Sorption-desorption behavior of carbendazim by sewage sludge-derived biochar and its possible mechanism

Tengda Ding [1,*] Tuo Huang [1], Zhenhua Wu[2], Wen Li[1], Kexin Guo[3], Juying Li [1]

[1] College of Chemistry and Environmental Engineering, Shenzhen University, Shenzhen 518060, China

[2] Dongyang Environmental Protection Monitoring Station, Dongyang 322100, China

[3] Xili Regenerative Water Plant, Shenzhen Water Group CO. LTD., Shenzhen 518055, China

**Corresponding Author*

College of Chemistry and Environmental Engineering, Shenzhen University,

Shenzhen 518060, China

Tel.: +86-0755-26932510 E-mail: dingtengda@szu.edu.cn

Text S1 Characterization of sewage sludge derived biochars

The total carbon (C), hydrogen (H), nitrogen (N) and oxygen (O) contents of the raw sewage sludge and sewage sludge derived biochars were determined by an automatic elemental analyzer (Vario EL, Hanau, Germany). The water soluble metals including K^+, Ca^{2+}, Na^+, and Mg^{2+} were measured by inductively coupled plasma optical emission spectrometer (ICP-OES, OPTIMA2100DV, PerkinElmer, USA). The specific surface area and pore volume of these samples were tested using N_2 sorption isotherms run on an automated surface area and pore size analyzer (BEL SORP-max, Japan). The detailed water soluble metals, elemental and BET values of the raw sewage sludge and the biochars are listed in Table 1 and Table S1.

Text S2 Quantitative determination of carbendazim by UPLC-MS/MS

The supernatants were filtrated through a 0.22 μm Millipore filter and subjected to a Waters ACQUITY ultra high performance liquid chromatography (UPLC) equipped with a micromass triple quadrupole detector (MS/MS) (Xevo-TQD, Waters, Milford, MA) for analysis of carbendazim. The elution was performed at 35 °C on an Acquity UPLC® BEH C18 50*2.1 mm; 1.7 μm (Waters, Milford, USA). The mobile phase consisted of an isocratic combination of 70% methanol and 30% water with a total run time of 4 min at a flow rate of 0.3 mL/min. An Acquity TQD® detector (Waters, Milford, USA) with electrospray ionization (ESI) in positive ion mode was used for detection. The mass spectrometer was operated in the multiple-reaction monitoring (MRM) mode. The ESI source temperature and desolvation temperature were set to be 350 °C and 625 °C, respectively. The cone gas flow and the desolvation gas flow were 50 and 1000 L/h, respectively. Data were acquired using MassLynx v.4.1 and were processed using QuanLynx v.4.1 (Waters Corp.)

Table S1 Elemental composition of biochar produced with different pyrolysis temperatures

Biochar	Elemental composition (%)				Soluble metal ions ($mg\ g^{-1}$)				TOC ($g\ kg^{-1}$)
	C	H	O	N	K^+	Ca^{2+}	Na^+	Mg^{2+}	
Raw sludge	24.51±0.39	4.76±0.04	31.00±6.18	3.31±0.05	---	---	---	---	261.6
BC 100	25.18±0.08	4.74±0.02	25.35±0.16	3.46±0.02	0.620±0.014	1.199±0.016	0.482±0.015	0.306±0.027	261.4
BC 200	26.19±0.05	4.11±0.12	22.25±0.24	3.54±0.01	0.519±0.029	1.264±0.012	0.532±0.014	0.281±0.026	265.4
BC 300	22.51±0.17	2.85±0.02	20.68±0.37	3.03±0.06	0.417±0.022	0.960±0.074	0.577±0.013	0.127±0.006	242.9
BC 400	21.74±0.25	1.60±0.05	15.53±0.17	2.22±0.00	0.553±0.034	1.224±0.059	0.595±0.005	0.192±0.013	186.0
BC 500	19.24±0.21	1.02±0.06	14.37±0.20	2.18±0.04	0.353±0.026	0.762±0.009	0.533±0.009	0.127±0.023	226.8
BC 600	15.80±0.13	0.79±0.01	13.90±0.80	1.39±0.02	0.337±0.006	0.445±0.031	0.512±0.006	0.063±0.003	169.5
BC 700	11.06±0.13	0.55±0.00	9.79±0.59	0.59±0.03	0.324±0.009	0.408±0.021	0.475±0.007	0.090±0.007	136.6

