaching, and increase yields. The increases of yields in successive is 10% and 6% for wheat and maize after application biochar of 10 Mg ha^{-1} (Baronti et al., 2010).

Biochar application with K fertilizer at the rate of 50 kg ha^{-1} (BK1/4) can increase the dry maize yield by 29%. These results are in line with the best maximum vegetative growth (dry weight plant) in the treatment of BK1/4. The further increase in fertilizer rate causes the dry maize yield decrease 6-20%. The biochar application with K fertilizer at the rate of 100 kg ha^{-1} (BK1/2) shows the lowest increase of dry maize (3%) and low K uptake in the seed is 7%, while the other treatments ranging from 13-30%. There may be a nutrient imbalance due to the overlyhigh accumulation of K. Too high concentration of K in soil is likely to reduce Ca and Mg uptake by plantsso that the growth is disturbed (Mutscher, 1995). The K fertilizer application (200 kg ha^{-1}) as well as biochar added with potassium fertilizer at the rate of 50-200 kg ha^{-1}, yield dried maize of 5.78-7.02 Mg ha^{-1}. The measurement of biochar effectiveness value is presented in Table 3. The biochar application without K fertilizer and with K fertilizer at the rate of 50-200 kg ha^{-1} does not significantly affect the relative agronomic effectiveness (RAE). The effectiveness is a result that emphasize on the effects / results and it is less concerned about the rate of K fertilizer used to obtain the maize. The highest value of RAE (137%) is obtained from biochar with K fertilizer at the rate of 50 Mg ha^{-1}. The reduction of K fertilizer rate as much as ¾ of the standard rate yield no different result from other treatments. This shows the role of biochar for plants when combined with the use of low rate of K fertilizer. The RAE value of K fertilizer use is lower than biochar with K fertilizer at various rate (111-137%).

Table 2. Mean of result component, dried maize result, and relative agronomic effectiveness (RAE)

Treatment	Weight of 1000 grain (g)	Cob Diameter (cm)	Cob Length (cm)	Dried Corn Results (Mg ha^{-1})	RAE (%)
K1	238.30	4.57	17.86	5.46	100
BK0	242.93	4.97	20.71	6.24	124
BK1/4	250.77	4.85	19.75	7.02	137
BK1/2	248.13	4.90	20.46	5.78	111
BK3/4	253.40	4.78	19.89	6.26	122
BK1	251.80	4.84	19.91	6.57	130

Means followed by the same letters in the same column are not significantly different (p=0.05).

3.5 Economic Feasibility of Maize Cultivation With Biochar and Potassium Fertilizer

Maize cultivation with and without biochar combined with inorganic fertilizers, shows economically feasible (R/C 1.5-1.8). Biochar with K fertilizer at the rate of 50 kg ha^{-1} (BK1/4) is the best technically and economically because it yield high production level (7.02 Mg ha^{-1}), highest value of sales (revenue) which is IDR 19,305,000 ha^{-1}, highest income which is IDR 8,663,000 ha^{-1} and highest economic feasibility (R/C) which is 1.8 (Table 3). A study assessing the impact of agronomic and cost to put biochar into the soil at various rate has been done Woolf (2008). Technically the benefits of biochar application are: it is easy for farmers to implement, reduce the use of K fertilizer rate, lower production costs, help to solve problems of inorganic fertilizers scarcity, simple production installation, easy production and application on farming land, abundant raw materials in the surrounding farm, and capable of using agricultural waste which has been wasted. labor use is categorized as productive because the wages paid is less than the contribution of the labor to the cultivation business. The highest labor productivity is on the treatment without biochar which is only uses inorganic fertilizers (K1). The productivity based on the revenue and production are amounted to IDR 82,139/HKO and 29.87 kg/HKO with the wage of IDR 30,000/HKO (below the productivity value). This is because there is a difference in using the labors *i.e.* the 182.8 HKO ha^{-1} (without biochar) and 400.8 HKO ha^{-1} (with biochar). The use of labor on the cultivation business with biochar is high, because in the first year it is needed to provide necessary facilities and process of making biochar. The cost of biochar application on cultivation soils by Williams et al. (2010): The application of biochar with array method at the level of 2.5, 5, 10, 25, 50 Mg ha^{-1} with the cost in successive are \$ 29, \$ 44, \$ 72, \$ 158, \$ 300 ha^{-1}. The cost depends on several variables including the rate of biochar application, depth of the trench, and operator efficiency. On biochar application at the rate of 5, 10, 25, 50, 75 Mg ha^{-1} , with 2 m deep trench and excavation levels of 15 per minute per hectare,the cost in successive are \$34, \$85, \$171, \$341, dan \$512.

