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Full Length Research Paper

Effects of Biochar, Mokusakueki and Bokashi application on soil nutrients, yields and qualities of sweet potato

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Abstract

Two field experiments were conducted to observe the effects of Biochar, Mokusakueki and Bokashi application on soil nutrients concentrations, yields and qualities of sweet potato. Results showed that the effect of different fertilizers on soil pH and EC, potassium, magnesium and NO_3^--N concentrations was significant and Biochar gave highest soil pH and EC, potassium, magnesium and NO_3^--N concentrations in FS Center, but this effect of Biochar was not found in Mito farmland. Biochar and Mokusakueki treatments produced higher yields than conventional treatment in Mito farmland. Biochar showed significantly positive effect on higher number of tubercles, and Mokusakueki showed significantly positive effect on higher weight. Biochar and Mokusakueki gave positive effect on higher sugar content of sweet potato, furthermore, Biochar and Mokusakueki had positive effect on good apparent quality and higher marketability of sweet potato. The results of this study revealed that Biochar and Mokusakueki could increase yield, sugar content and appearance quality of sweet potato, which was conducive to bringing more economic profits for farmers, and improving food safety through using organic fertilizers, and finally promoting sustainable crop production.

Keywords: Soil nutrient concentration, yield, sugar content, apparent quality, sweet potato.

INTRODUCTION

Sweet potato production has a long cultural history in Ibaraki prefecture, Japan. As one of the main local agricultural products, however, sweet potato yield has been getting lower after many years of continuous conventional chemical fertilizers application. Some experts found that the application of chemical fertilizers alone to sustain high yield had not been successful because crop response to applied fertilizer depended on soil organic matter (Agboola and Omueti, 1982). Inorganic fertilizers were applied repeatedly that leaded to the nutrients leaching and soil physical properties destroying and organic matter content decrease (Agbede, 2010). Many studies reported that crop productivity could be improved through applying organic fertilizer or the combination of organic and inorganic fertilizers. Pan et al. (2009) reported that combined organic/inorganic fertilization improved microbial activity and enhanced N efficiency, while increasing grain production.

In this study, Biochar, Mokusakueki and Bokashi were applied to compare the effects on soil properties and crop characters. Bokashi was developed in Japan and it was made of rice bran, rapeseed meal, rice husk, effective microorganisms (EM1), sugar cane molasses and water. It was widely applied to increase soil organic matter and

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crop's growth and yield. Kujira et al. (2000) observed that root system and yield of paddy rice were improved after Bokashi application. Mokusakueki was a Japanese term which meant pyroligneous acid**,** was already used traditionally by Japanese people as fertilizer, insect repellant and many other functions. The remarkable effect of pyroligneous acid on seed germination was widely known and used in various ways. Kadota et al. (2002) reported that pyroligneous acid improved Japanese pear rooting in vitro. Dilute bamboo vinegar had been shown to promote seed germination and radicle growth in several plant species (Mu et al., 2003). Another study suggested that bamboo vinegar had an inhibitory effect on the mycelial growth of several plant pathogenic fungi species (Wang et al., 2005). Biochar has been considered as a key input for rising and sustaining production and simultaneously reducing pollution and dependence on fertilizers (Barrow, 2012). In Japan, Biochar has been employed at least since 1697, it was applied in agriculture and horticulture, including for improving the vigor of ancient pine trees near shrines (Ogawa and Okimori, 2010). In Spain, Biochar was used to improve soil fertility, and this technique was still used in India and Bhutan (Olarieta et al., 2010). Generally speaking, Bokashi, Mokusakueki and Biochar have been found having positive effects on soil fertility and crop production in many studies. However, research on comparison of effects of Biochar, Mokusakueki and Bokashi on soil properties and crop characters have received little attention now. The objectives of this study were to compare the effects of Biochar, Mokusakueki and Bokashi with or without inorganic fertilizers application on soil nutrients concentrations, yields and yields contributing characters, sugar content and appearance quality of sweet potato.

MATERIALS AND METHODS

Description of the study areas

Two field experiments of sweet potato production were conducted in this study, one was located in Field Science Center (FS Center) (latitude 36°1'48"N, longitude 140°12'40"E), Ibaraki University, Japan, and another was located in Mito farmland (latitude 36°23'19" N, longitude 140°34'37"E), Ibaraki prefecture, Japan.

