Increases in available water content of soils by applying bagasse-charcoals

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Abstract
Biochar is charcoal produced from pyrolysis of biomass. Application of biochar with fine pore structures to agricultural soil may enhance the availability of water to crops. Miyako Island (target area) is located in a subtropical zone and consists of highly permeable coral limestone. The land surface is covered with calcareous soil called "Shimajiri-Maji". Because the soil has low available water for crops, land application of biochar to the soil may be used to reduce irrigation water needed for crops. The main biomass resource on the island is sugarcane bagasse because agriculture is the main industry and sugarcane is cultivated in approximately 80% of the farmland. Therefore, increases in available water content of the Shimajiri-Maji soil and Toyoura sand by applying bagasse-charcoal was evaluated in this study. The results were as follows: (1) Available water contents of the two soils were increased by application of bagasse-charcoal. The available water contents did not significantly differ with carbonization temperatures. (2) Available water contents of the two soils were proportionally increased by application of more bagasse-charcoal. Therefore, the need for irrigation water can likely be proportionally reduced by application of more bagasse-charcoal to these soils.

Key Words
Biochar, water retention curve, soil amendment, cay-rich soil, sand

Introduction
Biochar is charcoal produced from pyrolysis of biomass. Biochar may affect soil physical properties such as soil water retention and these effects may enhance the water available to crops (Glaser *et al.* 2002). Miyako Island (target area) is located in a subtropical zone and consists of coral limestone with high permeability. The land surface is covered with calcareous soil that is called "Shimajiri-Maji". The soil is clay-rich and the available water content for crops is low. Therefore, application of biochar with fine pore structures to the soil is expected to increase the available water content and reduce irrigation water needed for crops. The main biomass resource on the island is sugarcane bagasse because agriculture is the main industry and sugarcane is cultivated in approximately 80% of the farmland. Clay-rich soils and sand-rich soils, including sand, have low available water content for crops. In addition, the properties of biochar differ depending on the pyrolysis conditions, especially pyrolysis temperature (Downie *et al.* 2009).Therefore, increases in available water content of clay-rich soil (Shimajiri-Maji) and sand (Toyoura sand) by applying bagasse-charcoals were evaluated. Subsequently, the effects of carbonization temperature of bagasse-charcoal on available water content of the two soils were also evaluated.

Methods
Preparation of samples
Sugarcane bagasse, the residue from pressing sugarcane stalks to extract juice in a sugar factory, were air-dried and heated in a batch-type carbonization furnace at three different carbonization temperatures (400, 600 and 800°C) with a holding time of 2 h. The bagasse charcoals were sieved with a 2 mm-mesh for measurements of the water retention curve. Shimajiri-Maji soil and Toyoura sand were also air-dried and sieved with a 2 mm-mesh for the water retention curve measurements. The physicochemical properties of the bagasse-charcoal and soils were also measured.

Water retention curves of charcoal-amended soils
The water retention curves express the relationship between water content and matric potentials. We used the hanging water column method to obtain the retention curves at high matric potentials (>-3 kPa) and the pressure extractor method to obtain the retention curves at low matric potentials (-3 ~ -1,500 kPa). Measurements were made for charcoal-amended soils. The gravimetric charcoal content in soils amended by bagasse-charcoals at 400, 600 and 800°C of carbonization temperature was 3 wt % to study effects of carbonization temperatures on water retention and available water content of soils. The gravimetric charcoal

contents in soils amended by bagasse-charcoal at 800°C were 1, 3, 5 and 10 wt % to study effects of charcoal contents.

Results

Physicochemical properties of bagasse-charcoal and soils

The physicochemical properties of bagasse-charcoal at different carbonization temperatures are shown in Table 1. The pH value of the bagasse-charcoal varied from 5.0 at 400ºC to 9.8 at 800ºC. The cation exchange capacity (CEC) decreased, while the total carbon (T-C) and particle density increased with increasing carbonization temperature. Assuming that the ranges of matric potential of available water for crops were -33 to -1,500 kPa, the diameter of the capillary pores corresponding with the matric potentials were calculated from 200 to 9,000 nm. Pore volumes for 200 to 9,000 nm of bagasse-charcoal were not significantly different with carbonization temperatures. The physicochemical properties of the two soils used in this study are shown in Table 2. Shimajiri-Maji soil contained a lot of clay, while Toyoura sand contained only sand.

Table 1. Physicochemical properties of bagasse-charcoal at different carbonization temperatures.

