Supplementary Materials for

A bizarre layer cake: Why soil animals recolonizing polluted areas shape atypical humus forms

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Table S1. Characteristics of investigated humus forms

Humus form and its formula	Generalized description
Eumor Deg OL/nozOF1/ nozOF2/nozA	**OL** – new (not transformed) litter and slightly transformed entire leaves, needles, and twigs; **nozOF1** – brown, soft, slightly transformed recognizable entire or slightly fragmented plant remains to lie in well-discernible layers (layered horizons); fungal hyphae are possible; **nozOF2** – brown, very soft, and more or less fragmented tightly-packed plant remains with small fibrous residues to lie in well-discernible layers; the total thickness of organic horizons is 4–8 cm, the O/A transition is very sharp; **A** – non-zoogenic: structureless (massive), or powdery-granular, or cloddy.
Humimor Reg OL/nozOF+ [zoOF{micro}]/ nozOF/nozA	**OL** – new (not transformed) litter and slightly transformed entire leaves, needles, and twigs; **nozOF+[zoOF{micro}]** – brown, soft, slightly transformed recognizable entirely or slightly fragmented plant remains to lie in well-discernible layers (layered horizons); fine granular – microdroppings present (fine droppings ≤1 mm, not more than 10% of horizon volume) or sparsely single microdroppings between layers of leaves and needles or in clusters, located, as a rule, near twigs, cones, or roots, i.e., the continuous zoogenic horizon is not formed; thickness of the horizon is 1–2 cm and not more than half of the thickness of all organic horizons; **nozOF** – brown, very soft, and more or less fragmented tightly-packed plant remains partly transformed into small fibrous residues lie in well-discernible layers; the total thickness of organic horizons is 4–8 cm, the O/A transition is very sharp; **A** – non-zoogenic: structureless (massive), or powdery-granular, or cloddy.
Hemimor Reg OL/zoOF{micro}/ (nozOF, [nozOF])/ nozA	**OL** – new (not transformed) litter and slightly transformed entire leaves, needles, and twigs; **zoOF{micro}** – slightly fragmented leaves and needles lie in clearly discernible layers, with microdroppings between them (≥10% of horizon volume), allocated as a continuous zoogenic horizon more obvious and thicker than in Humimor Reg; thickness of horizon is 2–4 cm, which is half or more of the thickness of all organic horizons; **(nozOF, [nozOF])** – non-zoogenically (mycogenically) transformed plant residues are located in a continuous layer or discontinuous layer with fragments of zoOF{micro} over A; the total thickness of organic horizons is 4–7.5 cm, the O/A transition is very sharp; **A** – non-zoogenic: structureless (massive), or powdery-granular, or cloddy.

Hemimormull Reg OL/zoOF/ (nozOF, nozOF+ zoOF{micro})/ (nozA, miA)	**OL** – new (not transformed) litter and slightly transformed entire leaves, needles, and twigs; **zoOF** – more or less fragmented plant residues lie as clearly discernible layers, mesodroppings (1–2 mm) and microdroppings are between layers of leaves and needles (10–15% of the horizon volume), zoOF ≤ nozOF in terms of thickness; **nozOF** – composed of brown, very soft, and more or less fragmented tightly packed plant remains that are partly transformed into small fibrous residues. In some profiles, nozOF is discontinuous, with non-zoogenically altered plant residues alternating with sites containing microdroppings between layers of leaves and needles (fragments of zoOF{micro}); the total thickness of organic horizons is 3.5–6 cm, the O/A transition is very sharp; **A** – non-zoogenic: massive, powdery, or cloddy, may be locally biomicrostructured (fine granular).
Eumormull Reg OL/zoOF/(nozOF, nozOF+ zoOF{micro})/ (nozA, miA)	**OL** – new (not transformed) litter and slightly transformed entire leaves, needles, and twigs; **zoOF** – loose, highly fragmented recognizable plant remains mixed with organic and organic-mineral mesodroppings (1–2 mm, 10–25% of the horizon volume), zoOF>nozOF in terms of thickness; **nozOF** – non-zoogenically transformed plant residues commonly form a continuous layer above horizon A. In some profiles, however, nozOF is discontinuous, with non-zoogenically altered plant residues alternating with sites containing microdroppings between layers of leaves and needles (fragments of zoOF{micro}); the total thickness of organic horizons is 4–8 cm, the O/A transition is very sharp; **A** – non-zoogenic: massive, powdery, or cloddy, may be locally biomicrostructured (fine granular).