The experimental sites were located in Ibaraki prefecture, Kanto plain of Japan. The soil of study sites was clay loam humic allophane soil (haludands, haplic andosols). Soil pH and EC were fluctuant in sweet potato cropping season, ranged from 5.9-6.5 and 43-243 µs cm^{-1} in FS Center, and 5.5-6.0 and 38-130 µs cm^{-1} in Mito farmland, respectively. The total rainfall and mean temperature in sweet potato cropping season were 830 mm and 21.7 ℃ in FS Center, and 887.5 mm and 21.9 ℃ in Mito farmland, respectively (Japan Meteorological Agency, 2011).

Nine plots were laid out and three treatments (Biochar, Mokusakueki, and Bokashi) were assigned to the plots in a randomized complete block design with three replications in FS Center (Figure 1). Sweet potato was planted in June and harvested in November, 2010. The design of Mito farmland was consisted of three treatments (Biochar, Mokusakueki, and Conventional) with two replications (Figure 2). Sweet potato was planted in May and harvested in October, 2010. The nutrient concentration of Biochar, Mokusakueki and Bokashi were showed in Table 1.

Data collection

Soil samples were taken from topsoil (0-5cm) at three consecutive stages: (1) Before planting; (2) at Middle growth stage; (3) at harvest stage. Nutrient concentration analysis of soil samples was conducted by Soil and Plant Clinical Analyzer (SPCA-6210) in FS Center, Ibaraki University, Japan. Matured sweet potato samples were harvested to record yield, number of tubercles, weight, sugar content and ball index. The harvested sweet potato samples were separated into marketable sweet potato (＞130g) and non-marketable (≤130g) sweet potato. Sugar content of marketable sweet potato was measured on two dates respectively (Nov.15 and Dec.15, 2010 for sweet potato collected from FS Center, Oct.15 and Dec.15, 2010 for sweet potato collected from Mito farmland). Weight and ball index were used to evaluate the appearance quality of sweet potato and ball index was measured as following formula:

Ball Index = length of sweet potato (cm) / max diameter of sweet potato (cm);

Statistical analysis

ANOVA was performed to assess the effects of different treatments on soil properties and sweet potato characters. The data were statistically analyzed by stat view software to examine the significant variation of the results between different treatments. The statistically significant difference between different treatments was set at 5% level (P≤ 0.05%).

RESULTS

Soil pH, EC, and nutrient concentration

Results in FS Center showed that the effects of different

Mokusakueki	Bokashi	Biochar
Biochar	Mokusakueki	Bokashi
Bokashi	Mokusakueki	Biochar

Figure-1. Lay-out plan of FS Center farmland in sweet potato cropping season, 2010
Note: 1) Biochar (50L $6m^{-2}$) and Bokashi (1kg $6m^{-2}$) were applied in Biochar treatment; 2) Mokusakueki (1L $6m^{-2}$) and Bokashi (1kg $6m^{-2}$) were applied in Mokusakueki treatment; 3) only Bokashi (1kg $6m^{-2}$) was applied in Bokashi treatment; 4) planting area of each plot was 4m×1.5m.

Conventional	Mokusakueki	Biochar
Conventional	Mokusakueki	Biochar

Figure 1. Lay-out plan of Mito farmland in sweet potato cropping season, 2010
Note: 1) Biochar, Bokashi and chemical fertilizers were applied in Biochar treatment; 2) Mokusakueki, Bokashi and chemical fertilizers were applied in Mokusakueki treatment; 3) Bokashi and chemical fertilizers were applied in Conventional treatment; 4) lime (200kg ha^{-1}) was applied as additional fertilizer in the second replication, Lime0 and lime200 indicated the lime rates; 5) planting areas of Biochar, Mokusakueki, and Conventional treatment were 500 m^2, 500 m^2 and 1000 m^2, respectively.

