A preliminary investigation into the sequestration of biochar in Lime-GGBS treated Acid Sulphate Soils

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ABSTRACT

Lime activated GGBS has been investigated to improve the Acid Sulphate Soils (ASS) found along the coastline of Australia. Biochar is an environmentally friendly carbon negative material which has been incorporated for soil stabilisation works. ASS was treated with different proportions of biochar, lime and GGBS. Treated ASS was cured for up to 6 months in a humid chamber and tested for the unconfined compressive strength and mineralogical developments. Results of this study show that biochar can be sequestered in the stabilisation of ASS to achieve a desired strength and reduction of carbon intensive cementing materials (lime, cement). It has been found that the UCS of treated ASS increases up to 3 months curing for the additives proportions investigated.

Keywords: Acid sulphate soil, soil improvement, lime-GGBS-biochar, unconfined compressive strength, mineralogy

1 INTRODUCTION

Improvement of soft soils with cementitious additives (e.g., lime, cement) has been practised since 1990s for the development of a wide range of infrastructure. Some of the commonly investigated stabilizing agents are cement, lime, fly ash and ground granulated blast furnace slag (GGBS) (Wilkinson, et al., 2010). The use of industrial by-products such as GGBS and fly ash (which would otherwise be used for landfill) has economic, environmental and social benefits while improving the strength properties of soft soils. Approximately 3.1 million tons of GGBS is generated per year by iron and steel manufacturing industries in Australia (Cooper, 2005). However, GGBS alone is not effective for soil stabilization as it requires lime or cement to activate for cementitious reactions (Karmon & Nontananandan, 1991). Moreover, in the case for lime activated GGBS, an amount of lime satisfying the lime saturation pH is necessary for sustainable cementitious reactions (James, et al., 2007). Australia has significant deposits of soft acid sulphate soils (ASS) containing pyrite (FeS_2) mineral along the coastline (c. 95,000km^2). It has been reported that the consumption of lime to activate GGBS for the stabilization of ASS is significant (10-15%) (Islam et al., 2014; 2013). Although utilisation of GGBS may reduce green-house gas emissions, concern still arises from the lime and cement requirements as the production of these materials emits a significant quantity of CO_2 to the atmosphere. Moreover, properties of stabilised soils and concrete infrastructure built in ASS undergo degradation due to the formation of deleterious minerals, such as thaumasite (Alonso & Ramon, 2012). Therefore, it is of significant importance to reduce the amount of lime utilisation in an environmentally friendly, efficient and sustainable manner.

Biochar is an alkaline material produced from the burning of green wastes or tree residues in a low oxygen and medium-high temperature environment, known as pyrolysis. It has the ability to enhance soil fertility while permanently storing carbon in the soil (Zwieten, et al., 2009). Biochar with high pH has the potential to reduce the amount of lime required in the conventional stabilisation process. It has time-dependent cation exchange capacity which is beneficial for the long-term strength development. Even though biochar shows such environmentally friendly, sustainable and beneficial characteristics, its incorporation in soil stabilisation has been limited to date (Haque et al., 2014). This study investigates the time-dependent strength behaviour of lime-GGBS treated acid sulphate soils (ASS) by incorporating different proportions of biochar. In addition, mineralogical studies of treated ASS at six months curing were carried out. Results of these tests are analysed and reported in this paper.

2 EXPERIMENTAL INVESTIGATION

2.1 Materials

Coode Island Silt (CIS) is a soft ASS which can be found up to 25+m depth in the Melbourne CBD. It has high compressibility and low shear strength. Structures built on CIS undergo significant settlement under applied pressure (Ervin, 1992). CIS has been classified as a potential acid sulphate soil and has been recognized as harmful to the environment (Marie, 1999).

In this study, CIS (Liquid Limit=82, Plasticity Index=43, % finer 75□=55%) was collected from the Dockland area of Melbourne CBD from a depth of 10 to 12 m. Laboratory test showed that it had an initial pH value of 7.6 and moisture content of approximately 67%. The soil consists of quartz (24%), smectite (32%), kaolinite (23%), illite/mica (10%), feldspar (5%) and pyrite (4%). The natural CIS was left in the air for about two years to simulate the oxidation process of pyrite. The CIS had a moisture content of 5% and a pH of 3.44 simulating a real ASS which is the subject of this study. The CIS has been stabilised by adding various proportions of lime (2, 4, 6%), GGBS (15, 20%) and biochar (10, 20%). Hydrated lime [95% $Ca(OH)_2$] and GGBS (43% CaO, 32% SiO_2, 14% Al_2O_3) have been used in this investigation. The properties of biochar are given in Table 1.