Carbonization temp.	pH*1	CEC(pH7)*2	Total-C	Total-N	Particle Density	BET surface area*3	Pore volume*4 (200–9000 nm)
ºC		cmol$_c$ /kg	%	%	g/cm^3	m^2/g	cm^3/g
400	5	12.2	72.1	0.4	1.5	10.8	1.72
600	7.7	10.4	84.2	0.2	1.56	179	1.6
800	9.8	4.4	85.2	0.2	1.86	126	1.33

*1 charcoal:solution＝1 g:25 mL
*2 Shollenbergar method
*3 N_2 adsorption method
*4 Mercury intrusion method

Table 2. Physicochemical properties of Shimajiri-Maji soil and Toyoura sand.

	pH*1	CEC(pH7)*2	Org.-C	C/N	Particle Density	Sand (>0.02 mm)	Silt (0.002–0.02 mm)	Clay (<0.002 mm)
		cmol$_c$ /kg	g /kg		g/cm^3	%	%	%
Shimajiri-Maji	8.0	11.2	13.4	8.4	2.8	7.7	19.0	73.3
Toyoura sand	6.6	0.5	0	-	2.6	100	0	0

*1 soil：solution＝5 g:25 mL
*2 Shollenbergar method

Effects of carbonization temperature on water retention properties of soils

The water retention curves of Shimajiri-Maji soil and Toyoura sand amended with 3 wt % of bagasse-charcoals at three different carbonization temperatures are shown in Figures 1 and 2, respectively. Near saturation, volumetric water content of charcoal-amended soils was 400ºC<600ºC=800ºC. Tars that have water repellency remain in charcoal at low pyrolysis temperatures but are volatilized and almost disappear above 600ºC (Amonette and Joseph 2009).Therefore, the differences in volumetric water content near saturation may be caused by water repellency of tar. Except for near saturation, water retention properties of charcoal-amended soils did not significantly differ with carbonization temperature. At matric potentials less than -10 kPa, the volumetric water content of Shimajiri-Maji amended with charcoal were slightly lower than the original Shimajiri-Maji soil. The result showed that water in the pores of the charcoal is easily released while water adsorbed by clay in the soil is scarcely released at low matric potentials.

Available water content (-33 ~ -1,500 kPa) of Shimajiri-Maji soil and Toyoura sand amended with 3 wt % of bagasse-charcoal at three different temperatures is shown in Figure 3. Available water content of both clay-rich soil (Shimajiri-Maji) and sand (Toyoura sand) increased with application of bagasse-charcoal. In addition, the available water content of the two soils did not differ significantly with carbonization temperature. Therefore, the irrigation water needed for crops can likely be reduced by application of bagasse-charcoal to these soils.

Effects of charcoal content on water retention properties of soils

The water retention curves of Shimajiri-Maji soil and Toyoura sand amended with 0–10 wt % of bagasse-charcoal at 800°C are shown in Figures 4 and 5, respectively. The water retention of Toyoura sand was enhanced with application of more charcoal.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

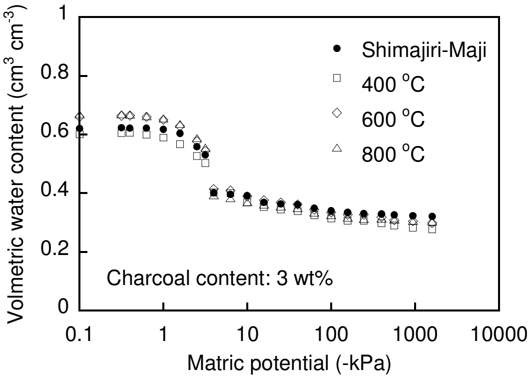

Figure 1. Water retention curves of Shimajiri-Maji soil amended with bagasse-charcoals at three different carbonization temperatures.

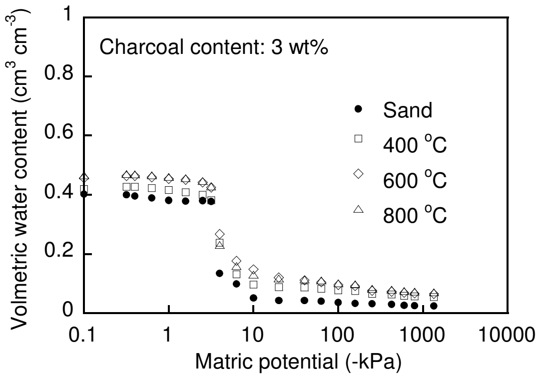

Figure 2. Water retention curves of Toyoura sand amended with bagasse-charcoals at three different carbonization temperatures.

