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Solubility characteristics of soil humic substances as a function of pH: mechanisms and biogeochemical perspectives

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Table S1. The pH values of diverse soils in the six continents and Antarctic and Arctic regions.

Continent	Country/Region	Soil type	pH	Reference
Asia	China	Paddy (n = 1), Shanghai	7.82	This study
"	"	Maize (n = 1), Tianjin	8.21	"
"	"	Forest (n = 25), 5 provinces	4.21–8.52	"
"	"	Riverside (n = 18), Tianjin+Hubei+Shaanxi	5.80–8.89	"
"	"	Agriculture (n = 26), 5 provinces	4.67–9.03	"
"	"	Degraded (n = 21), Tianjin + Inner Mongolia +Xinjiang + Shaanxi	6.58–9.21	"
"	"	Grassland (n = 6), Xinjiang	7.15–7.99	"
"	"	Agriculuure (n = 18), four main climate regions, China	4.90–8.80	(Gao *et al.*, 2017)
"	"	Cropped surface soil (n = 43)	6.44–8.01	(Li *et al.*, 2019)
"	"	Natural surface soil (n = 16)	5.01–8.67	"
"	"	Forest (n = 549), northern China	3.88–9.39	(Hong *et al.*, 2018)
"	"	Forest (n = 4), eastern China	4.30–7.23	(Xing *et al.*, 2019)
"	South Korea	Greenhouse soil (n = 230)	4.50–7.60	(Kim *et al.*, 2016)
"	Thailand	Agriculuure (n = 3)	5.60–6.10	(Zhou *et al.*, 2019)
"	"	non-agricultural lands (n = 4)	4.20–5.60	"
Europe	Germany	Bavarian Forest (n = 1)	4.00	(Nägele and Conrad, 1990)
"	"	Donau valley agriculture (n = 1)	7.60	"
"	"	Wollmatingen agriculture (n = 1)	7.80	"
"	UK	Grassland (n = 16)	3.70–7.20	(Köhler *et al.*, 2016)
"	"	Hoosfield acid strip at Rothamsted Research (n = 27)	4.10–8.30	(Rousk *et al.*, 2009)
"	Sweden	agriculture (n = 1)	7.80	(Pietikäinen *et al.*, 2005)
"	"	Forest (n = 1)	4.10	"
Africa	Kenya	Forestland, croplands, and grassland (n = 220)	4.79–7.03	(Odhiambo *et al.*, 2020)
"	Ethiopia	Amhara Region (n = 475)	4.20–7.50	(Mossa *et al.*, 2021)
"	Algeria	saline wetland (n = 16)	6.88–7.75	(Koull and Chehma, 2016)
"	Papua New Guinea	Sweet potato gardens (n = 209)	5.50–6.80	(Bailey *et al.*, 2008)
"	Egypt	The eastern desert plateau to the Nile Valley (n = 4)	7.80–8.00	(Ramadan and Omar, 2000)
"	Morocco	Agadir agricultural region (n = 4)	7.37–7.95	(Bihadassen *et al.*, 2020)
"	Austria	Mawson Lakes, Kersbrook and Kulpara (n = 3)	6.20–8.50	(Cáceres *et al.*, 2008)
South America	Ecuador	Flavio Alfaro (n = 1)	6.8	
	Costa Rica	Forest (n = 3）	4.10–4.15	"
"	Brazil	Deforestation (n = 8）	4.50–5.60	(De Moraes *et al.*, 1996)
"	"	Pasture (n = 36)	5.50–6.90	"
"	Argentina	Pampas pristine vegetation and forest (n = 1456)	6.60–8.30	(Alvarez *et al.*, 2020)
"	Chile	Western foot of the Andes Mountains (n = 35)	5.20–7.20	(Sadzawka R. *et al.*, 1972)
North America	USA	California's primary agricultural valleys (n = 125)	5.50–8.20	(DeClerck and Singer, 2003)
	"	Temperate steppe ecoregion (n = 36)	5.67–6.95	(Liebig *et al.*, 2017a)
"	"	Agriculture (n = 34), North Dakota	6.16–8.83	(Liebig *et al.*, 2017b)
"	"	Corn plots (n = 2), East Troy, WI	5.40–8.40	(Pedersen *et al.*, 2010)
"	"	Riparian (n = 14), northwest Vermont	5.40–6.60	(Young and Ross, 2018)
"	"	Agriculture (n = 61), south central Wisconsin	6.20–7.10	(Hartemink *et al.*, 2017)
"	"	Northwest Alaska (n = 36)	3.90–5.02	(Kim et al., 2014)
"	Canada	Acidic forest (n = 67)	2.80–6.30	(Courchesne *et al.*, 1995)
Antarctica	Antarctica	Bulgarian Antarctic Base (n = 38)	4.81–8.61	(Ganzert *et al.*, 2011)
"	"	Gelic gleysols, tundra (n = 8)	4.23–8.48	(Jones *et al.*, 2004)
Arctic	Arctic	"	5.75–7.03	"

Table S2. The pH values of rainwaters in the six continents and Arctic region.

