**Supplementary materials**

**Soil characterization methods in details**

**pH**: 10 g of air-dried soil was added to 25 mL deionised water in 50 mL centrifuge tube and shaken for 15 minutes. Thermo Scientific Orion Model 420 plus pH meter was calibrated with pH buffer solutions (pH 4.00, 7.00 and 10.00). Then pH electrode was placed in the soil suspension and the pH was recorded. (Rowell, 1994).

**Organic carbon** was measured using a vario MACRO C/N analyzer (Elementary, Germany).

**Cation exchange capacity (CEC)**: 1) 2 g of air-dried soil was added to 20 mL 0.2 M BaCl2 solution in 50 mL centrifuge tube and shaken for 2 hours. Then exchangeable cations in the supernatant were analysed by ICP-OES. 2) The soil was washed for 3 times with 20 mL 0.01 BaCl2 and shaken for 1 hour every time. Then the supernatant was discarded. 3) 20 ml of 0.025 M MgSO4 solution was added to soil and the mixture was shaken overnight. Then Mg concentrations in the supernatant were analysed by ICP-OES and CEC was calculated by the difference. (Hendershot and Duquette, 1986)

**Soil texture** was determined using a Malvern Mastersizer Hydro2000 MU laser granulometer (Malvern Instruments, UK).

Table S1. Assignments of FTIR absorption bands present in the spectra for SHLA and CHA (Stevenson, 1994; Jokic et al., 2004; Fukushima et al., 2009; Hardie et al., 2009; Shiotsuka et al., 2015; Yang and Hodson, 2018a; Yang and Hodson, 2018b).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SHLA |  |  | CHA |  |
| Wavenumber/cm-1 | Assignment |  | Wavenumber/cm-1 | Assignment |
| 2918 | C-H stretching of aliphatic structures |  | 2921 | C-H stretching of aliphatic structures  |
| 2121 | C≡C stretching and the presence of cyano group |  |  |  |
| 1717 | C=O stretching of carbonyl groups |  |  |  |
| 1579 & 1488  | C=C ring stretching, symmetric C–O stretch of COO- and N-H deformation and C=N stretching (amide II band) |  | 1572 | C=C ring stretching, symmetric C–O stretch of COO- and N-H deformation and C=N stretching (amide II band) |
| 1382 | O-H deformation of phenols, C-H deformation, symmetric and asymmetric stretching of CH3 and C-O stretch of COO- |  | 1375 | O-H deformation of phenols, C-H deformation, symmetric and asymmetric stretching of CH3 and C-O stretch of COO- |
| 1179 | C–O stretching and C–O–H deformation of alcohols, phenols and ethers |  |  |  |
|  |  |  | 1008 | C-O stretching vibration in alcohols, phenols and ethers |



Figure S1. Metal concentrations after SHLA washing at different initial SHLA concentrations (a,b), pH (c,d), L/S ratios (e,f) and contact time (g,h). (n=3, mean values ± standard deviation). For a & b, experiments were conducted at a pH of 6, a L/S ratio of 40:1 and a temperature of 25 °C for 24h. For c & d, experiments were conducted at a SHLA concentration of 1000 mg/L, a L/S ratio of 40:1 and a temperature of 25 °C for 24h. For e & f, experiments were conducted at a pH of 6, a SHLA concentration of 1000 mg/L and a temperature of 25 °C for 24h. For g & h, experiments were conducted at a pH of 6, a SHLA concentration of 1000 mg/L, a L/S ratio of 40:1 and a temperature of 25 °C.



Figure S2. BCR-defined metal speciation distribution (%) of Soil 1 (a,b) and Soil 2 (c,d) before and after SHLA washing.

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