Table 1: Properties of biochar

Properties	Units	Values
Total organic matter	%	3
Total organic Carbon	%	1.5
Exchangeable Calcium	meq/100g of soil	0.99
Exchangeable Magnesium	meq/100g of soil	0.13
Exchangeable Sodium	meq/100g of soil	0.34
Exchangeable Potassium	meq/100g of soil	0.57
Cation Exchange Capacity	meq/100g of soil	2.3
pH		8.3

2.2 Initial consumption of lime (ICL) test

ICL test was conducted to determine the minimum quantity of lime required to maintain a sustainable cementitious reaction environment in the stabilisation of CIS containing different proportions of biochar (10, 20, 30%). In this test, 30g of solid (CIS and biochar) was mixed with 100ml of water and the pH of the mix was measured after 1.5hours. Figure 1 shows the variation of pH with the increase of lime and biochar contents. It can be seen from the figure that, the increase of biochar from 10 to 20% increases the pH from 7 to 12 for a low dose of lime (2%). Further addition of biochar (30%) has not shown any appreciable increase of pH. The pH remains constant after reaching the lime saturation pH of 12.53, with 4% lime and 10% or greater amount of biochar. In this study, 2 to 6% lime was investigated to stabilise the CIS with different proportions of GGBS and biochar as shown in Table 2.

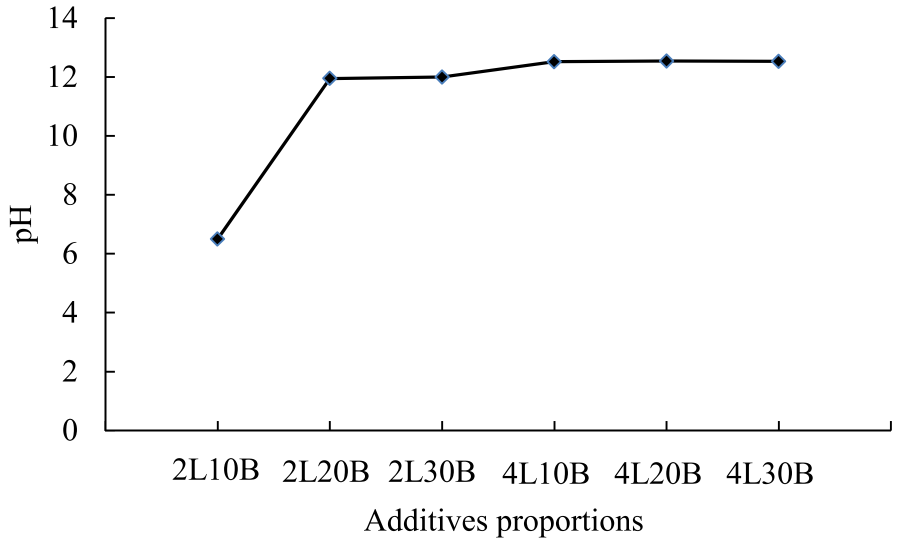

Figure 1. Results of initial consumption of lime tests (L: Lime; B: Biochar)

Table 2. Proportions of additives investigated

Hydrated Lime (%)	GGBS (SLAG) (%)	Biochar (%)
2	15	10
		20
	20	10
		20
4	15	10
		20
	20	10
		20
6	15	10
		20
	20	10
		20

2.3 Sample preparation

The biochar was oven dried, ground into fine particles and passed through 425 microns sieve. The CIS was treated by mixing different proportions of biochar, lime and GGBS as mentioned in Table 2. Mixed CIS and additive slurries were carefully weighed into a steel bowl and sufficient water was added to make the moisture content of 130%, which is about 1.3 times the liquid limit of CIS. This enabled the intimate mixing of soil components with stabilizing agents and ensures a sustained hydration reaction (Wilkinson, et al., 2010). The mixing was performed within 20 minutes using a mixer machine to avoid initial hardening. The mixed slurry was then poured into a 52mm diameter and 110mm height poly vinyl chloride (PVC) moulds. A thin layer of grease was applied in the inner surface of PVC moulds to ensure smooth extraction of the sample from the mould after curing. A mild vibration was applied on the outer surface of the moulds after placement of the slurry to minimise the voids and entrapped air bubbles within the samples. The ends of the moulds were sealed with plastic sheets to minimize carbonation and stored at 23°C in a humid chamber for various curing periods (1, 3, 6 months).

