Phosphorus Dynamics in the Soil and Crop upon Sewage Sludge Biochar Application

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Introduction

Sewage sludge is expected to be recycled as alternative phosphorus (P) resources in agriculture. Especially, pyrolytic conversion of sewage sludge into biochar could be one of the sustainable management options for agricultural soils. The pyrolysis temperature, however, is one of the critical deciding factors for properties of biochar derived from sewage sludge (SSB). In this study, two biochars pyrolysed at two different temperatures were separately mixed with two different types of Japanese soils for a pot study. Nutrient, in particular, P cycling in soil, biochar, and crop was investigated.

Materials and Methods

Soil and biochar

Soil (≤2 mm): An Andosol in Tokyo and tropical acid soil called "Kunigami-mahji" in Okinawa, Japan.

Biochar (milled and sieved ≤300 μm): Sewage sludge was pyrolysed at 800°C (SSB800) and 300°C (SSB300).

Table1. Agronomic properties of soil and biochar

		Andosol	Kunigami-mahji	SSB800	SSB300
pH		7.10	4.61	6.61	5.60
EC	μS/cm	59.33	34.40	1170	112
TC	g/kg	45.08	1.12	532.2	528.4
TN	g/kg	2.81	0.15	34.1	54.8
TP	g/kg	0.73	0.26	44.8	26.2
H_2O-P	mg/kg	1.16	0.17	30.5	105.9
Citric-P	mg/kg	0.14	0.04	2234	1651
Truog-P	mg/kg	0.43	0.70	278.2	205.5

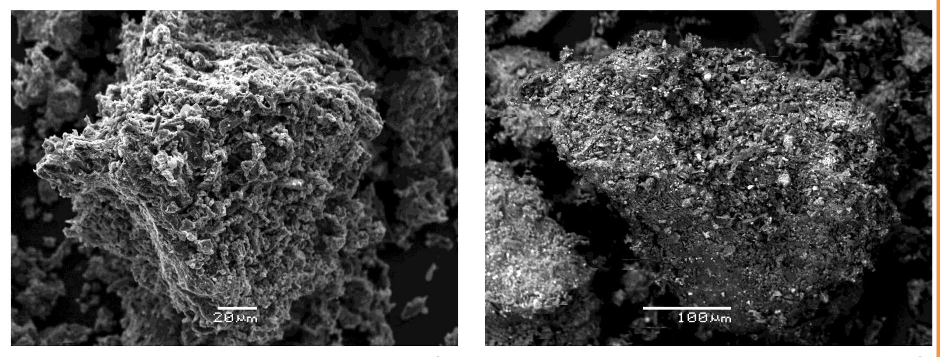

Fig. 1. SEM images of SSBs (left:SSB800; right: SSB300)

Phosphorus Adsorption and Desorption Isotherm

P adsorption isotherms were developed on soils without or with 5% (w/w) SSB, respectively. Two grams of soil sample and 20 mL of 50 mM KCl with 11 levels of P (Andosol: 0–2000 mg L^{-1}; Kunigami-mahji: 0–200 mg L^{-1}) solution were shaken for 16 hour. Adsorbed P was calculated as the difference between the initial solution concentration added and the final concentration in the filtrate. Maximum adsorption capacity b and diffusion coefficient K_d were calculated by Langmuir equation below.

P desorption isotherms were developed on SSB800 and SSB300, respectively. SSB and 40 mL of 50 mM KCl were mixed at 6 different soil:solution ratios (1:500–1:10000) and shaken for 5 days. Soluble inorganic P was measured by Murphy and Riley method.

$$C_s = \frac{k\,b\,C_l}{1 + kC_l} \cdots (1) \qquad \frac{dC_s}{dC_l} = K_d = \frac{k\,b}{(1 + kC_l)^2} \cdots (2)$$

Cs: P on solid phase
Cl: P on solution phase at equilibrium
k and b: Langmuir coefficient