Note. In the formulas for humus forms, a slash separates the horizons while the sign "+" denotes a combination of several sub-horizons in one horizon. In parentheses, options for the horizon's structure separated by commas are indicated; if a single horizon is listed in parentheses, this means that it is optional. A discontinuous (fragmentary) horizon is in brackets. The explanations (e.g., the horizon peculiarity) are in curly braces. Sizes of invertebrate droppings are categorized as *micro*, which are less than 1 mm in size, and *meso*, which are between 1–4 mm in size. The indices used to describe organic horizons are *noz*, indicating non-zoogenic, and *zo*, indicating zoogenic. For organic-mineral horizons, the indices are *noz* for non-zoogenic and *mi* for biomicrostructured.

Table S2. Vertical distribution of pH, total acidity (TA), exchangeable calcium and magnesium, saturation of the exchange complex with bases (BS), and concentrations of organic carbon and total nitrogen (mean±SE) in the different humus forms and habitat types

Humus form (habitat type)	Horizon (layer)	*n*	*d*, cm	pH	TA, cmol kg^{-1}	Ca^{2+}, cmol kg^{-1}	Mg^{2+}, cmol kg^{-1}	BS, %	C, %	N, %	C/N
Eumor Deg (Birch forest)	OL+nozOF	5	2	5.4 ± 0.10	38 ± 2	55 ± 8	42 ± 8	71 ± 4	40.9 ± 0.5	1.7 ± 0.14	28.7 ± 2.3
	nozOF{1}	5	4	5.2 ± 0.14	50 ± 4	50 ± 5	43 ± 10	63 ± 6	38.1 ± 0.7	2.1 ± 0.04	21.3 ± 0.6
	nozOF{2}	3	6	5.2 ± 0.08	44 ± 3	50 ± 8	31 ± 7	65 ± 1	24.8 ± 3.8	1.9 ± 0.06	15.8 ± 2.8
	A	5	–	5.0 ± 0.14	13 ± 1	15 ± 1	8 ± 1	65 ± 3	5.9 ± 0.5	0.5 ± 0.04	15.1 ± 1.1
Eumor Deg (Spruce-fir forest)	OL+nozOF	15	2	5.0 ± 0.05	47 ± 1	46 ± 3	29 ± 2	61 ± 1	40.4 ± 0.3	1.5 ± 0.04	31.2 ± 1.0
	nozOF{1}	15	4	4.6 ± 0.07	60 ± 2	44 ± 2	24 ± 2	53 ± 1	36.4 ± 0.8	1.7 ± 0.06	26.2 ± 1.1
	nozOF{2}	13	6	4.4 ± 0.06	59 ± 1	42 ± 2	16 ± 2	49 ± 1	30.5 ± 1.3	1.6 ± 0.05	22.8 ± 0.6