Table S2 Effect of sewage sludge and biochars treatments on adsorption and desorption parameters of carbendazim in soils (data given as means ± standard errors, n=3)

Samples	Linear parameters			sorption			desorption			irreversibility
	K_{OC} (L g^{-1})	K_d (L g^{-1})	R^2	$K_{f,ads}$ (μg^{1-n} L^n g^{-1})	1/n	R^2	$K_{f,des}$(ug^{1-n} L^n g^{-1})	1/n	R^2	TII
BC 100	0.0490	0.0128	0.888	0.1342	0.735	0.943	0.00085	0.957	0.990	0.232
BC 200	0.0501	0.0133	0.921	0.1721	0.711	0.981	0.00065	0.960	0.999	0.259
BC 300	0.0807	0.0196	0.993	0.0478	0.895	0.998	0.00081	0.930	0.999	0.038
BC 400	0.0946	0.0176	0.982	0.0646	0.849	0.993	0.00090	0.928	0.995	0.085
BC 500	0.1265	0.0287	0.981	0.0361	0.945	0.988	0.00061	0.948	0.991	0.003
BC 600	0.2826	0.0479	0.992	0.2994	0.705	0.924	0.00014	1.092	0.999	0.354
BC 700	0.8981	0.1225	0.992	0.2691	0.885	0.996	$3.994*10^{-8}$	1.861	0.999	0.524
Soil	0.1559	0.0019	0.953	0.0239	0.738	0.989	0.00208	1.141	0.974	0.353