Table 3. Recapitulation of production, cost of farming business, price-selling of products, revenue, income and economic feasibility of maize farming business with biochar and potassium fertilizer dosage

Treatment	Production (Mg ha^{-1})	Labor Use (HKO)	Production Cost (IDR ha^{-1})	Products Selling Price IDR kg^{-1}	Revenues (IDR ha^{-1})	Income (IDR ha^{-1})	Economic Efficiency (R / C)	Labor Productivity (IDR / HKO)	Labor Productivity (kg / HKO)
K1	5.46	182.8	8,405,000	2,750	15,015,000	6,610,000	1.8	82,139	29,87
BK0	6.24	400.8	10,417,000	2,750	17,160,000	6,743,000	1.6	42,814	15,57
BK1/4	7.02	400.8	10,642,000	2,750	19,305,000	8,663,000	1.8	48,166	17,51
BK1/2	5.78	400.8	10,867,000	2,750	15,895,000	5,028,000	1.5	39,658	14,42
BK3/4	6.26	400.8	11,092,000	2,750	17,215,000	6,123,000	1.6	42,952	15,62
BK1	6.57	400.8	11,317,000	2,750	18,067,500	6,750,500	1.6	45,079	16,39

3.6 Biochar and Potassium Fertilizers Dosage to Nutrient Element Availability

The biochar application is significantly different than without biochar (control and treatment K1) in terms of potassium (total and available), calcium, nitrogen and phosphorus (Table 4). After harvest, nutrient from treatments K1 is not different from control. The i nutrient taken through the harvest lead to the reduced availability of nutrient provided by fertilizers. However, biochar cause the nutrient decrease to be low. The results show that the nutrient availability increases by biochar application, which is 69-89% (K^+), 61-70% (Ca^{++}), 39-53% (N total), 179-208% (P), and 14-184 % (K total). The results are in line with Major et al., 2010 who reports that the availability of K, Ca, Mg increased in the following years after biochar application of wood and KCl fertilizer. K level increases after: 37 days of wood biochar application Oxisol Amazon Brazilian (Lehmann et al., 2003) ; 42 days after biochar application of green waste in Alfisol (Chan et al., 2007); and 75 days after biochar application (Rondon et al., 2007). In contrast, Steiner et al. (2007) does not observe that K availability becomes greater after one cultivation season with wood biochar application on Oxisol. The availability of N in the soil increases with biochar application (Steiner et al., 2008; Widowati et al., 2012). One time biochar application will be useful in the next planting season. Long-term effects of biochar on nutrient availability, due to the increased surface of oxidation and cation exchange capacity (CEC) (Liang et al., 2006) and can lead to greater nutrient retention.

4. Conclusions

The results show the sole application of biochar increased maize production (6.28 Mg ha^{-1}) by 14% compared to the sole application of KCl fertilizer (5.45 Mg ha^{-1}). In contrast, dual application of biochar and 75% lower rate of KCl fertilizer application increased maize production by 29%. Application of biochar and KCl fertilizer at the rate of 50 kg ha^{-1} resulted in the highest relative agronomic effectiveness (137%) and K fertilizer efficiency (18%). This application rate was also superior both technically and economically as assessed in terms of production (7.02 Mg ha^{-1}), value of sales (revenue; IDR 19,305 million ha^{-1}), income (IDR 8,663 million ha^{-1}), and economic feasibility (R/C, 1.8).

Table 4. Mean of N levels, P, K, K^+, Ca^{2+}, and Mg^{2+} in Soil after Harvest Time

Treatment	N (%)	Available P (ppm)	K (%)	Exchangeable K^+ (cmol kg^{-1})	Exchangeable Ca^{2+} (cmol kg^{-1})	Exchangeable Mg^{2+} (cmol kg^{-1})
Control	0.14 a	34.90 a	30.91 a	0.25 a	14.30 a	1.15
K1	0.17 a	59.97 b	50.20 ab	0.46 a	17.08 a	1.27
BK0	0.24 c	167.42 c	122.86 c	0.88 c	27.44 bc	1.27
BK1/4	0.26 c	173.25 c	142.36 c	0.82 c	29.08 c	1.28
BK1/2	0.24 c	180.51 c	63.25 b	0.78 bc	29.06 c	1.55
BK3/4	0.24 c	183.31 c	57.12 ab	0.83 c	27.57 c	1.52
BK1	0.23 b	184.62 c	44.50 ab	0.82 c	27.44 bc	1.50

Means followed by the same letters in the same column are not significantly different (p=0.05).