	nozOF{3}	2	8	4.7 ± 0.23	62 ± 1	39 ± 2	13 ± 2	46 ± 1	33.4 ± 0.7	2.0 ± 0.01	19.6 ± 0.3
	A	15	–	4.5 ± 0.06	18 ± 1	13 ± 1	6 ± 1	50 ± 2	6.7 ± 0.7	0.4 ± 0.04	18.3 ± 1.0
Humimor Reg (Birch forest)	OL	2	1	5.5 ± 0.01	38 ± 1	44 ± 0	38 ± 4	68 ± 2	43.5 ± 0.4	1.9 ± 0.03	27.3 ± 0.2
	OL+zoOF{micro}	2	2	5.6 ± 0.10	36 ± 1	64 ± 3	52 ± 3	77 ± 0	38.8 ± 2.0	1.9 ± 0.09	24.1 ± 2.4
	nozOF+[zoOF{micro}]{1}	2	2.3 (2–2.5)	5.2 ± 0.05	49 ± 0	33 ± 6	44 ± 11	61 ± 2	40.6 ± 0.5	1.9 ± 0.02	25.1 ± 0.1
	nozOF{1}	4	4 (3.5–4.5)	5.2 ± 0.09	50 ± 4	48 ± 6	46 ± 12	63 ± 6	38.3 ± 2.1	2.0 ± 0.03	22.1 ± 1.0
	nozOF{2}	3	5.3 (5–6)	5.0 ± 0.08	52 ± 6	60 ± 10	27 ± 3	62 ± 5	36.0 ± 0.6	2.1 ± 0.12	20.3 ± 0.9
	A	4	–	5.0 ± 0.11	14 ± 2	17 ± 1	7 ± 2	65 ± 4	6.3 ± 0.3	0.5 ± 0.06	15.0 ± 0.9
Humimor Reg (Spruce-fir forest)	OL	6	0.8 (0.5–1)	5.6 ± 0.09	35 ± 2	53 ± 4	31 ± 4	71 ± 1	40.6 ± 1.1	1.6 ± 0.06	30.6 ± 0.8
	nozOF+[zoOF{micro}]{1}	6	2.3 (2–3)	5.3 ± 0.10	46 ± 3	54 ± 3	36 ± 3	66 ± 3	41.1 ± 0.3	1.8 ± 0.05	26.3 ± 0.6
	nozOF+[zoOF{micro}]{2}	2	4	4.8 ± 0.08	54 ± 1	41 ± 1	27 ± 1	56 ± 0	41.7 ± 1.7	1.8 ± 0.00	26.6 ± 1.1
	nozOF+[zoOF{micro}]{3}	1	6	4.4	66	40	10	43	40.5	1.8	26.9
	nozOF{1}	4	4.4 (3.5–5)	5.0 ± 0.13	56 ± 4	46 ± 4	28 ± 3	57 ± 3	37.8 ± 0.8	1.9 ± 0.04	23.0 ± 0.8
	nozOF{2}	6	6 (5–8)	5.0 ± 0.12	51 ± 3	37 ± 2	19 ± 3	53 ± 2	30.8 ± 3.0	1.6 ± 0.12	22.2 ± 1.3
	nozOF{3}	1	6	5.2	43	38	8	52	25.6	1.5	20.3
	A	6	–	4.5 ± 0.08	12 ± 2	7 ± 1	4 ± 1	47 ± 4	3.4 ± 0.6	0.2 ± 0.03	16.2 ± 1.9
Hemimor Reg (Birch forest)	OL	2	1	5.6 ± 0.04	37 ± 1	62 ± 4	27 ± 11	71 ± 2	41.4 ± 0.8	1.9 ± 0.04	26.1 ± 1.1
	zoOF{micro}{1}	2	3	5.0 ± 0.02	58 ± 1	55 ± 12	25 ± 15	58 ± 1	40.8 ± 0.1	2.1 ± 0.01	22.8 ± 0.0
	nozOF{1}	2	4.5 (4–5)	5.0 ± 0.01	60 ± 1	41 ± 2	10 ± 3	46 ± 3	35.3 ± 0.4	2.2 ± 0.07	18.8 ± 0.8
	A	2	–	4.8 ± 0.01	13 ± 2	12 ± 1	8 ± 1	59 ± 1	5.6 ± 1.1	0.5 ± 0.14	14.9 ± 1.6