Raw sludge	0.0428	0.0112	0.981	0.0308	0.875	0.988	0.00351	0.831	0.996	--

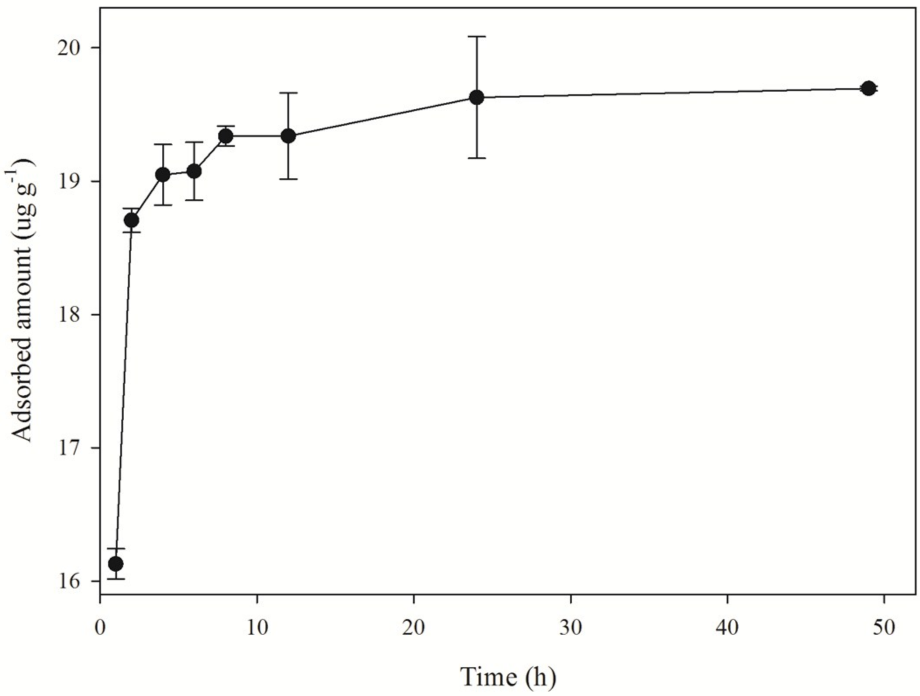

Fig. S1 The sorption kinetics for carbendazim in the pure soil

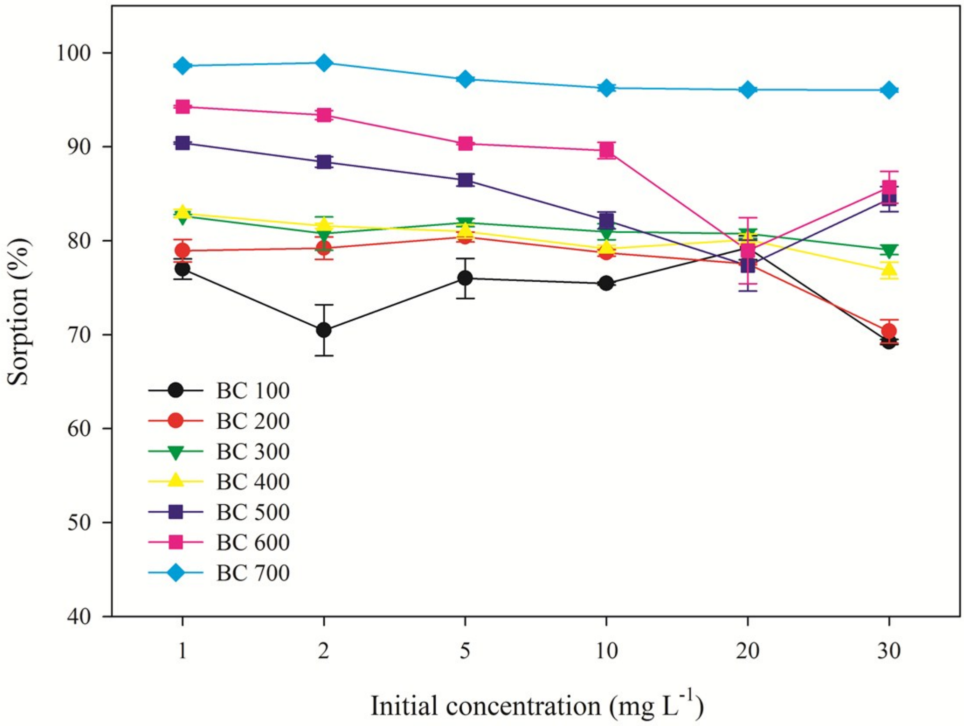

Fig. S2 The sorption efficiency for carbendazim in the biochar-amended soil at different concentrations