2.4 Unconfined compressive strength (UCS) test

UCS test was carried out on cured samples as per AS 1141.51 (1996) Tests were conducted on at least three samples for each combination of additives and curing periods.

2.5 Scanning electron microscopy (SEM)

SEM imaging was carried out at 6 months of curing to study the mineralogical development within the treated CIS. A JEOL 7001F available at the Monash Centre for Electron Microscopy (MCEM) was used for this purpose. Crushed specimens of treated samples were used for SEM imaging. A platinum coating of 3-nm thickness was applied using a vacuum evaporator prior to analysis.

3 RESULTS AND DISCUSSIONS

3.1 Unconfined compressive strength (UCS) of treated CIS

UCS tests were conducted on three samples for each combination of additives and curing periods. Average UCS results of three samples were determined and plotted against the curing periods in Figures 2 and 3.

Figure 2 shows the UCS variation with curing for 10% biochar containing CIS treated with 2 to 6% lime, and 15 and 20% GGBS. It can be seen that lime and GGBS have significant influence on the strength development of treated CIS. For a fixed biochar and lime contents, an increase in GGBS content is found to increase the UCS for all curing periods. On the other hand, for a fixed amount of GGBS, an increase in lime content increases the UCS except for CIS treated with 4% lime at 6 months. It can also be seen that the increase in UCS with curing for all additive contents increases up to 3 months and thereafter the increase of UCS is insignificant. The addition of more lime in the reaction environment ensures activation of higher quantity of GGBS leading to more pozzolanic reactions products. The slow rate of increase of strength development after 3 months could be due to the unavailability of lime in the reaction system. Recently Islam (2014) reported UCS results of 10% biochar mixed CIS treated with 10 and 15% lime and 15% GGBS. This study found that 10% lime was still inadequate to increase the UCS after 3 months curing. However, an increase of lime from 10 to 15% was reported to contribute to the development of cementitious reaction products and the UCS of CIS up to 6 months. It can also be seen that increase of GGBS alone can impart appreciable UCS development after 3 months (Figure 2).

Figure 3 shows the UCS variation with curing for 20% biochar containing CIS treated with different proportions of lime and GGBS. Likewise 10% biochar (Figure 2), the increase of lime and GGBS increases the UCS for all curing periods investigated. More interestingly, the UCS is observed to increase up to 3 months curing with insignificant changes thereafter. It is important to note that 10% biochar containing CIS shows relatively higher UCS except for CIS treated with 4% lime and 15% GGBS, where 20% biochar containing CIS shows high UCS. As found for 10% biochar containing CIS, 6% lime is found to be inadequate for 20% biochar mixed CIS for strength development after 3 months curing. This again shows that higher quantity of lime may be required if long-term strength development is of concern.

The two biochar contents (10, 20%) investigated in this study show that the UCS of ASS can be improved significantly by adding relatively lower dose of lime (2-6%) compared to that of the 10-15% lime required for treating ASS. This study is encouraging from the soil stabilisation viewpoint, where incorporation of biochar in the treatment of ASS can potentially reduce CO2 emissions to the atmosphere through the utilisation of reduced amount of carbon intensive additives (lime, cement) as well as permanently sequestering carbon into soils.