Table 1. Nutrient Concentration of Biochar, Mokusakueki and Bokashi

	Ca (mg $100g^{-1}$)	K (mg $100g^{-1}$)	Mg (mg $100g^{-1}$)	NH_4^+-N (mg $100g^{-1}$)	NO_3^--N (mg $100g^{-1}$)	P (%)	C (%)	N (%)	C/N
Bokashi	2	52	7	0.8	115.6	3.46	45.22	4.59	9.85
Biochar	3	51	2	13.5	116.2	4.7	35.50	0.27	129.78
Mokusakueki	9	43	5	36.7	118.1	5.7	---	---	---

Note: Nutrients Concentrations of Biochar, Mokusakueki and Bokashi were conducted by CN corder (made by J-science lab co., Ltd.) and soil and plant clinical analyzer (SPCA-6210, SHIMADZU) in Ibaraki University, Japan.

fertilizers on soil pH and EC were significant (Table 2). Soil pH and EC observed in Biochar treatment were significant and remarkably higher than Mokusakueki and Bokashi treatments. However, these effects were not significant in Mito farmland (Figure 3). Table 2 showed that the effects of different fertilizers on soil potassium (K), magnesium (Mg) and NO_3^--N concentrations were significant. Biochar and Conventional treatments showed highest K, Mg and NO_3^--N concentrations in the two sites, respectively (Figure 4).The effects of lime rates on K, Mg and NO_3^--N concentrations were significant in Mito farmland, and most lime200 plots gave more or less higher soil nutrients concentrations than lime0 plots regardless of different fertilizers and dates.

Yield, sugar content and apparent quality of sweet potato

In FS center, results showed that Bokashi treatment produced highest yield and Biochar treatment produced highest number of tubercles although different fertilizers did not have significant effect on the yield and number of tubercles. In Mito farmland, results showed that Biochar and Mokusakueki treatments produced higher yields than Conventional treatment although the effect of different fertilizers on sweet potato yield was insignificant. The effect of different fertilizers on the number of tubercles was significant, and Biochar treatment produced remarkably highest number of tubercles. The effect of lime

Table 2. ANOVA of soil properties in sweet potato cropping, 2010

Treatments	pH	EC	Ca	K	Mg	NH_4^+-N	NO_3^--N	P
FS Center								
Fertilizer	***	***	NS	***	**	NS	***	NS
Date	***	***	***	***	*	***	***	***
Fertilizer × Date	**	**	NS	***	NS	NS	*	NS
Mito farmland								
Fertilizer	NS	NS	NS	***	*	NS	***	NS
Lime rate	NS	**	NS	***	***	***	***	***
Date	NS	*	***	***	*	***	***	***
Fertilizer × Lime rate × Date	NS	*	NS	***	NS	***	***	NS

Note: The significant variation between different treatments was computed by stat view software in FS Center, Ibaraki University, Japan. *、**、*** meant 5%、1%、0.1% significant each symbol. And NS meant not significant.