Pot Study

Japanese mustard spinach (*Brassica rapa*) was grown in 1 L pots with Andosol including SSB. SSB were mixed at 4 different rates (v/v), respectively (0%, 0.8%, 1.6%, and 3.2% of SSB800; 0%, 0.6%, 1.2%, and 2.3% of SSB300). The rates corresponded to a half (x½P), the same amount (x1P), and twice (x2P) of the recommended rates for the spinach in Tokyo based on 2% citric acid-extractable P concentrations in each SSB. After a month of cultivation, dry weight and total P of the aboveground plant were analyzed.

Results and Discussion

Phosphorus Adsorption and Desorption Isotherm

While P adsorption isotherms on Andosol showed only minor differences when either SSB was added (Fig. 2A), the isotherm on Kunigami-mahji with SSB300 exhibited lowered shape compared to those on soil and soil+SSB800 (Fig. 2B). In fact, Langmuir b value for isotherm on soil+SSB300 was 88% of that on Kunigami-mahji only (Table 2). Higher amount of H_2O-P in SSB300 than in SSB800 (Table 1) may have reduced the adsorption capacity which Kuhigami-mahji was already lower than Andosol (Table 2).

P desorption isotherms on SSBs were expressed as remained adsorbed from the total P in SSBs (Fig. 3). SSB800 and SSB300 desorbed 1% and 10% of the total P, respectively. Moreover, K_d value from P desorption isotherm on SSB300 was consistently greater than that on SSB800 (Fig. 4), indicating, for example, that water soluble P in SSB300 was 63 times more easily desorbable than that in SSB800 when equilibrium concentration was 2 mg L^{-1} (K_d = 0.024 and 1.506, respectively).