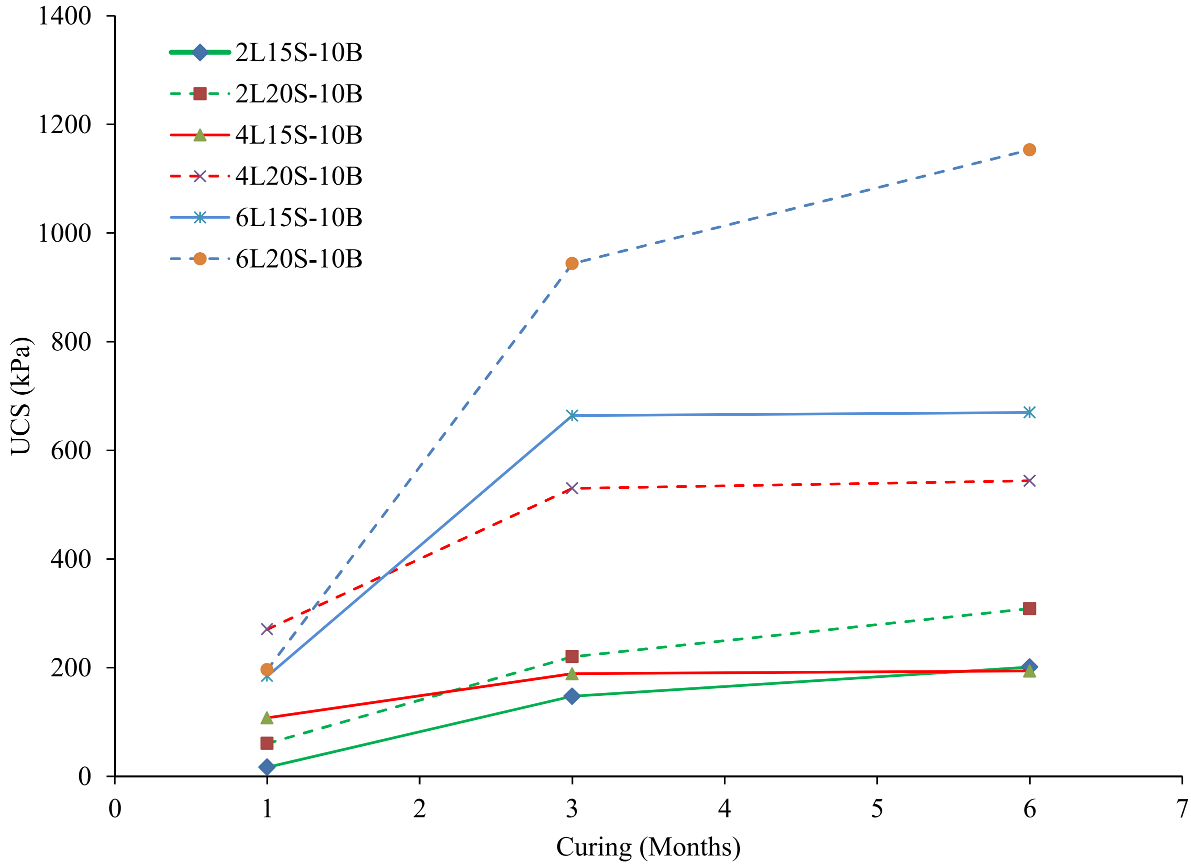

Figure 2. UCS test results of 10% biochar mixed CIS treated with different proportions of lime and GGBS [L: Lime, S: GGBS, B: Biochar]