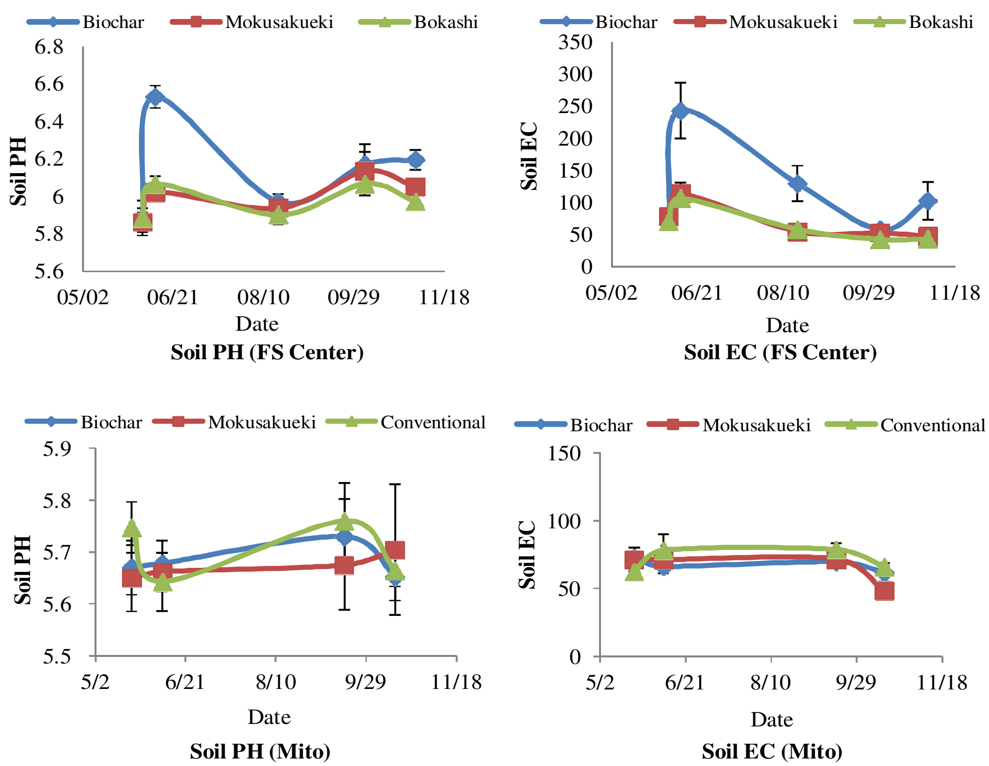

Figure 3. The changes of soil pH and EC in sweet potato cropping seasoning, 2010. The changes of soil pH and EC in the two sites showed different results.

rates on the yield and number of tubercles was significant, and lime200 plots produced significantly higher yield and number of tubercles than lime0 plots, irrespective of different fertilizers application (Table 3).

Sugar content of rotted sweet potato was not included in this study. Results in FS Center showed that sugar content observed in Biochar treatment was highest although the effect of different fertilizers on sugar content

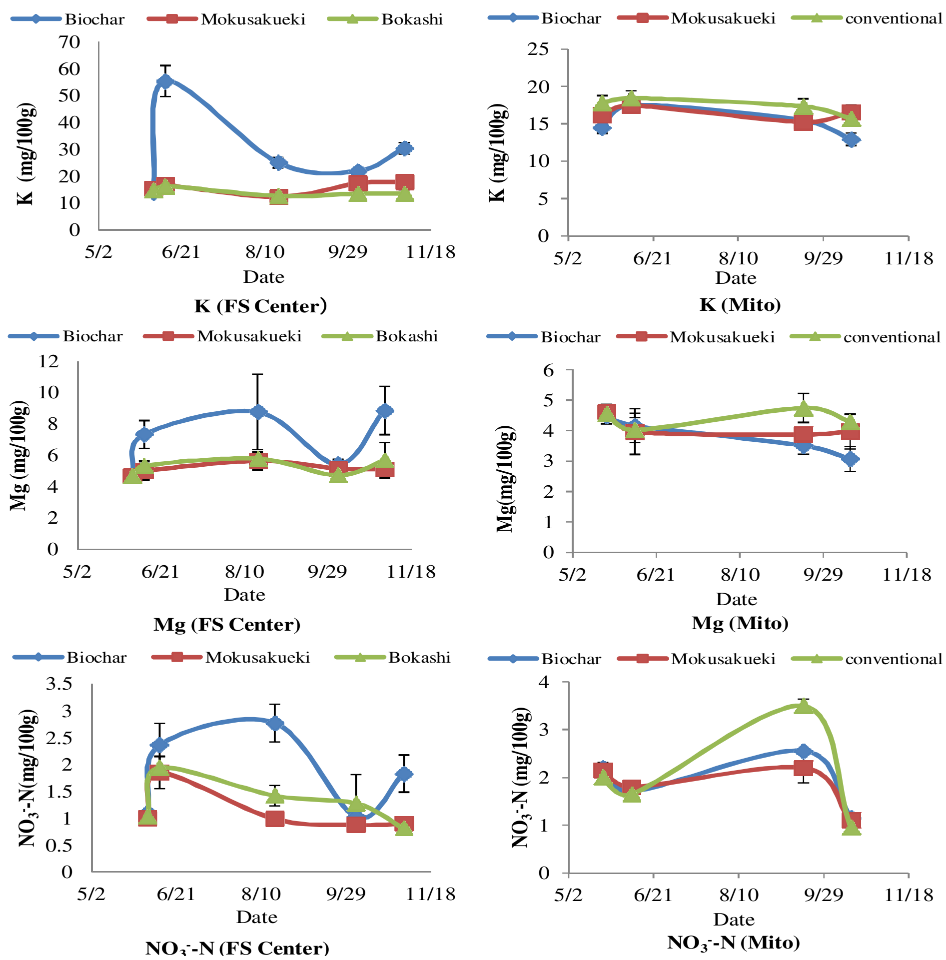

Figure 4. The changes of soil nutrients concentrations in sweet potato cropping seasoning, 2010. The effect of different fertilizers and dates on potassium, magnesium and NO_3^--N concentrations was significant both in FS Center and Mito farmland, Japan.