Hemimor Reg (Spruce-fir forest)	OL	11	0.7 (0.5–1.5)	5.4 ± 0.10	39 ± 2	41 ± 2	25 ± 4	62 ± 2	41.4 ± 0.6	1.7 ± 0.04	28.6 ± 0.7
	zoOF{micro}{1}	11	2.3 (2–3)	4.8 ± 0.08	54 ± 2	37 ± 2	22 ± 3	52 ± 2	41.8 ± 0.3	1.7 ± 0.07	28.7 ± 1.5
	zoOF{micro}{2}	4	3.9 (3.5–4.5)	4.5 ± 0.09	69 ± 3	37 ± 3	11 ± 3	41 ± 1	39.6 ± 0.4	1.8 ± 0.07	26.2 ± 0.9
	nozOF+[zoOF{micro}]{1}	7	4.4 (3.5–6)	4.5 ± 0.07	61 ± 5	34 ± 2	11 ± 2	43 ± 2	37.5 ± 1.4	2 ± 0.06	21.9 ± 0.5
	nozOF+[zoOF{micro}]{2}	2	5.5 (5–6)	4.3 ± 0.05	71 ± 2	36 ± 1	13 ± 6	40 ± 4	33.3 ± 0.9	1.9 ± 0.08	21.0 ± 0.3
	nozOF{1}	8	5.6 (4–7.5)	4.4 ± 0.05	66 ± 2	30 ± 2	14 ± 2	40 ± 1	32.9 ± 1.0	1.7 ± 0.07	22.6 ± 1.0
	nozOF{2}	1	8.5	4.3	66	28	8	35	26.9	1.2	26.8
	A	11	–	4.4 ± 0.04	20 ± 1	10 ± 1	5 ± 1	44 ± 1	6.0 ± 0.5	0.5 ± 0.05	15.1 ± 0.6
Hemimormull Reg (Birch forest)	OL	8	0.6 (0.5–1)	5.7 ± 0.05	36 ± 1	50 ± 4	38 ± 4	71 ± 1	40.9 ± 0.5	1.7 ± 0.12	29.7 ± 3.1
	zoOF{1}	8	1.9 (1.5–2.5)	5.2 ± 0.1	50 ± 3	54 ± 4	33 ± 2	63 ± 2	41.6 ± 0.2	1.8 ± 0.11	28.7 ± 1.9
	nozOF+[zoOF{micro}]{1}	4	3.1 (2.5–3.5)	4.8 ± 0.09	64 ± 1	42 ± 5	19 ± 2	48 ± 2	37.2 ± 1.5	2.1 ± 0.07	20.5 ± 1.0
	nozOF{1}	7	3.9 (3–4)	5.0 ± 0.09	53 ± 2	41 ± 3	19 ± 5	52 ± 3	30.2 ± 1.8	1.8 ± 0.11	19.4 ± 0.4
	nozOF{2}	1	4	5.1	44	38	14	54	22.2	1.4	18.8
	A	8	–	4.9 ± 0.09	12 ± 1	10 ± 1	6 ± 1	56 ± 4	4.8 ± 0.2	0.4 ± 0.02	15.8 ± 0.5
Hemimormull Reg (Spruce-fir forest)	OL	9	0.6 (0.5–1)	5.4 ± 0.07	39 ± 1	45 ± 3	20 ± 3	62 ± 2	42.6 ± 0.4	1.6 ± 0.07	31.8 ± 1.8
	OL+zoOF	5	1.8 (1–2)	5.7 ± 0.18	35 ± 4	59 ± 5	30 ± 5	71 ± 4	41.4 ± 0.2	1.9 ± 0.05	25.1 ± 0.8
	zoOF{1}	12	2.5 (1.5–4)	5.0 ± 0.08	52 ± 2	38 ± 3	23 ± 3	54 ± 2	40.8 ± 0.9	1.8 ± 0.04	26.4 ± 0.7
	zoOF{micro}{1}	8	3.3 (2.5–4)	5.1 ± 0.12	51 ± 3	44 ± 4	31 ± 6	59 ± 3	39.9 ± 0.8	1.9 ± 0.07	24.5 ± 1.0
	zoOF{micro}{2}	1	4.5	5.0	46	42	30	61	34.7	1.6	25.0
	zoOF{micro}{3}	1	6	5.3	42	36	22	58	29.1	1.6	21.6
	nozOF+[zoOF{micro}]{1}	8	5 (3–6)	4.7 ± 0.09	63 ± 3	42 ± 9	28 ± 12	47 ± 5	33.7 ± 2.1	1.9 ± 0.08	21.3 ± 1.0
	nozOF+[zoOF{micro}]{2}	1	6	4.8	56	30	20	47	33.0	1.9	19.8
	nozOF{1}	6	4.7 (3.5–6)	4.7 ± 0.15	56 ± 5	32 ± 3	18 ± 4	46 ± 4	32.1 ± 1.9	1.8 ± 0.06	21.0 ± 0.8
	A	14	–	4.4 ± 0.09	17 ± 1	10 ± 1	5 ± 1	47 ± 3	5.5 ± 0.5	0.4 ± 0.05	15.7 ± 1.1
Eumormull Reg (Birch forest)	OL	1	0.5	5.7	32	60	26	73	42.1	1.8	26.7
	zoOF{1}	1	2	5.4	43	70	34	71	41.4	1.9	25.3
	nozOF+[zoOF{micro}]{1}	1	3	4.5	67	42	20	48	43.5	–	–
	nozOF{1}	1	4	4.6	48	36	22	55	25.8	1.4	21.5
	A	1	–	5.2	7	11	4	66	3.0	0.3	10.6