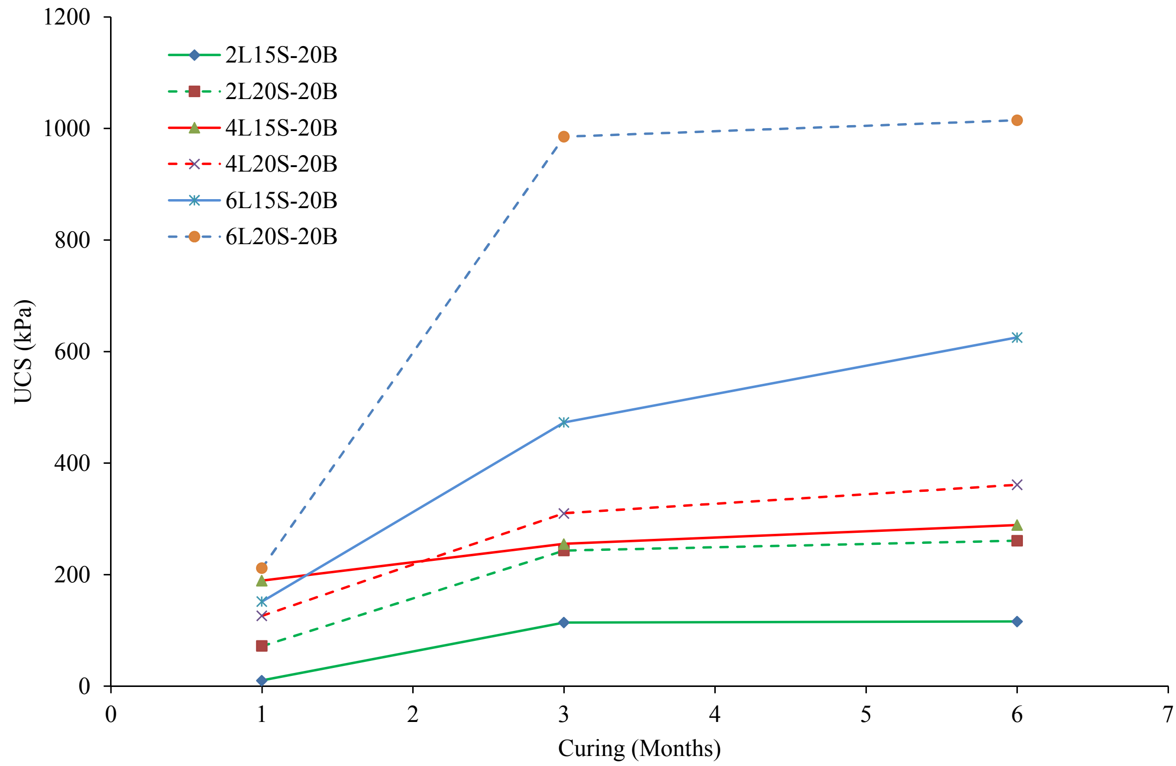

Figure 3. UCS test results of 20% biochar mixed CIS treated with different proportions of lime and GGBS [L: Lime, S: GGBS, B: Biochar]

3.2 Mineralogical analysis of treated CIS

SEM imaging was carried out on treated CIS to analyse the mineralogical development. Figure 4 shows the SEM images of CIS containing 10% biochar treated with 4% lime and 20% GGBS at 6 months of curing. The image shows the biochar and clay particles together with the cementitious reaction products (C-S-H). The interaction between biochar and cementitious minerals can be observed in Figure 4a. It can be seen that the cementitious reaction products form on the surface of the clay particles as well as at the biochar-clay particles interfaces. Figure 4b shows the zoomed in image of Figure 4a, where the honeycomb structure of biochar is evident. Moreover, the integration of cementitious materials (e.g., C-S-H) with biochar can be observed, which is believed to enhance the UCS of treated CIS with time. A recent study carried out by Islam (2014) on 10% biochar mixed CIS treated with 10% lime and 15% GGBS reported the mineralogical developments using the X-Ray Diffraction test at 6 months curing (Figure 5). The investigation found the presence of cementitious minerals of jennite, apophyllite, gismondine and afwillite in the XRD patterns at 6 months curing.