Table 3. Yield and number of sweet potato in 2010

FS Center	Yield (t ha^{-1})	Number (×1000 ha^{-1})	Mito Farmland	Yield (t ha^{-1})	Number (×1000 ha^{-1})
Biochar	37.97	159.00	Biochar	25.98	140.45
Mokusakueki	37.25	116.67	Mokusakueki	26.17	97.78
Bokashi	40.03	134.33	Conventional	24.05	111.79
ANOVA of yield and number of sweet potato					
Fertilizer	NS	NS	Fertilizer	NS	**
			Lime rate	**	***
			Fertilizer × Lime rate	NS	NS

Source: Author's calculation. *、**、*** meant 5%、1%、0.1% significant each symbol. And NS meant not significant.

was insignificant. Results in Mito farmland showed that the effects of different fertilizers and dates and lime rates on sugar content were significant. Sugar contents observed in Biochar and Mokusakueki treatments were significantly higher than Conventional treatment (Table 4). In addition, sugar content observed in lime0 plots was

Table 4. Sugar content of marketable sweet potato, 2010

FS Center	Brix (%)			Mito farmland	Brix (%)		
	Nov.15	**Dem.15**	**Increase (%)**		**Nov.15**	**Dem.15**	**Increase (%)**
Biochar	11.27	12.72	13	Biochar	9.97	12.00	20
Mokusakueki	10.48	12.70	21	Mokusakueki	9.7	11.82	22
Bokashi	10.91	12.45	14	Conventional	9.59	11.49	20
ANOVA of sugar content of marketable sweet potato							
Fertilizer			NS	Fertilizer			*
Date			***	Lime rate			***
Fertilizer × Date			NS	Date			***
				Fertilizer × Lime rate × Date			NS

Note: Sugar content of each marketable sweet potato sample was measured three times by Atago 3810 PAL-1 Digital Hand-Held Pocket Refractometer in FS Center, Ibaraki University, Japan. Brix (%) was used to record sugar content. *、**、*** meant 5%、1%、0.1% significant each symbol. And NS meant not significant.

Figure 5. The shapes of sweet potatoes. The ball indexes of sweet potatoes were 3.1, 2, 1.5 and 1 from left to right respectively. The marketability of sweet potato was affected by apparent quality to some extent, the last one was considered as none marketability.

higher than that in lime200 plots. The effect of dates on sugar content was significant in the two sites, as the results showed that sugar content increased over time and Mokusakueki gave the highest increment than another two treatments.

Figure 5 showed the different apparent shapes of sweet potatoes. Sweet potato that ball index was in 1.6~4.5, was recognized as good shape tubercle in this study, sweet potatoes were divided into different sizes according to the weight (Figure 6). Results showed that Biochar treatment gave the highest ball index than another two treatments although different fertilizers did not have significant effect on ball index in the two sites. Results in Mito farmland showed that the effect of lime rates on ball index was significant and lime200 plots gave higher mean ball index than lime0 plots. The effect of different fertilizers on the weight of sweet potato was significant in the two sites, and Mokusakueki treatment showed highest weight and Biochar treatment showed lowest weight (Table 5). Although the effect of lime rates on the weight of sweet potato was insignificant, lime0 plots gave higher mean weight than lime200 plots.