Eumormull Reg (Spruce-fir forest)	OL	7	0.6 (0.5–1)	5.5 ± 0.05	37 ± 2	44 ± 4	23 ± 2	64 ± 1	42.4 ± 0.3	1.5 ± 0.07	34.1 ± 1.9
	OL+zoOF	2	2	5.6 ± 0.21	38 ± 4	57 ± 8	35 ± 9	70 ± 6	39.9 ± 0.4	1.9 ± 0.04	24.1 ± 0.7
	zoOF{1}	9	2.5 (1.5–4)	5.3 ± 0.08	45 ± 2	44 ± 4	28 ± 2	61 ± 2	40.9 ± 0.5	1.7 ± 0.07	28.1 ± 1.2
	zoOF{2}	3	4 (3.5–4.5)	5.0 ± 0.14	56 ± 5	46 ± 4	31 ± 1	58 ± 4	40.9 ± 0.4	1.7 ± 0.05	28.0 ± 0.9
	zoOF{3}	2	5.5	4.6 ± 0.16	65 ± 3	37 ± 1	23 ± 2	48 ± 1	40.3 ± 1.4	1.4 ± 0.17	34.8 ± 3.1
	zoOF{micro}{1}	4	4.1 (3–6)	4.9 ± 0.13	57 ± 4	40 ± 4	22 ± 3	52 ± 4	37.6 ± 1.1	1.8 ± 0.05	24.3 ± 1.0
	nozOF+[zoOF{micro}]{1}	6	5.3 (4–7)	4.8 ± 0.11	55 ± 4	33 ± 5	14 ± 3	45 ± 3	30.7 ± 1.6	1.7 ± 0.08	20.9 ± 1.0
	nozOF{1}	3	6.3 (4.5–8)	4.7 ± 0.09	59 ± 5	36 ± 3	11 ± 2	44 ± 2	28.1 ± 4.2	1.4 ± 0.28	23.6 ± 1.5
	nozOF{2}	1	6	4.4	60	22	10	35	26.7	1.5	20.6
	A	9	–	4.3 ± 0.09	19 ± 2	8 ± 2	5 ± 1	40 ± 4	6.2 ± 1.0	0.4 ± 0.06	20.5 ± 2.7

Note: *d* represents the average depth of the lower boundary of the forest litter from its surface (with minimum and maximum values for the different mini-plots provided in parentheses); *n* denotes the sample size. For codes used to identify the different horizons, refer to Table S1 and Fig.1 in the main text. Figures in curly brackets indicate the index number of the layer within the horizon, while a dash indicates the absence of data.

Table S3. Vertical distribution of the acid-soluble metals (μg g^{-1}) in the different humus forms and habitat types (mean±SE)