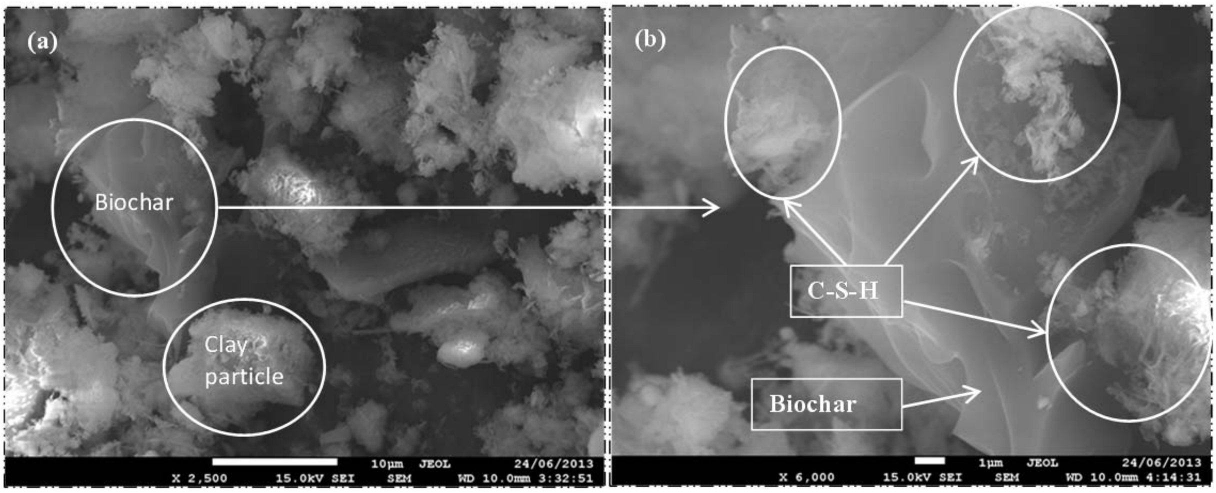

Figure 4. (a) SEM image of CIS containing 10% biochar treated with 4% lime and 20% GGBS at 6 months curing, and (b) interaction of biochar-clay-cementitious materials (zoomed).

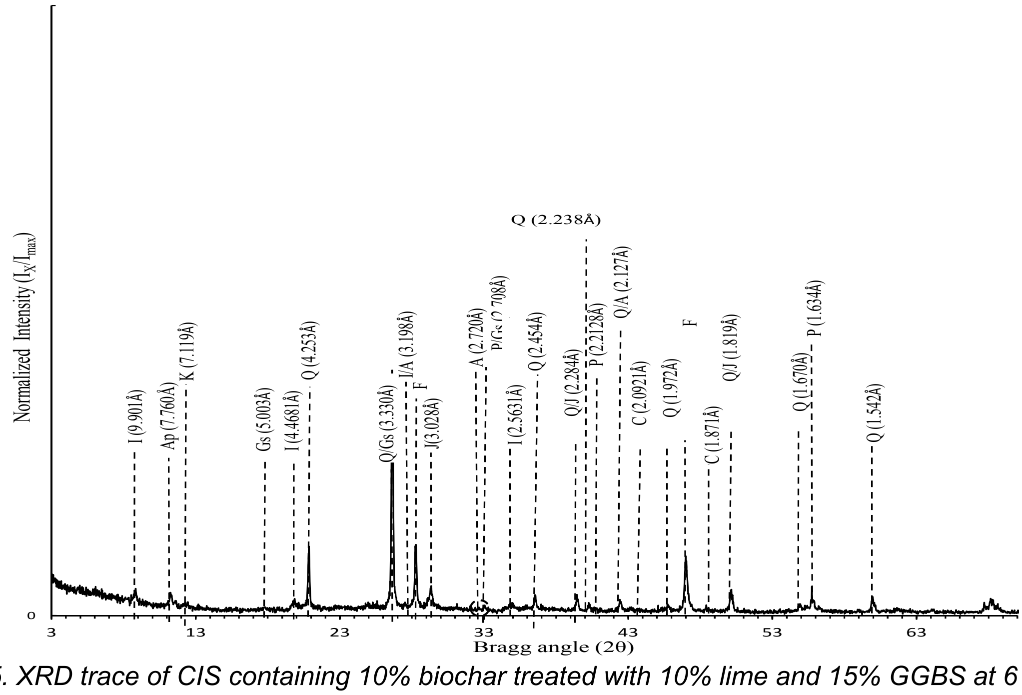

Figure 5. XRD trace of CIS containing 10% biochar treated with 10% lime and 15% GGBS at 6 months curing (Islam, 2014) [Q: Quartz, I: Illite, K: Kaolinite, P: Pyrite, C: Calcite, Ap: Apophyllite, Gs: Gismondine, F: Fluorite, A: Afwillite, J: Jennite].

4 CONCLUSIONS

Acid sulphate soil (ASS) was treated with biochar, lime and GGBS in the laboratory. The treated ASS was cured in a humid chamber for up to 6 months and tested for unconfined compressive strength (UCS) developments. Scanning electron microscopy was also conducted on treated ASS.

Results shows that increase of lime and GGBS increases the UCS of treated ASS for all curing periods investigated. It has also been observed that UCS increases with curing up to 3 months and thereafter insignificant change has been registered for all the additive contents investigated. Addition of further lime and GGBS may influence the strength development at longer curing periods. This study finds that biochar (10-20%) can be sequestered during the improvement of soft ASS by mixing lime-GGBS. Inclusion of biochar in ASS treatment could reduce the use of carbon intensive alkaline materials (lime). The reduction of lime consumption could bring significant benefits to construction industries through reducing CO2 emissions and permanently sequestering biochar carbon into soils.

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