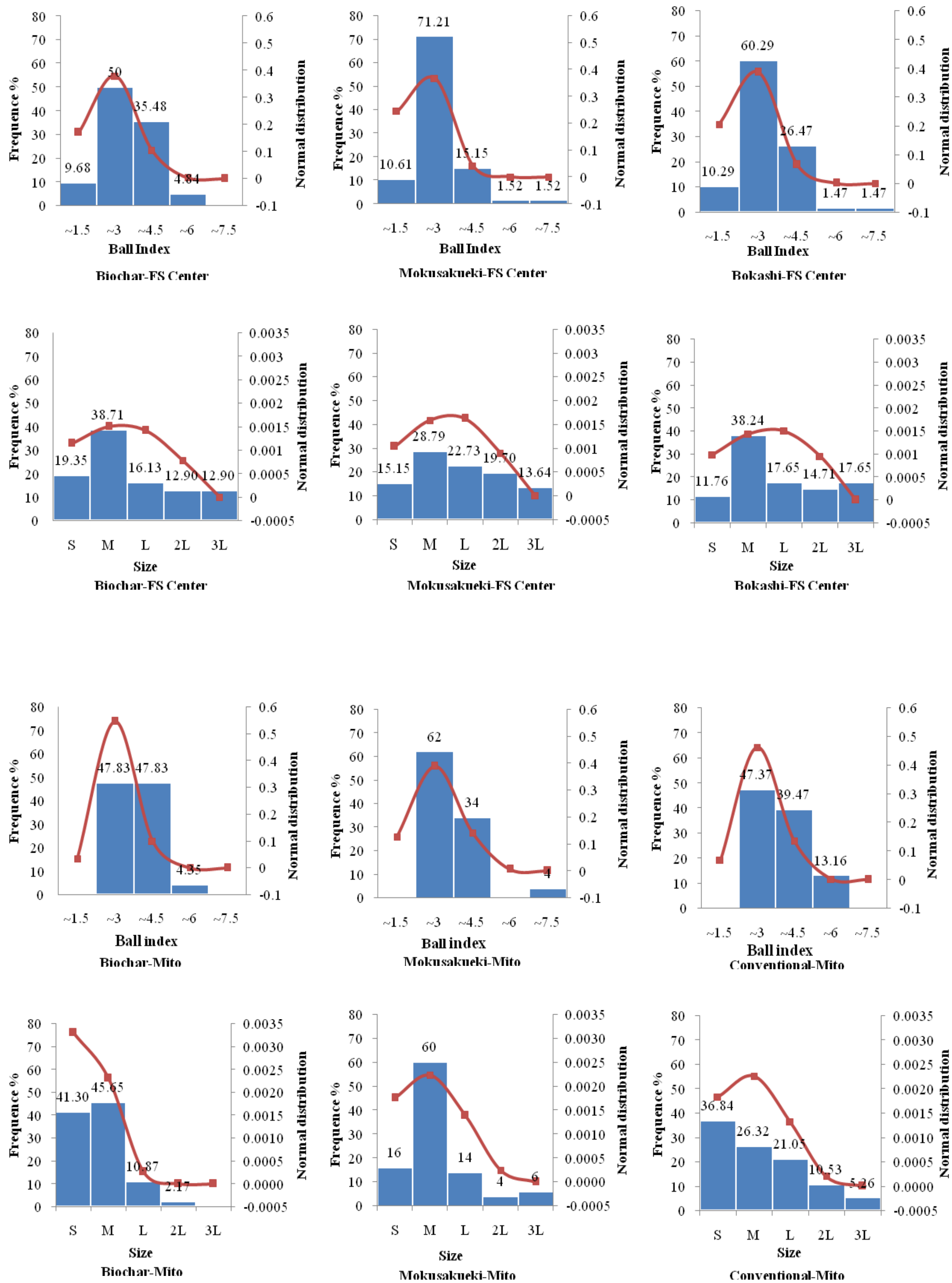

Figure 6. Histogram and normal distribution of ball indexes and sizes of marketable sweet potatoes. S, M, L, 2L, 3L meant the weights of sweets potatoes were in 130~200g, 200~350g, 350~500g, 500~700g, 700g~, respectively.

Table 5. Appearance quality of sweet potato, 2010

FS Center	Marketable Sweet potato		Sweet potato	Mito Farmland	Marketable Sweet potato		Sweet potato
Fertilizer	Mean Ball Index	Mean Weight (g)	Mean Weight (g)	Fertilizer	Mean Ball Index	Mean Weight (g)	Mean Weight (g)
Biochar	2.82	375	239	Biochar	3.18	252	184
Mokusakueki	2.49	429	319	Mokusakueki	3.04	338	276
Bokashi	2.64	442	298	Conventional	3.17	311	214
ANOVA of weight and ball index of sweet potato							
Fertilizer	NS	NS	*	Fertilizer	NS	NS	**
				Lime rate	*	NS	NS
				Fertilizer× Lime rate	NS	NS	NS

Source: Author's calculation. *、**、*** meant 5%、1%、0.1% significant each symbol. And NS meant not significant.