Humus form (habitat type)	Horizon (layer)	*n*	*d*, cm	Cu	Pb	Cd	Zn	Fe
Eumor Deg (Birch forest)	OL+nozOF	5	2	615 ± 228	232 ± 42	9.4 ± 1.4	1240 ± 193	1140 ± 62
	nozOF{1}	5	4	1590 ± 539	2040 ± 152	36.5 ± 9.9	1170 ± 298	3860 ± 1800
	nozOF{2}	3	6	3090 ± 302	2790 ± 127	48.6 ± 3.3	1600 ± 210	6790 ± 596
	A	5	–	998 ± 253	85 ± 33	5.7 ± 1.4	285 ± 70	8140 ± 1270
Eumor Deg (Spruce-fir forest)	OL+nozOF	15	2	1330 ± 287	1440 ± 313	14.5 ± 3.2	797 ± 131	2310 ± 385
	nozOF{1}	15	4	2350 ± 309	2130± 190	14.9 ± 2.5	538 ± 50	5110 ± 800
	nozOF{2}	13	6	2590 ± 597	1620 ± 301	12.7 ± 2.5	405 ± 75	9580 ± 1200
	nozOF{3}	2	8	6360 ± 62	2390 ± 19	22.9 ± 0.5	635 ± 8	14900 ± 1000
	A	15	–	729 ± 81	122 ± 19	4.2 ± 0.5	160 ± 15	7530 ± 356
Humimor Reg (Birch forest)	OL	2	1	467 ± 32	152 ± 32	11.7 ± 3.5	1140 ± 107	798 ± 115
	OL+zoOF{micro}	2	2	360 ± 41	147 ± 32	7.4 ± 0.8	1760 ± 276	4220 ± 2250
	nozOF+[zoOF{micro}]{1}	2	2.3	1510 ± 88	367 ± 2	26.2 ± 5.6	990 ± 136	1260 ± 81
	nozOF{1}	4	4	1900 ± 707	2120 ± 272	35.4 ± 9.0	1430 ± 386	3230 ± 1303
	nozOF{2}	3	5.3	2340 ± 474	2580 ± 123	41.3 ± 12.9	1470 ± 399	3910 ± 402
	A	4	–	914 ± 159	215 ± 47	4.7 ± 0.9	582 ± 326	9730 ± 1830
Humimor Reg (Spruce-fir forest)	OL	6	0.8	317 ± 32	157 ± 15	6.0 ± 0.3	1050 ± 120	1150 ± 140
	nozOF+[zoOF{micro}]{1}	6	2.3	330 ± 38	714 ± 154	15.8 ± 2.7	1070 ± 124	1010 ± 106
	nozOF+[zoOF{micro}]{2}	2	4	452 ± 1	1300 ± 673	19.6 ± 9.0	718 ± 248	1070 ± 185
	nozOF+[zoOF{micro}]{3}	1	6	928	909	5.4	239	1620
	nozOF{1}	4	4.4	1940 ± 421	2800 ± 118	49.3 ± 3.2	1390 ± 99	2750 ± 501
	nozOF{2}	6	6	2660 ± 527	1480 ± 120	34.1 ± 6.4	767 ± 131	5290 ± 513
	nozOF{3}	1	6	3180	2040	23.8	625	9180
	A	6	–	259 ± 47	25 ± 10	2.5 ± 0.6	118 ± 30	4750 ± 389