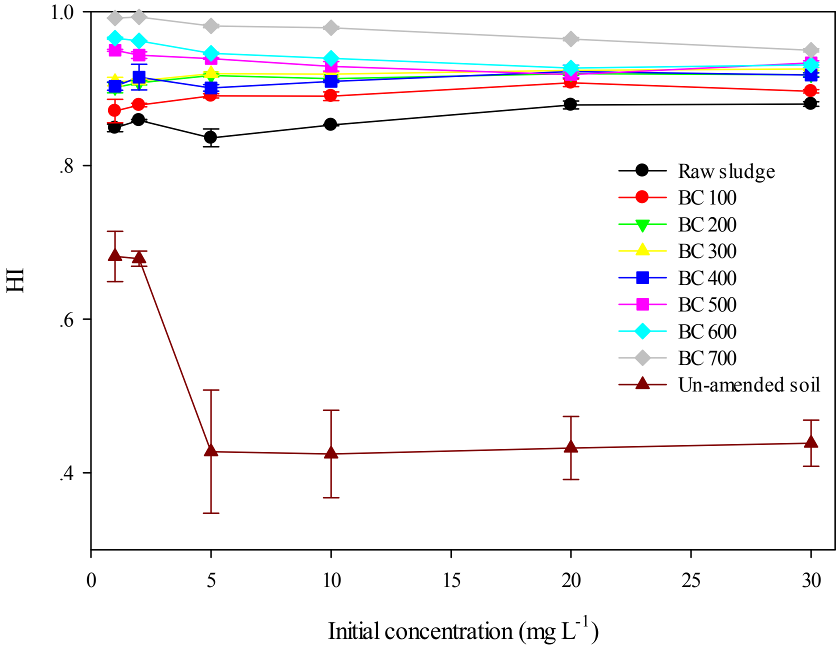

Fig. S3 The hysteresis indexes (HI) of carbendazim in biochar-amended soil at various concentrations.

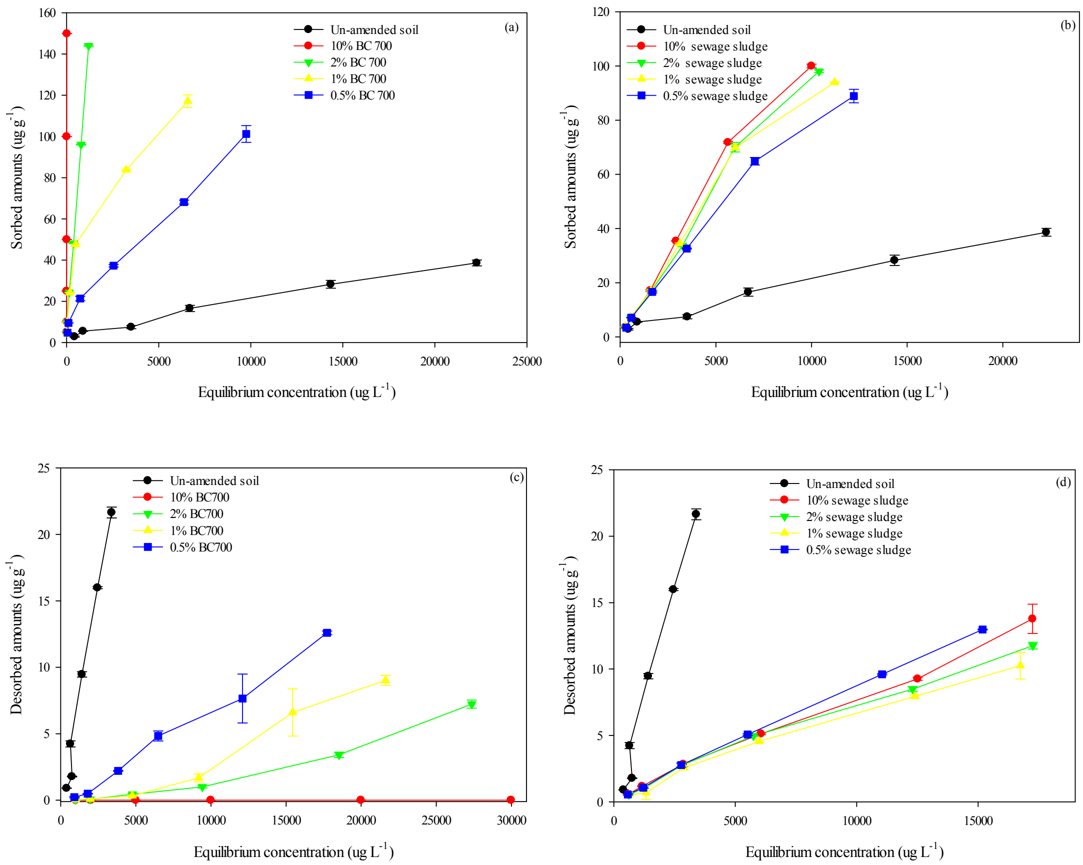

Fig. S4 The sorption-desorption of carbendazim by BC700 (a, c) and raw sewage sludge-amended (b, d) soil at different rates