Acknowledgements

The gratitude is presented to General Directorate of Higher Education Department of Education and Culture, which has been providing research funding of Competitive Grant in 2012.

Biochar Can Enhance Potassium Fertilization Efficiency and Economic Feasibility of Maize Cultivation

ORIGINALITY REPORT

21%	16%	15%	8%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	link.springer.com Internet Source	2%
2	Submitted to Montana State University, Bozeman Student Paper	2%
3	xdocs.net Internet Source	2%
4	Submitted to High Tech High Student Paper	1%
5	agribisnis.fp.uns.ac.id Internet Source	1%
6	www.ijoardjournal.org Internet Source	1%
7	Submitted to University of Technology, Sydney Student Paper	1%
8	www.researchjournal.co.in Internet Source	1%

9	Submitted to Universiti Teknologi MARA Student Paper	1%
10	Michal Safar, Bo-Jhih Lin, Wei-Hsin Chen, David Langauer et al. "Catalytic effects of potassium on biomass pyrolysis, combustion and torrefaction", Applied Energy, 2019 Publication	1%
11	E. Garzón, F. González-Andrés, V. M. García-Martínez, J. M. de Paz. "Mineralization and Nutrient Release of an Organic Fertilizer Made by Flour, Meat, and Crop Residues in Two Vineyard Soils with Different pH Levels", Communications in Soil Science and Plant Analysis, 2011 Publication	1%
12	Nguyen, Quynh Chi Thi, and Mitsuyasu Yabe. "Shrimp Poly-Culture Development and Local Livelihoods in Tam Giang-Cau Hai Lagoon, Vietnam", Journal of Agricultural Science, 2014. Publication	1%
13	Submitted to Buford High School Student Paper	1%
14	Lara, Tulio S., Jean Marcel S. Lira, Amanda C. Rodrigues, Miroslava Rackocevic, and Amauri A. Alvarenga. "Potassium Nitrate Priming Affects the Activity of Nitrate Reductase and	1%

Antioxidant Enzymes in Tomato Germination", Journal of Agricultural Science, 2014.
Publication

15	A. Zahoor, T. Honna, S. Yamamoto, M. Irshad, Haytham El-Sharkawi, W.H. Abou El-Hassan, Faridullah. " Wheat (L.) response to combined organic and inorganic phosphorus fertilizers application under saline conditions ", Acta Agriculturae Scandinavica, Section B - Plant Soil Science, 2007 Publication	<1 %
16	www.thaiscience.info Internet Source	<1 %
17	A. R. Overman, R. V. Scholtz. "Model Analysis Of Response Of Pensacola Bahiagrass To Applied Nitrogen On Two Soils", Communications in Soil Science and Plant Analysis, 2011 Publication	<1 %
18	Moacyr Bernardino Dias-Filho. "Physiological responses of two tropical weeds to shade: I. Growth and biomass allocation", Pesquisa Agropecuária Brasileira, 1999 Publication	<1 %
19	Suparman, Andy Bhermana, Laela Nuraini, Wahyu A Nugroho, Joko Mulyono. "Growth and yield of shallot using KCl fertilizer at	<1 %

peatlands in Central Kalimantan, Indonesia", E3S Web of Conferences, 2021
Publication

20	Julie Major, Marco Rondon, Diego Molina, Susan J. Riha, Johannes Lehmann. "Maize yield and nutrition during 4 years after biochar application to a Colombian savanna oxisol", Plant and Soil, 2010 Publication	<1 %
21	Li, H.. "Simulation modeling of soil and plant nitrogen use in a potato cropping system in the humid and cool environment", Agriculture, Ecosystems and Environment, 200607 Publication	<1 %
22	Djoyowasito, G., W. H. Utomo, B. Suharto, and Nur Basuki. "The Organic Planting Ribbon (OPR) Made of Banana Sheath and Its Effect on Rice Growth in Direct Seedling System", Journal of Agricultural Science, 2014. Publication	<1 %
23	Sanjib Kumar Behera, Arvind Kumar Shukla. "Spatial Distribution of Surface Soil Acidity, Electrical Conductivity, Soil Organic Carbon Content and Exchangeable Potassium, Calcium and Magnesium in Some Cropped Acid Soils of India", Land Degradation & Development, 2015 Publication	<1 %