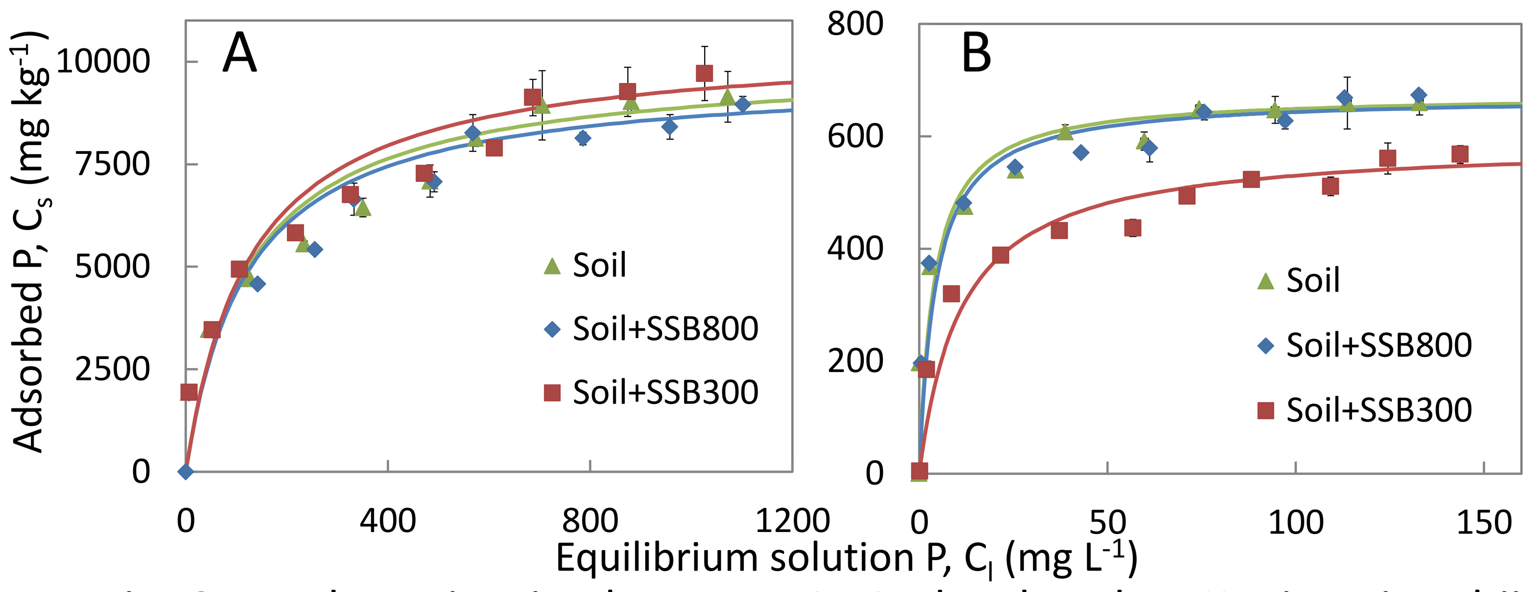

Fig. 2. P adsorption isotherm on A: Andosol and B: Kunigami-mahji without and with SSB800 and SSB300, respectively.

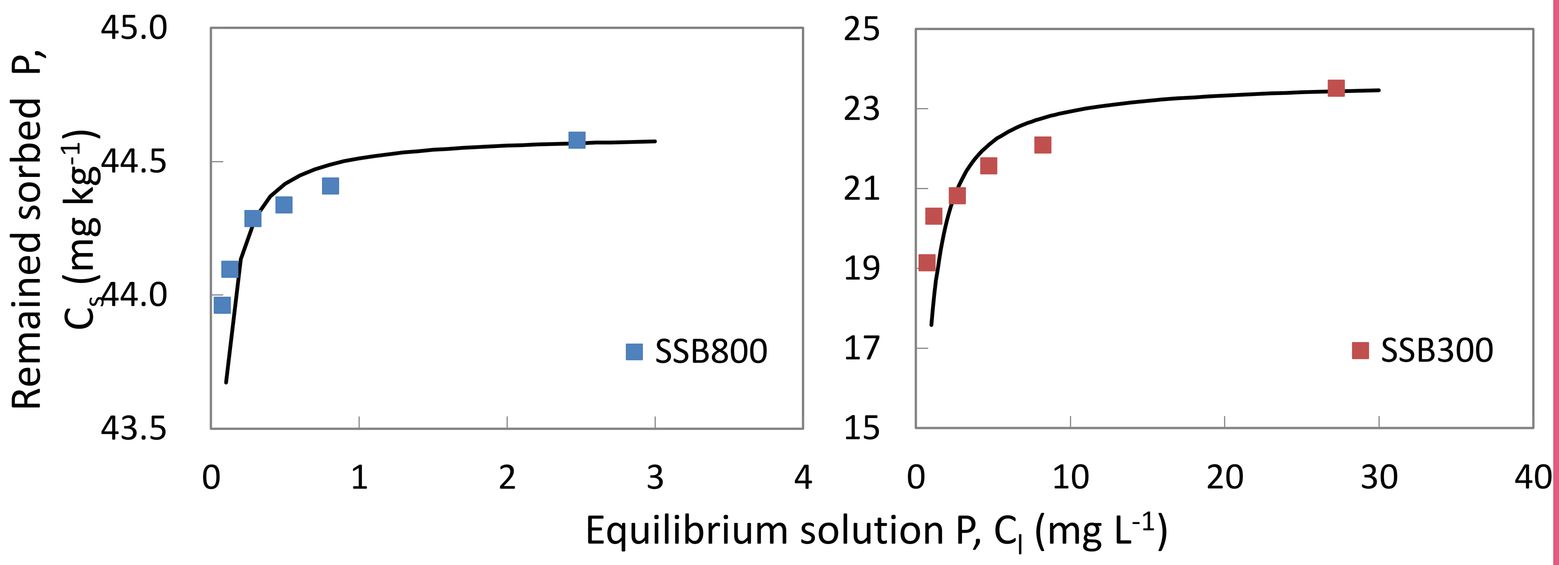

Fig. 3. P desorption isotherm on SSB800 and SSB300

Plant Growth and Phosphorus Absorption

All pots containing SSB showed an increase of dry weight compared with control (Fig. 5). Especially under SSB300x1P treatment, the dry weight was more than that under chemical fertilizer, indicating potential of SSB as alternative P fertilizer.