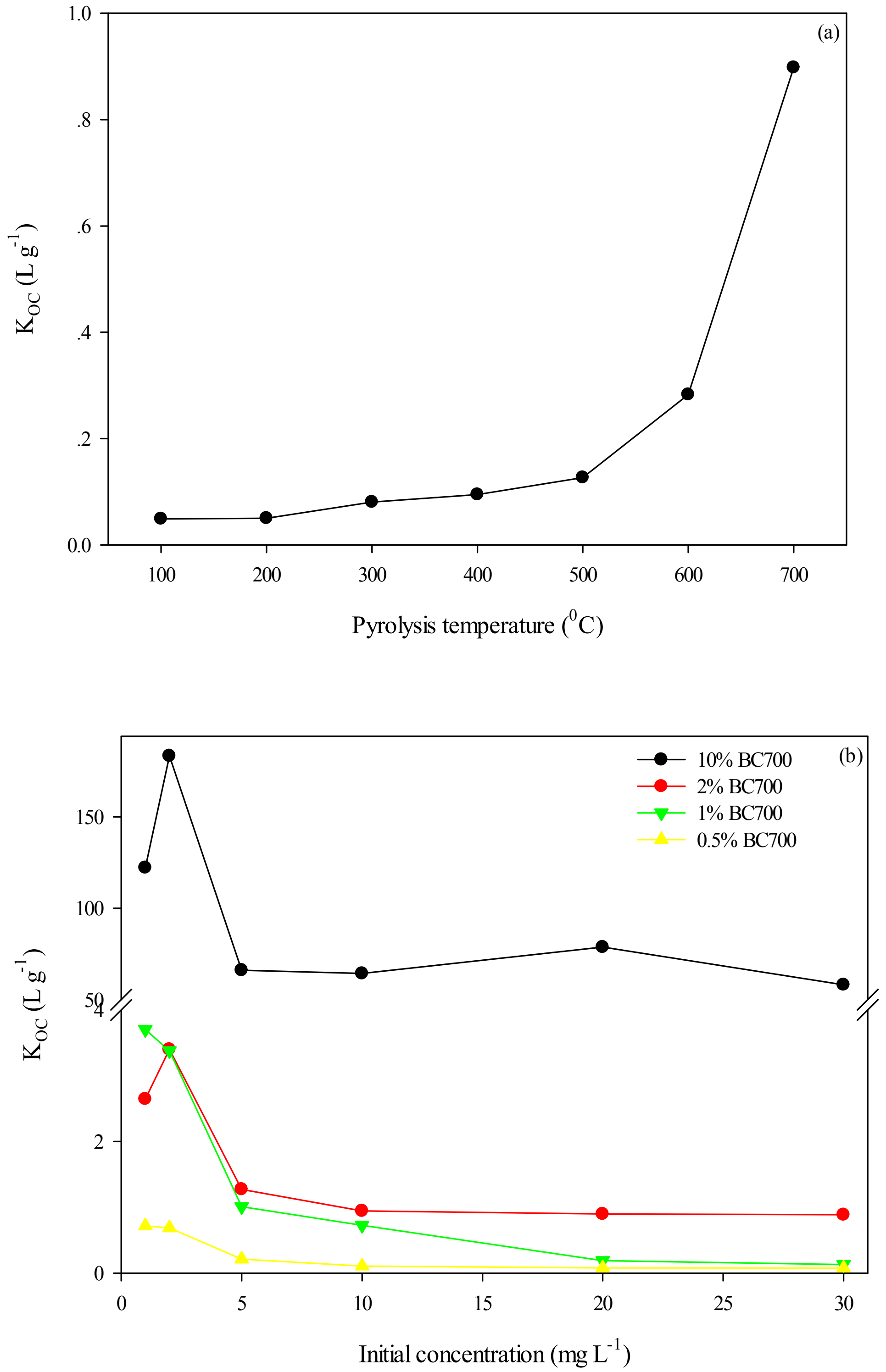

Fig. S5 The changes of K_{OC} in soils amended with biochars produced at different temperature (a) and different percentages of BC700 (b) at different carbendazim concentrations