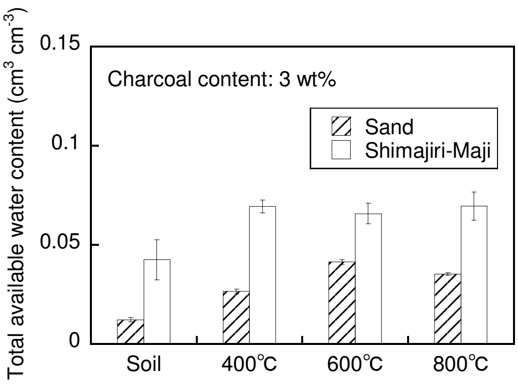

Figure 3. Available water content of soils amended with bagasse-charcoals at three different carbonization temperatures.

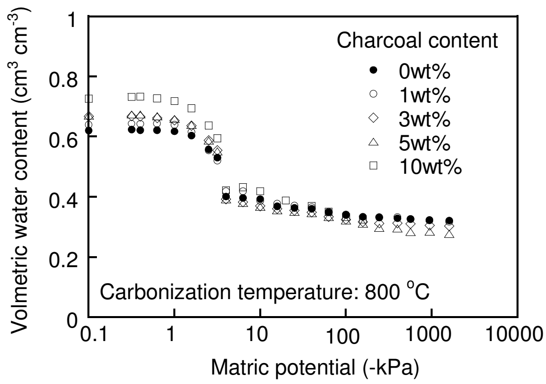

Figure 4. Water retention curves of Shimajiri-Maji soil amended with bagasse-charcoal at 800°C.

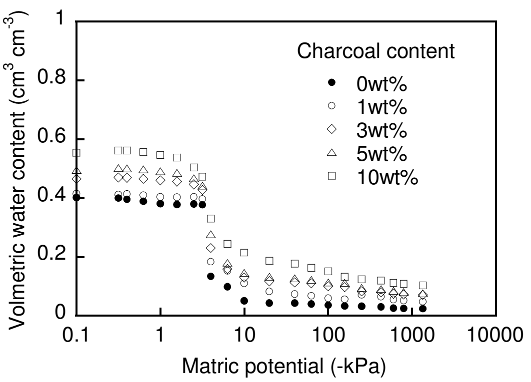

Figure 5. Water retention curves of Toyoura sand amended with bagasse-charcoal at 800°C.

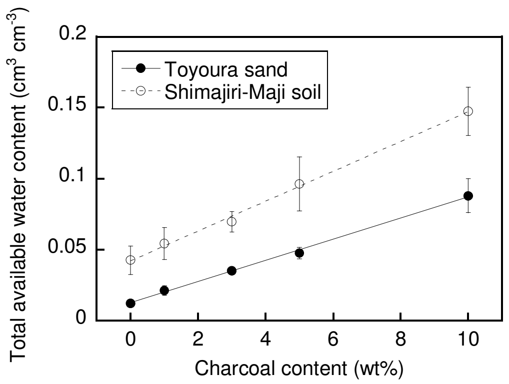

Figure 6. Available water content of soils amended with bagasse-charcoal at 800°C.

Available water content (-33 ~ -1,500 kPa) of Shimajiri-Maji soil and Toyoura sand amended with 0–10 wt % of bagasse-charcoal at 800°C is shown in Figure 6. Available water contents of the two soils were proportionally increased by application of more bagasse-charcoal. Therefore, irrigation water needed for crops can likely be proportionally reduced by application of more bagasse-charcoal to these soils.

Conclusion

Increases in available water content of the clay-rich soil (Shimajiri-Maji) and sand (Toyoura sand) by applying bagasse-charcoal were evaluated in this study. The results were as follows: (1) Available water contents of the two soils increased with application of bagasse-charcoal. The available water contents did not significantly differ with carbonization temperature. (2) Available water contents of the two soils were proportionally increased by application of more bagasse-charcoal. Therefore, irrigation water can likely be reduced by application of more bagasse-charcoal to these soils.

References

Amonette JE, Joseph S (2009) Characteristics of Biochar: Microchemical Properties. In 'Biochar for Environmental Management’. (Eds J Lehmann, S Joseph) pp. 33-52. (Earthscan).

Downie A, Crosky A, Munroe P (2009) Physical Properties of Biochar. In 'Biochar for Environmental Management’. (Eds J Lehmann, S Joseph) pp. 13-32. (Earthscan).

Glaser B, Lehmann J, Zech W (2002) Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal – a review. *Biology and Fertility of Soils* **35,** 219-230.