Use of Soil-Charcoal Mixture as a Soil-Cover System for Plant Growth and CO_2 Capture

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1. Introduction

Charcoal is a non-biodegradable and lightweight porous material derived from wood using various methods. Soils with charcoal amendment have excellent nutrient absorption and water retention which are necessary to promote plant growth for higher yield (Glaser et al., 2002). Such properties could further benefit and enhance vegetation growth to act as cover system for rainfall-induced soil erosion. Furthermore, mixing soil with charcoal can be beneficial geomaterial for ground improvement as permeability of the mixture can be increased allowing higher infiltration.

Emissions of carbon dioxide (CO_2) have been increased worldwide and are major concerns for climate change. It was reported that the amount of CO_2 emissions in Japan in year 2009 was 1145 tons CO_2 per capital (Fig 1). Charcoal-soil mixture has potential to sequester carbon in soil (Bracmort, 2010).

Effective use of the charcoal-soil mixture as a cover system for plant growth along embankment slope, for slope stabilization and for capturing CO_2 emission from transport has not been fully investigated. Therefore, this study is to investigate saturated and unsaturated properties of the mixtures such as water retention characteristics, and permeability function of the mixtures.

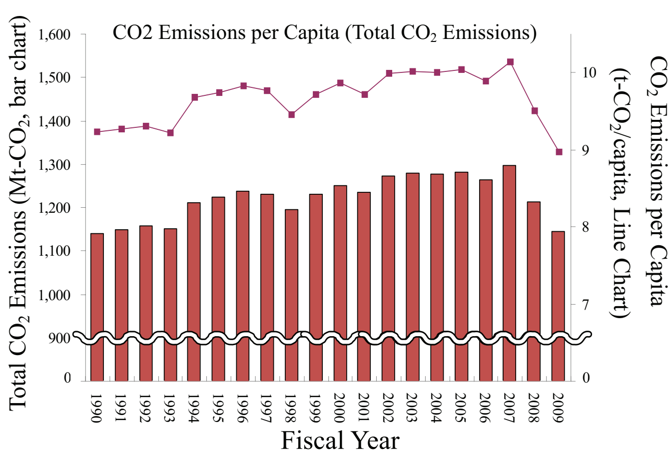

Fig 1. CO_2 Emission per capital in Japan (from Greenhouse Gas Inventory Office of Japan, 2011)

2. Materials

Red soil from Okinawa of Japan was used as soil sample for experiments. Used charcoal was a granular type and grain size is between 4.75mm-9.5mm. Mixtures of charcoal and red soil were prepared by percentage of dried mass of charcoal of 10%, 20% and 30% corresponding to symbols CS-10, CS-20, and CS-30, respectively. RS indicates the Okinawa red soil. Basic properties of the red soil, charcoal –soil mixtures are shown in Table 1 and their grain size distributions are shown in Fig 2. Compaction of the mixtures was carried out manually using hand and lightly tapped the mixture at dry condition to various densities as shown in Table 1.

Table 1. Basic properties of Okinawa red soil and the charcoal-soil mixtures

Properties	Charcoal-soil mixtures			
	RS	CS-10	CS-20	CS-30
Specific gravity, G_s	2.645	2.422	2.245	2.134
Void ratio, e	0.65	-	-	-
Dry density, ρ_d (Mg/m^3)	1.51	1.43	1.25	1.07
Atterberg's Limit Tests				
Liquid limit (%)	32.71	-	-	-
Plastic limit (%)	18.89	-	-	-

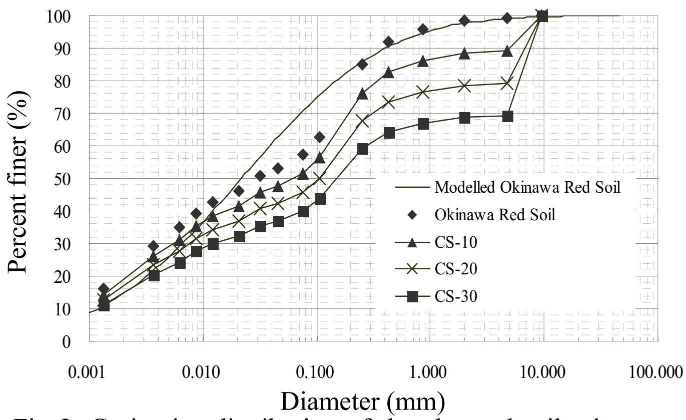

Fig 2. Grain size distribution of the charcoal-soil mixtures and Okinawa red soil