Continent	Country	Specific location	pH	Reference
Asia	China	Shenzhen (1986–2006, n = 20)	4.45–5.91	(Huang *et al.*, 2008)
"	"	Northwest of the Pearl River Delta (n = 6)	4.55	(Yongtai Yang, Wugeng Su, 1996)
"	"	North of the Pearl River Delta (n = 2)	4.84	"
"	"	East of the Pearl River Delta (n=3)	5.22	"
"	"	Jinhua City (n = 42), Zhejiang Province	3.64–6.76	(Zhang *et al.*, 2007)
"	"	Southeastern fringe of the Tengger Desert (n = 5)	6.50–7.50	(Zhang *et al.*, 2013)
"	"	Changsha (1992–2001, n = 10)	3.00–4.69	(Jiang Yimin, Zeng Guangmin, Zhang Gong, 2003)
"	"	Nanjing (1992–2002, n = 192)	4.93–5.36	(Tu *et al.*, 2005)
"	"	Beijing (2001–2003, n = 65)	4.74–6.78	(Yang *et al.*, 2004)
"	"	Hong Kong (n = 32)	3.60–6.40	(Tanner and Wong, 2000)
"	Israel	Golan, Galilee, North-south coastal plain, Jordan, south Israel (n = 569)	5.30–7.57	(Herut *et al.*, 2000)
"	Jordan	Eshidiya phosphate mine (n = 21)	5.33–7.90	(Al-Khashman, 2005)
"	Japan	Tokyo (n = 2331)	4.23–4.62	(Okuda *et al.*, 2005)
"	"	Northern area of Okinawa Island (n = 12)	5.03–5.64	(Vuai and Tokuyama, 2011)
"	South Korea	Seoul (n = 129)	4.20–5.80	(Kyoung Lee *et al.*, 2000)
"	India	A rural forest station near Bhubaneswar	4.00–7.50	(Das *et al.*, 2010)
"	"	Tirupati (n = 105)	6.13–7.74	(Chandra Mouli *et al.*, 2005)
"	"	Arabian Sea (2013)	4.25–9.07	(Ramaswamy *et al.*, 2017)
Europe	Europe	2000-2017 (n = 450)	4.19–5.82	(Keresztesi *et al.*, 2020)
"	Central East Europe	Belarus (2000–2017)	4.56–5.33	"
"	Northern Europe	Estonia and United Kingdom (2000–2017)	4.47–5.15	"
"	Southern Europe	Serbia and Spain (2000–2017)	4.39–5.17	"
"	Germany	Berlin- Adlershof (WISTA Scientific Park) (n = 48)	4.50–5.00	(Möller, 2009)
"	"	Eastern Erzgebirge (n = 27)	3.26–5.38	(Lange *et al.*, 2003)
"	Greece	Patras (n = 95)	4.07–8.51	(Glavas and Moschonas, 2002)
"	Italy	Sardinia (n = 27)	5.24–7.48	(Le Bolloch and Guerzoni, 1995)
"	Czech Republic	Sumava Mts (n = 99)	3.93–5.82	(Elias *et al.*, 1995)
"	Poland	Moraine hills, lowands and mountainous region (n = 24)	4.14–5.61	(Polkowska *et al.*, 2005)
Africa	South Africa	Bergville in KwaZulu-Natal Province (n = 35), Metallic	6.30–7.49	(Selala *et al.*, 2018)
"	"	Bergville in KwaZulu-Natal Province (n = 42), Yard	6.30–7.10	"
"	"	Welgegound atmospheric (n = 20)	4.32–5.11	(Kok, 2017)
"	Zimbabwe	The University of Zimbabwe (n = 6)	5.60–6.72	(Jonnalagadda *et al.*, 1994)
"	Niamey	Banizoumbou (n = 7)	4.90–5.40	(Desboeufs *et al.*, 2010)
Oceania	Australia	Sydney (n = 12)	4.34–5.08	(Ayers and Gillett, 1984)