Hemimor Reg (Birch forest)	OL	2	1	644 ± 265	93 ± 13	10.3 ± 2.9	906 ± 58	868 ± 81
	zoOF{micro}{1}	2	3	2250 ± 486	821 ± 211	14.5 ± 0.9	675 ± 39	3220 ± 1270
	nozOF{1}	2	4.5	3030 ± 511	1260 ± 333	8.1 ± 0.5	428 ± 20	4510 ± 1190
	A	2	–	607 ± 197	330 ± 187	2.3 ± 0.1	118 ± 15	7700 ± 1420
Hemimor Reg (Spruce-fir forest)	OL	11	0.7	202 ± 44	183 ± 25	4.2 ± 0.8	349 ± 41	801 ± 96
	zoOF{micro}{1}	11	2.3	516 ± 57	630 ± 73	6.2 ± 0.4	331 ± 17	1340 ± 115
	zoOF{micro}{2}	4	3.9	953 ± 65	1150 ± 140	5.2 ± 0.9	267 ± 29	2400 ± 175
	nozOF+[zoOF{micro}]{1}	7	4.4	1240 ± 117	1160 ± 119	6.4 ± 0.8	260 ± 21	3360 ± 374
	nozOF+[zoOF{micro}]{2}	2	5.5	1210 ± 36	851 ± 124	6.0 ± 0.2	216 ± 6	4880 ± 500
	nozOF{1}	8	5.6	1110 ± 193	721 ± 116	4.4 ± 0.7	188 ± 20	5350 ± 171
	nozOF{2}	1	8.5	1430	477	5.7	244	5620
	A	11	–	206 ± 19	48 ± 7	1.1 ± 0.1	77 ± 4	4930 ± 278
Hemimormull Reg (Birch forest)	OL	8	0.6	246 ± 43	110 ± 16	5.1 ± 0.7	1030 ± 147	803 ± 107
	zoOF{1}	8	1.9	848 ± 166	720 ± 227	14.2 ± 1.5	1020 ± 46	1050 ± 76
	nozOF+[zoOF{micro}]{1}	4	3.1	1540 ± 306	1910 ± 300	16.6 ± 1.3	647 ± 77	2960 ± 480
	nozOF{1}	7	3.9	2130 ± 311	2000 ± 307	14.5 ± 1.6	587 ± 65	5270 ± 947
	nozOF{2}	1	4	1452	3090	10.3	387	6600
	A	8	–	477 ± 80	116 ± 24	3.3 ± 0.4	122 ± 11	5370 ± 374
Hemimormull Reg (Spruce-fir forest)	OL	9	0.6	159 ± 16	173 ± 30	3.2 ± 0.3	396 ± 38	574 ± 58
	OL+zoOF	5	1.8	414 ± 80	269 ± 56	11.8 ± 0.8	717 ± 63	917 ± 72
	zoOF{1}	12	2.5	604 ± 121	739 ± 135	8.7 ± 0.9	451 ± 37	1390 ± 265
	zoOF{micro}{1}	8	3.3	951 ± 102	1110 ± 125	14.9 ± 2.3	593 ± 65	1650 ± 183
	zoOF{micro}{2}	1	4.5	1570	1410	26.4	888	2370
	zoOF{micro}{3}	1	6	2370	1230	25.3	989	4600
	nozOF+[zoOF{micro}]{1}	8	5	1340 ± 134	1210 ± 114	8.8 ± 1.5	299 ± 31	4550 ± 579
	nozOF+[zoOF{micro}]{2}	1	6	842	712	3.4	220	4960
	nozOF{1}	6	4.7	1920 ± 385	1460 ± 147	11.1 ± 2.8	355 ± 70	5510 ± 515
	A	14	–	235 ± 29	56 ± 9	1.6 ± 0.2	88 ± 7	5060 ± 157
Eumormull Reg (Birch forest)	OL	1	0.5	128	57	3.1	936	405
	zoOF{1}	1	2	281	179	9.3	1282	813
	nozOF+[zoOF{micro}]{1}	1	3	504	1682	24.7	899	1200
	nozOF{1}	1	4	1260	2077	13.3	359	3950
	A	1	–	654	178	4.7	134	5010

Eumormull Reg (Spruce-fir forest)	OL	7	0.6	134 ± 9	172 ± 21	2.8 ± 0.2	324 ± 25	517 ± 50
	OL+zoOF	2	2	380 ± 69	344 ± 63	10.5 ± 3.2	688 ± 153	1130 ± 2
	zoOF{1}	9	2.5	397 ± 110	549 ± 127	8.4 ± 1.4	487 ± 46	1080 ± 245
	zoOF{2}	3	4	322 ± 17	676 ± 153	9.7 ± 1.5	429 ± 44	870 ± 45
	zoOF{3}	2	5.5	825 ± 198	1240 ± 452	13.9 ± 5.7	437 ± 124	1490 ± 341
	zoOF{micro}{1}	4	4.1	1160 ± 185	1560 ± 185	15.4 ± 1.7	511 ± 94	2590 ± 541
	nozOF+[zoOF{micro}]{1}	6	5.3	2060 ± 221	1580 ± 149	12.5 ± 2.3	410 ± 85	5700 ± 728
	nozOF{1}	3	6.3	2000 ± 311	1410 ± 312	17.0 ± 2.5	392 ± 50	5140 ± 490
	nozOF{2}	1	6	1510	734	6.3	214	6320
	A	9	–	271 ± 41	56 ± 17	2.5 ± 0.6	101 ± 11	4670 ± 101

Note: *d* represents the average depth of the lower boundary of the forest litter from its surface, the depth range is presented in Table S2; *n* denotes the sample size. For codes used to identify the different horizons, refer to Table S1 and Fig.1 in the main text. Figures in curly brackets indicate the index number of the layer within the horizon, while a dash indicates the absence of data.