P absorbed by plants under all SSB800 treatments was equivalent to that with chemical fertilizer. The plant with SSB300 treatments exhibited higher P absorption than those with fertilizer and SSB800 treatments, suggesting higher P bioavailability in SSB300 than in SSB800.

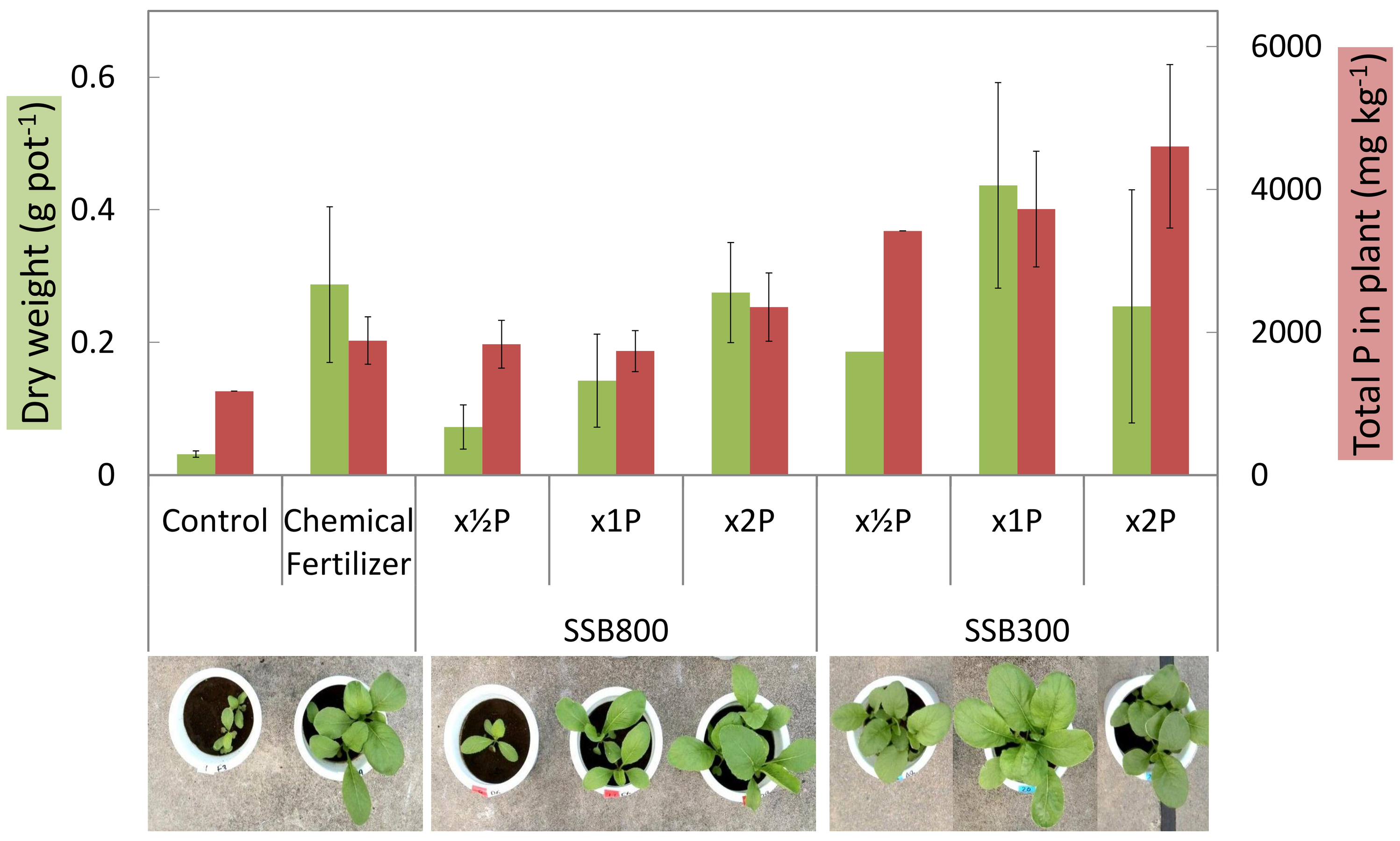

Fig. 5. Dry weight and total P in aboveground plant

Table 2. Langmuir coefficients of adsorption isotherms

Sample		Langmuir coefficient	
		K	b
		L mg^{-1}	mg kg^{-1}
Andosol	Soil	0.0081	9997 (100%)†
	Soil+SSB800	0.0083	9702 (97%)
	Soil+SSB300	0.0078	10509 (105%)
Kunigami-mahji	Soil	0.2557	674 (100%)
	Soil+SSB800	0.2292	671 (96%)
	Soil+SSB300	0.0882	590 (88%)

† Percentage is relative to b value for each soil only.

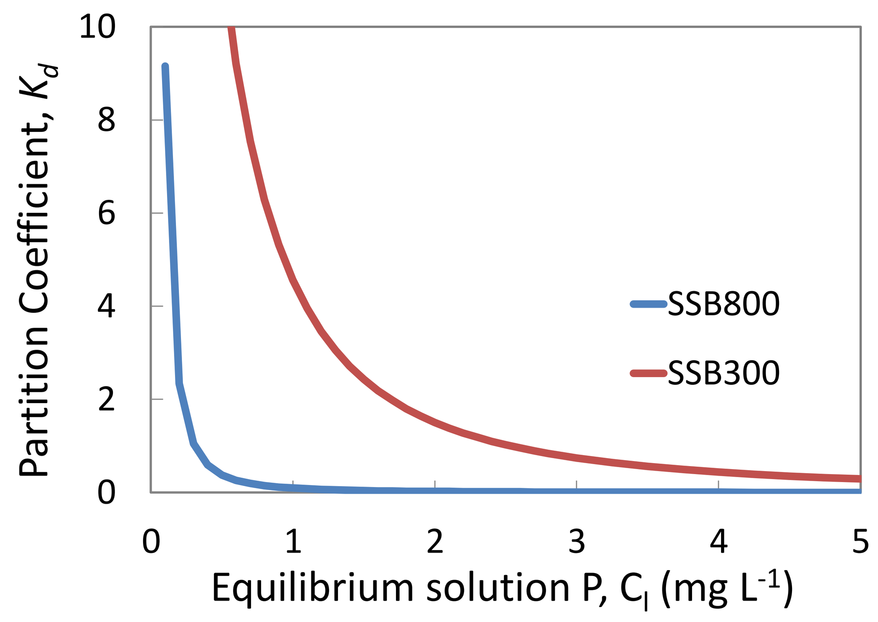

Fig. 4. Partition coefficients relative to equilibrium P concentration for desorption isotherm for SSBs

Conclusion

1. Maximum P adsorption capacity may have decreased in a combination of soils with low adsorption capacity such as Kunigami-mahji and SSB with high water soluble P such as SSB300 in this study.
2. Comparing SSBs used in this study, although SSB800 contained greater amount of total P than SSB300, SSB300 was richer in water soluble P than SSB800. Therefore, P in SSB300 was more easily desorbable than SSB800. This was obvious from the difference of K_d values from the P desorption isotherms of SSBs.
3. From the pot study results, it was concluded that SSB300 had higher P bioavailability, thus higher potential to be used as P alternative fertilizer than SSB800.

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