"	"	Katherine NT (n = 40)	4.00–5.40	(Bridgman, 1989)
"	"	Sydney NSW (n = 294)	4.25–5.08	"
South America	Ecuador	Eastern Andes Cordillera (n = 11)	4.54–5.61	(Beiderwieden *et al.*, 2005)
"	Brazil	Limeira (n = 30)	4.90–6.90	(Martins *et al.*, 2019)
"	"	Porto Alegre (n = 177)	5.30	"
"	"	Florianópolis (n = 22)	4.79	"
"	Argentine	Bahía Blanca (n = 11)	6.95–9.01	(Campo *et al.*, 2012)
"	"	Tandil (n = 10)	6.35–8.04	"
North America	USA	USA (n = 86470), Wye, Maryland and Yosemite and Yosemite National Park	3.04–8.29	(Keresztesi *et al.*, 2020)
"	"	America's Midwest	5.10–6.40	"
"	"	Eastern part of the USA	4.30–6.10	"
"	"	An open area of the University of North Carolina at Wilmington (n = 81)	3.85	(Kieber *et al.*, 2001)
"	"	An open area of the University of North Carolina at Wilmington (n = 120)	4.39–4.76	(Kieber *et al.*, 2007)
"	"	An open area of the University of North Carolina at Wilmington (n = 19)	4.42–5.49	(Kieber *et al.*, 2009)
"	"	An open area of the University of North Carolina at Wilmington (n = 23)	4.00–5.20	(Witt *et al.*, 2007)
"	"	Luquillo Mountains (n = 2075)	3.20–7.90	(Gioda *et al.*, 2013)
"	Canada	Guelph (n = 360)	5.20–8.20	(Despins *et al.*, 2009)
Arctic	Arctic	Hornsund Polish Polar Station (n = 33)	3.35–5.15	(Nawrot *et al.*, 2016)

Table S3 Soil properties of the two soils.

Sample name	Location	Soil classification	Water content (%)	Sand (%)	Silt (%)	clay (%)	pH	EC (μs/cm)	STC (mg/g)	STN (mg/g)
Maize land (Agriculture)	N38°59′32″-E117°17′25″	Calcaric Fluvisol	20.3	22.5	57.6	8.6	8.21	356	17.4	4.71
Paddy field (Wetland)	N31°21′22″-E121°45′24″	Fluvi-stagnic Fluvisol	39.4	36.0	38.3	2.5	7.82	297	14.38	4.21

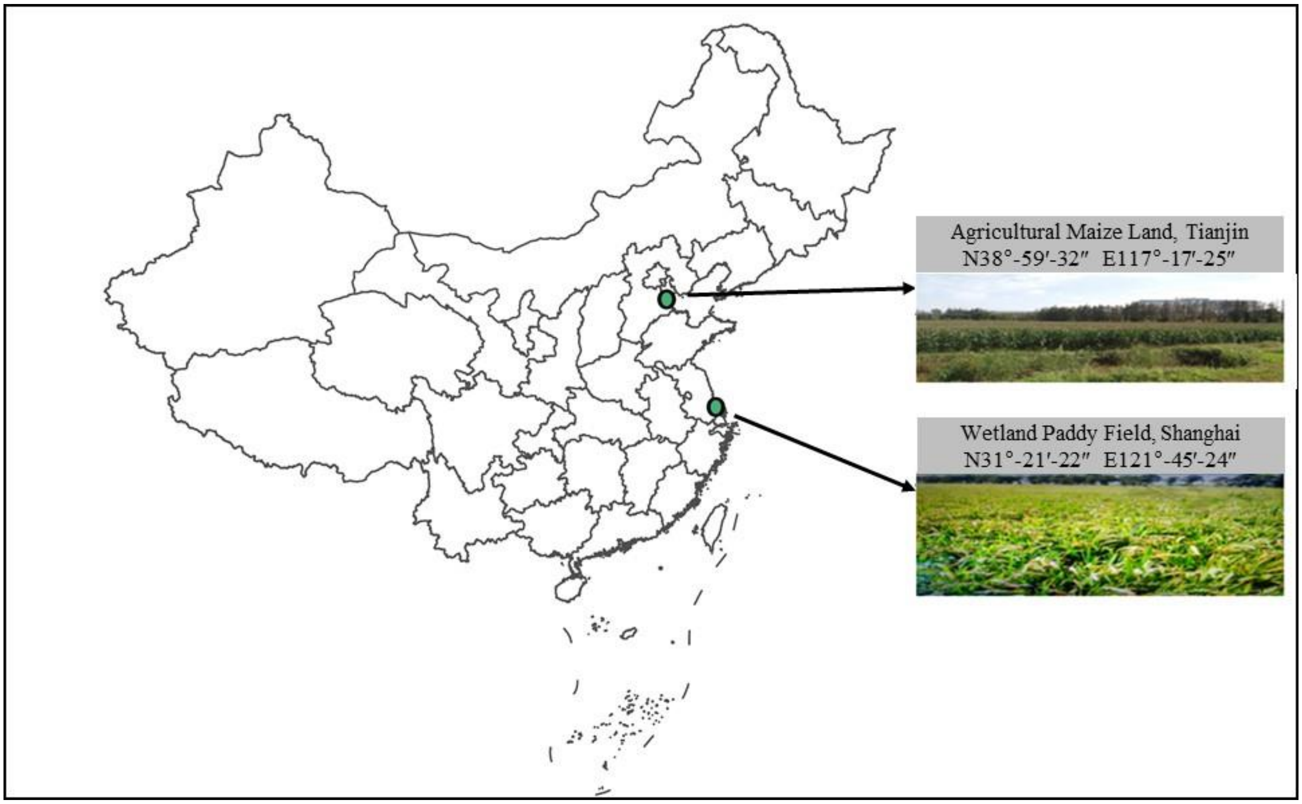

Figure S1. Soil sampling locations.