Table 6. Statistical data of sweet potato yields in Japan and Ibaraki prefecture

Year	Japan (t ha^{-1})	Ibaraki (t ha^{-1})	Year	Japan (t ha^{-1})	Ibaraki (t ha^{-1})
2004	25	27	2007	23.8	26.4
2005	25.8	26.6	2008	24.8	26.1
2006	24.2	24.8	2009	25.3	27.3

Source: Agricultural Production Bureau, Ministry of Agriculture, Forestry and Fisheries, Japan.

DISCUSSION

Changes of soil nutrient concentration response to different fertilizers

Some studies reported that Biochar had the potentiality to increase soil pH (Moses Hensley Duku, 2011). Rodriguez et al. (2009) used biochar produced from sugarcane bagasse to increase soil pH from 4.0–4.5 to 6.0–6.5 in a maize trial in Colombia. Sohi (2009) reported that Biochar could improve the physical and biological properties of soils such as water holding capacity and soil nutrients retention. Oguntunde et al. (2004) showed a significant increase in soil pH, electrical conductivity and exchangeable Ca, Mg, K, Na and P in the soil at the charcoal site soils. In this study, Biochar treatment showed higher soil pH, EC and exchangeable Ca, Mg, K, NO_3-N, and P concentrations than Mokusakueki and Bokashi treatments in FS Center, however, this effect of Biochar was not found in Mito farmland, which may be because of different soil properties in the two sites. In addition, the strong resistance of biochar to microbial decomposition and hence its continued persistence in the soil ensure that the benefits of biochar application would be long-term (Hidetoshi, 2009). In FS Center, soil available phosphorous concentration inclined over time, which implied that sweet potato production had little phosphorous demand. More calcium was lost from the soil in sweet potato cropping, which could be explained by the nutrient recycle and output. Sweet potato had a relatively low calcium demand. In contrast, sweet potato production has high potassium demand, and nitrogen influences sweet potato yield by increasing leaf area duration, which in turn increase sweet potato weight and thus the yield (Bourke, 1985). Some studies reported that Biochar application in the presence of N fertilizer could improve N fertilizer use efficiency and increased crop productivity (Chan et al., 2007; Pan et al., 2009). In Mito farmland, Biochar and Mokusakueki treatments showed lower soil potassium and NO_3^--N concentrations, which suggested higher potassium and NO_3^--N uptake by the plants and leading to higher yield. In FS Center, the use efficiency of potassium and nitrogen in Biochar treatment was lower, which could be explained that the yield was lowest.

Sweet potato properties response to different fertilizers

The effects of Biochar and pyroligneous acid on crop characters had been reported in some studies. Hidetoshi et al. (2009) reported that Biochar application has the potential to improve crop productivity, but the effect of Biochar application was highly dependent on soil fertility and fertilizer management. Jeffery (2011) observed an overall relatively small (approximately 10%) but statistically significant, positive effect of biochar application to soils on crop production by meta-analysis. However, this did not imply that the random addition of Biochar would always lead to a small yield increase. Chen et al. (2007) reported that in the absence of N fertilizer, application of biochar to the soil did not increase crop yield in radish cropping. Appropriate concentration of pyroligneous acid application was effective in increasing crop yield (Tsuzuki et al., 1989, Zulkarami et al., 2011). Moreover, the application of pyroligneous acid and the mixture with charcoal in greenhouse soil could increase vegetable yield (Hu et al, 2011). In FS Center, Biochar and Mokusakueki treatments yielded similar amounts, a little bit lower than Bokashi treatment, which may be because of none inorganic fertilizer application. However, sweet potato yields observed in FS Center were remarkably higher than that of Japan and Ibaraki prefecture (Table 6). In Mito farmland, Mokusakueki and Biochar treatments produced higher yields than Conventional treatment, which implied that Biochar and Mokusakueki had positive effect on higher yield in inorganic fertilizers application plots. Biochar treatment produced largest number of tubercles in the two sites, which implied that Biochar had positive effect on larger number of tubercles. In addition, high lime rate had significantly positive effect on high yield and number of tubercles.