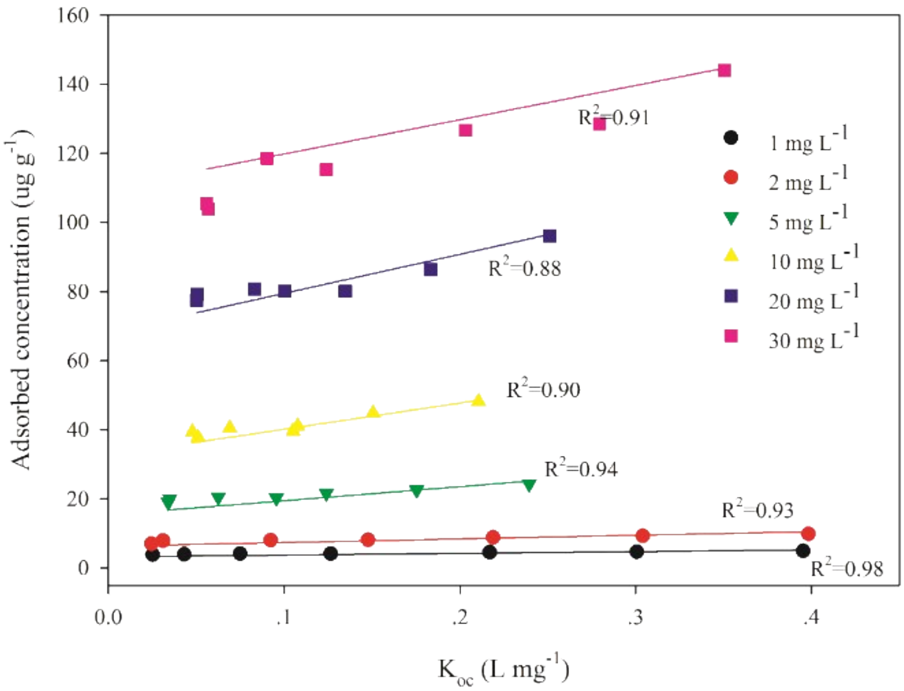

Fig. S6 The relationship between the KOC and the adsorption capacity.