3. Methods

3.1 Determination of Water Retention Characteristics

Moisture movement through unsaturated soil mass is commonly described by water retention characteristic curve (WRCC) or relationship between volumetric water content and matric suction (u_a-u_w), u_a and u_w are pore-air and pore-water pressure, respectively. WRCC has adsorption and desorption characteristics following wetting and drying paths, respectively. Difference between the two characteristics is called "the hysteresis". For the WRCC of all mixtures between charcoal and Okinawa red soil were measured by laboratory experiments using Tempe cell apparatus for suction below 200 kPa. Result data of the experiment for the WRCCs were fitted with the Fredlund and Xing (1994) (1) function using the correction factor, C(ψ), equal to 1 as suggested by Leong and Rahardjo (1997).

$$\theta(\psi, a, m, n) = C(\psi)\frac{\theta_s}{\left\{\ln\left[e + \left(\frac{\psi}{a}\right)^n\right]\right\}^m} \qquad \text{Eq (1)}$$

where θ is volumetric water content; θ_s is saturated volumetric water content; a, m, n are a constant; e is natural number (2.71828…); ψ is soil suction, $C(\psi)$ is a correction function

3.2 Determination of permeability functions

Saturated permeability, k_{sat}, for all specimens was determined by falling head test method. Unsaturated coefficient of permeability, k_w, or permeability function of the tested specimens were indirectly derived from a statistical model proposed by Childs and Collis-George (1950). Detail is described in Fredlund and Rahardjo (1993).

4. Results and Discussion

4.1 Results for Water Retention Characteristics

Fig 3 shows WRCC of the mixtures. For all mixtures, volumetric water contents (VWC) gradually decreased with increased matric suction. At matric matric suction more than 400 kPa, VWC of RS showed the lowest indicating that all the mixtures could preserve higher moisture than RS at the same dry condition. Results of all fitting parameters are tabulated in Table 2.

4.2 Results for Permeability Functions

Fig 4 shows permeability functions obtained. At saturation, k_{sat} of CS-30 was the highest indicating the fastest drainage among the tested specimens. At matric suction more than 400 kPa, permeability of RS was the highest due to the highest air-enter value and more water drained from the all mixtures while water drainage in RS still remained slow.

Table 2. SWCC parameters and saturated permeability

Symbol	Unit	Charcoal-Soil Mixtures			
		RS	CS-10	CS-20	CS-30
θ_S		0.39	0.38	0.37	0.33
ψ_a	kPa	25	3.0	4.2	5.2
ψ_r	kPa	700	400	300	150
θ_r		0.10	0.165	0.155	0.150
a	kPa	49.978	6.727	8.851	8.733
n		2.059	1.195	1.597	2.081
m		0.564	0.387	0.363	0.323
k_{sat}	m/s	$4.53\text{x}10^{-8}$	$3.94\text{x}10^{-8}$	$1.95\text{x}10^{-7}$	$1.24\text{x}10^{-6}$

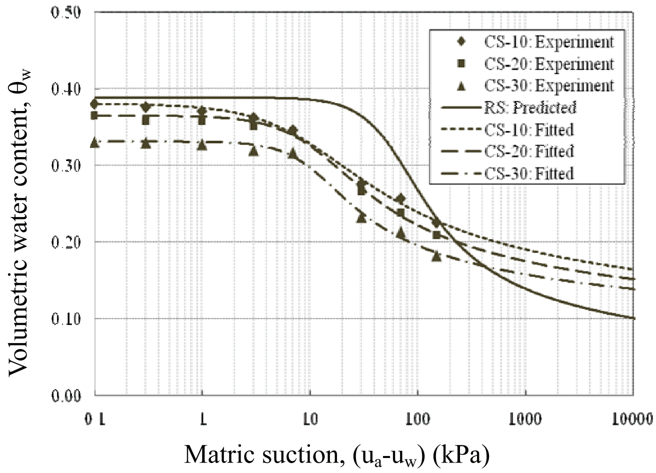

Fig 3. Water retention characteristic curves

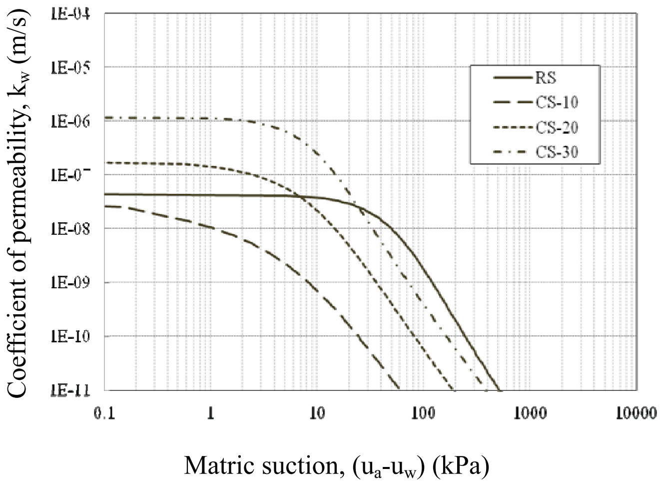

Fig 4. Permeability functions

The results obtained will be basic input data into numerical analysis to analyze the cover system, slope stabilization and CO_2 capture in future research.

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