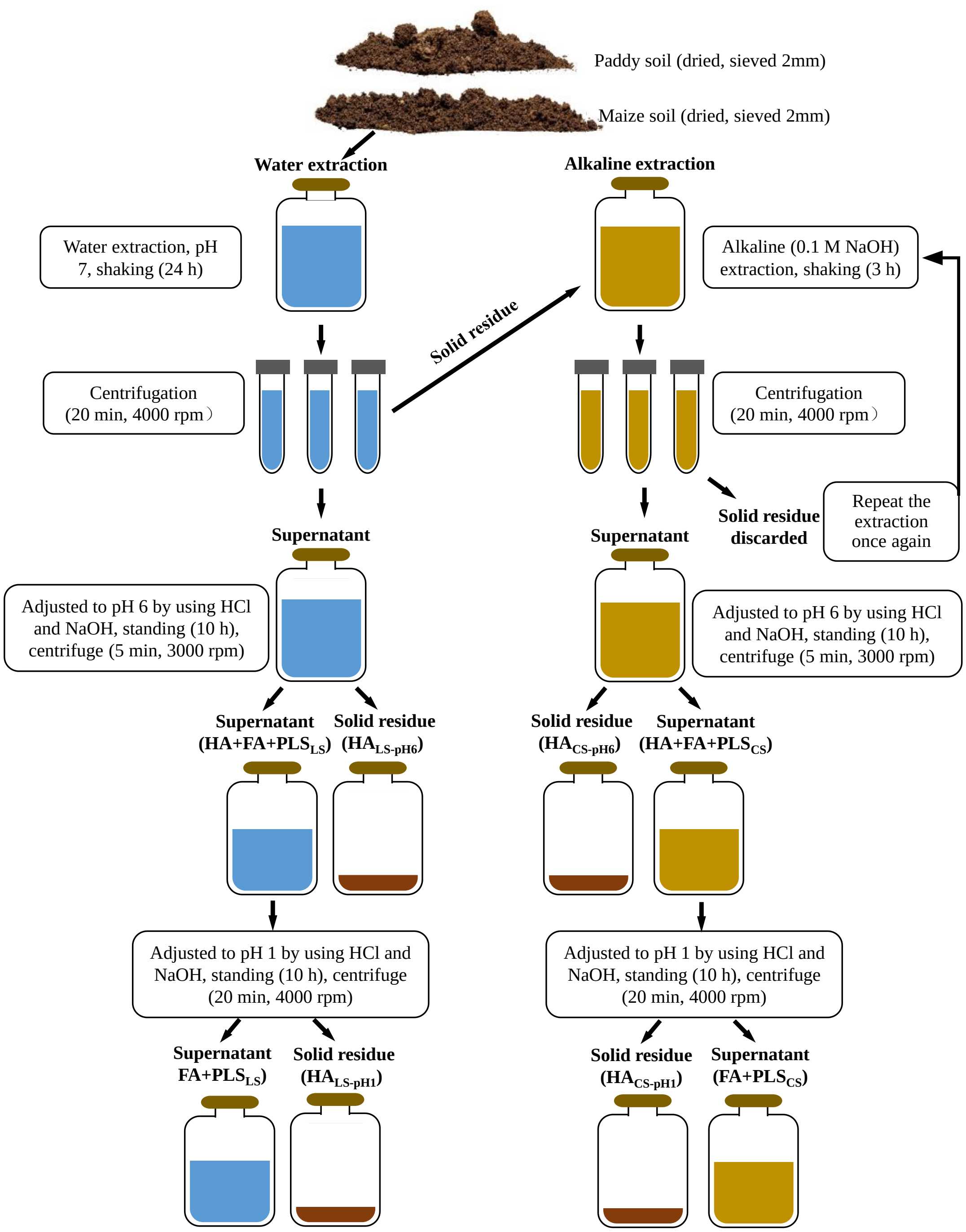

Figure S2. Flow diagram of the extraction of soil liquid phase by water followed by alkaline (0.1 M NaOH) solution, which would operationally represent, respectively, the labile state (LS) and the water insoluble complexed state (CS) of soil organic matter (SOM).

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