In FS Center, sugar content observed in Biochar treatment was highest than Mokusakueki and Bokashi treatments. On the first measure, the 26.67% observing samples in Mokusakueki treatment were low-sugar content (Brix ≤10%), followed by Bokashi and Biochar treatments (20% and 0), and the 6.67% and 6.67% samples in Biochar and Bokashi treatments respectively were high-sugar content (Brix ≥13%), which was not observed in Mokusakueki treatment. On the second measure, the samples of low-sugar content were not observed in all treatments, and the 38.46% samples were high-sugar content in Biochar treatment, followed by Bokashi and Mokusakueki treatments (28.57% and 26.67%).

In Mito farmland, sugar contents observed in Biochar and Mokusakueki treatments were significantly higher than Conventional treatment. The similar results were also reported in some studies. Du et al. (1998b) found that the application of mixture of charcoal with pyroligneous acid increased the synthesis of sucrose in melon fruits. Pyroligneous acid was reported to increase sugar content of rock melon and higher sugar content was obtained in combinations of fertilizer with 10 and 20% of pyroligneous acid (Zulkarami et al., 2011). On our first measure, all samples in Conventional treatment were low-sugar content, followed by Mokusakueki and Biochar treatments (70% and 50%), and the samples of high-sugar content were not observed in all treatments. On the second measure, although the samples of low-sugar content were not observed, the samples of high-sugar content were observed only in Biochar treatment (25%). Sugar contents observed in FS Center were higher than that in Mito farmland, which could be explained by different soil properties and lime application in the two sites. The results also revealed that Biochar treatment produced more number of high-sugar content sweet potatoes and Biochar and Mokusakueki treatments showed higher sugar content on the second measure both in the two sites.

Ball Index and weight were used to evaluate the apparent quality of sweet potato in this study. Highest ball index was observed in Biochar treatment in the two sites, this result showed that Biochar had positive effect on the length of tubercle. Du et al., 1998a) reported that the length and dry weight of sweet potato were increased by soaking in a pyroligneous acid solution, however, ball index observed in Mokusakueki treatment was lowest in our study, which might be because of the bigger diameter of tubercle. Ball index observed in lime200 plots was significant higher than that in lime0 plots. High lime rate had significant positive effect on the length of tubercle, which influenced the apparent quality of sweet potato to some extent. In FS Center, Biochar treatment produced most number of good shape tubercles (75.98 thousand ha^{-1}) than Mokusakueki and Bokashi treatments (70.21 and 72.30 thousand ha^{-1}). In Mito farm, Biochar and Mokusakueki treatments produced more number of good shape tubercles (83.68 and 71.40 thousand ha^{-1}) than Conventional treatment (59.96 thousand ha^{-1}).

Zulkarami et al. (2011) observed that pyroligneous acid application increased the weight of rock melon by 37.3 and 27.5% with 10 and 20% application respectively as compared with control. In our study Mokusakueki also showed similar effect of increasing the weight of sweet potato, which was also in accordance with the sweet potato study conducted by Du et al., 1998a). The highest weight was observed in Mokusakueki treatment in the two sites, which suggested that Mokusakueki had positive effect on higher weight of sweet potato. Biochar treatment produced most number of S and M sweet potatoes and Mokusakueki treatment produced most number of L and 2L sweet potatoes in FS Center. Biochar treatment produced most number of S sweet potatoes and Mokusakueki treatment produced most number of M sweet potatoes in Mito Farmland. The weights observed in FS Center were heavier than those in Mito farmland, which may be caused by different lime application, and high lime rate showed negative effect on high weight. In addition, sweet potato that the weight was in 130~700g, was considered as having higher marketability in this study, and results showed that Biochar and Mokusakueki treatments produced more number of salable sweet potatoes both in the two sites.

CONCLUSION

Biochar treatment gave significantly effect on soil properties in FS Center, but this effect of Biochar was not observed in Mito farmland. However, only topsoil nutrient concentration was analyzed in the experimental sites, as observation period was one cropping season, so the analysis of soil properties had some limitation in this study. The results of this study revealed that Biochar had significantly positive effect on larger number of tubercles; Mokusakueki had positive effect on higher weight of sweet potato. Furthermore, Biochar and Mokusakueki combining with inorganic fertilizers could improve yield, sugar content and apparent quality of sweet potato, which will bring more economic profits for farmers, improve the food safety by reducing the application of inorganic fertilizers and help to promote the sustainable development.

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