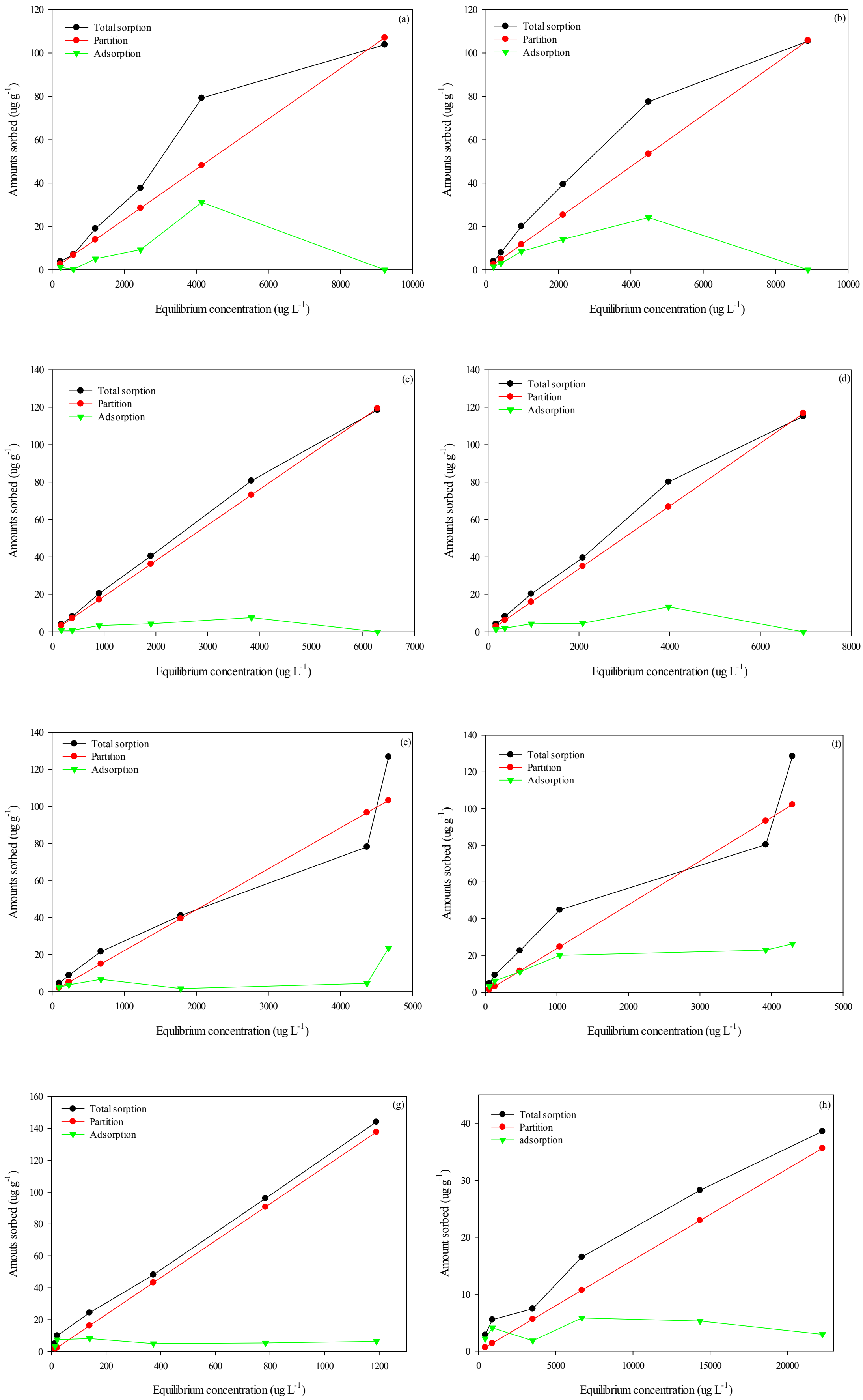
(a)
Total sorption
Partition
Adsorption
Amounts sorbed (ug g-1)
Equilibrium concentration (ug L-1)
(b)
Total sorption
Partition
Adsorption
Amounts sorbed (ug g-1)
Equilibrium concentration (ug L-1)
(c)
Total sorption
Partition
Adsorption
Amounts sorbed (ug g-1)
Equilibrium concentration (ug L-1)
(d)
Total sorption
Partition
Adsorption
Amounts sorbed (ug g-1)
Equilibrium concentration (ug L-1)
(e)
Total sorption
Partition
Adsorption
Amounts sorbed (ug g-1)
Equilibrium concentration (ug L-1)
(f)
Total sorption
Partition
Adsorption
Amounts sorbed (ug g-1)
Equilibrium concentration (ug L-1)
(g)
Total sorption
Partition
Adsorption
Amounts sorbed (ug g-1)
Equilibrium concentration (ug L-1)
(h)
Total sorption
Partition
adsorption
Amount sorbed (ug g-1)
Equilibrium concentration (ug L-1)

Fig. S7 The contributions of adsorption and partition effect for carbendazim sorption in soils amended with biochars (a: BC100; b: BC200; c: BC300; d: BC400; e: BC500; f: BC600; g: BC700) and un-amended soil (h)