24	hal.univ-lorraine.fr Internet Source	<1%
25	repository.tuc.ac.ke:8080 Internet Source	<1%
26	Atina Rahmawati, Agnes Murdiati, Yustinus Marsono, Sri Anggrahini. "Changes of Complex Carbohydrates of White Jack Bean (Canavalia Ensiformis) During Autoclaving-Cooling Cycles", Current Research in Nutrition and Food Science Journal, 2018 Publication	<1%
27	Mohamed I Dawo, J Michael Wilkinson, Francis ET Sanders, David J Pilbeam. "The yield and quality of fresh and ensiled plant material from intercropped maize (Zea mays) and beans (Phaseolus vulgaris)", Journal of the Science of Food and Agriculture, 2007 Publication	<1%
28	docplayer.net Internet Source	<1%
29	hortsci.ashspublications.org Internet Source	<1%
30	onlinelibrary.wiley.com Internet Source	<1%
31	"Handbook of Climate Change Mitigation and Adaptation", Springer Science and Business	<1%

Media LLC, 2017
Publication

32	César Ferreira Santos, Sheila Isabel do Carmo Pinto, Douglas Guelfi, Sara Dantas Rosa et al. "Corn Cropping System And Nitrogen Fertilizers Technologies Affect Ammonia Volatilization In Brazilian Tropical Soils", Research Square Platform LLC, 2021 Publication	<1%
33	www.researchsquare.com Internet Source	<1%
34	juniperpublishers.com Internet Source	<1%
35	kiran.nic.in Internet Source	<1%
36	mro.massey.ac.nz Internet Source	<1%
37	www.ncbi.nlm.nih.gov Internet Source	<1%
38	Abewa, Anteneh, Birru Yitaferu, Yihenew G.Selassie, and Tadele Tadele Amare. "The Role of Biochar on Acid Soil Reclamation and Yield of Teff (Eragrostis tef [Zucc] Trotter) in Northwestern Ethiopia", Journal of Agricultural Science, 2013. Publication	<1%

39 Bruno Glaser, Katja Wiedner, Sebastian Seelig, Hans-Peter Schmidt, Helmut Gerber. "Biochar organic fertilizers from natural resources as substitute for mineral fertilizers", Agronomy for Sustainable Development, 2014 <1%

Publication

---

40 Mohammad I. Al-Wabel, Qaiser Hussain, Adel R.A. Usman, Mahtab Ahmad, Adel Abduljabbar, Abdulazeem S. Sallam, Yong Sik Ok. "Impact of biochar properties on soil conditions and agricultural sustainability: A review", Land Degradation & Development, 2018 <1%

Publication

---

41 Xiuwen Wu, Dian Wang, Muhammad Riaz, Lin Zhang, Cuncang Jiang. "Investigating the effect of biochar on the potential of increasing cotton yield, potassium efficiency and soil environment", Ecotoxicology and Environmental Safety, 2019 <1%

Publication

---

42 Aldon MHP Sinaga, Masyhuri, Dwidjono Hadi Darwanto, Sri Widodo. "Employing Gravity Model to Measure International Trade Potential", IOP Conference Series: Materials Science and Engineering, 2019 <1%

Publication

---

43 Anda, M.. "Properties of organic and acid sulfate soils and water of a 'reclaimed' tidal backswamp in Central Kalimantan, Indonesia", Geoderma, 20090215 <1%

Publication

44 Muhammad Arif, Muhammad Ilyas, Muhammad Riaz, Kawsar Ali, Kamran Shah, Izhar Ul Haq, Shah Fahad. "Biochar improves phosphorus use efficiency of organic-inorganic fertilizers, maize-wheat productivity and soil quality in a low fertility alkaline soil", Field Crops Research, 2017 <1%

Publication

Exclude quotes	Off	Exclude matches	Off
Exclude bibliography	Off		