Table S4. Vertical distribution of the exchangeable metals (μg g^{-1}) in the different humus forms and habitat types (mean±SE)

Humus form (habitat type)	Horizon (layer)	*n*	*d*, cm	Cu	Pb	Cd	Zn	Fe
Eumor Deg (Birch forest)	OL+nozOF	5	2	11.8 ± 3.4	17.7 ± 6.0	3.2 ± 0.7	210 ± 21	4.2 ± 0.9
	nozOF{1}	5	4	30.7 ± 13.3	17.9 ± 10.6	11.2 ± 2.1	311 ± 56	15.4 ± 5.4
	nozOF{2}	3	6	39.6 ± 2.5	6.3 ± 1.0	19.4 ± 1.5	536 ± 20	22.2 ± 13.5
	A	5	–	46.1 ± 12.6	0.3 ± 0.1	3.7 ± 0.8	113 ± 26	3.5 ± 2.1
Eumor Deg (Spruce-fir forest)	OL+nozOF	15	2	25.2 ± 4.8	17.8 ± 4.5	5.5 ± 1.4	253 ± 34	17.9 ± 9.2
	nozOF{1}	15	4	119.8 ± 30.8	36.7 ± 8.2	7.1 ± 1.5	278 ± 37	80.2 ± 28.8
	nozOF{2}	13	6	179.7 ± 56.0	28.0 ± 3.9	6.4 ± 1.8	226 ± 35	158.7 ± 38.6
	nozOF{3}	2	8	502.3 ± 117	31.6 ± 11.1	12.7 ± 1.6	394 ± 2	47.5 ± 28.4
	A	15	–	73.7 ± 19.5	4.4 ± 1.1	3.8 ± 0.5	87 ± 12	53.7 ± 14.4
Humimor Reg (Birch forest)	OL	2	1	6.3 ± 0.1	6.1 ± 2.4	3.9 ± 0.9	195 ± 28	2.4 ± 0.1
	OL+zoOF{micro}	2	2	5.8 ± 1.4	2.1 ± 0.4	1.5 ± 0.1	183 ± 30	11.4 ± 5.7
	nozOF+[zoOF{micro}]{1}	2	2.3	19.0 ± 0.2	13.4 ± 6.6	11.2 ± 2.0	256 ± 35	16.8 ± 9.6
	nozOF{1}	4	4	31.1 ± 13.7	14.2 ± 6.4	10.1 ± 0.8	294 ± 49	7.2 ± 2.3
	nozOF{2}	3	5.3	29.1 ± 12.2	8.3 ± 2.6	15.2 ± 4.0	398 ± 100	8.3 ± 2.2
	A	4	–	32.2 ± 4.8	1.9 ± 0.7	3.1 ± 0.5	92 ± 17	4.6 ± 2.5
Humimor Reg (Spruce-fir forest)	OL	6	0.8	8.2 ± 2.0	1.9 ± 0.5	1.7 ± 0.2	173 ± 27	4.5 ± 2.1
	nozOF+[zoOF{micro}]{1}	6	2.3	6.6 ± 0.6	3.8 ± 0.7	5.0 ± 1.4	234 ± 37	5.4 ± 1.3
	nozOF+[zoOF{micro}]{2}	2	4	7.9 ± 1.1	9.0 ± 2.9	7.8 ± 3.3	200 ± 73	6.2 ± 1.7
	nozOF+[zoOF{micro}]{3}	1	6	16.4	10.4	3.2	90.0	12.4
	nozOF{1}	4	4.4	33.2 ± 7.5	8.8 ± 4.2	16.6 ± 4.0	398 ± 56	9.6 ± 3.2
	nozOF{2}	6	6	70.7 ± 18.0	5.4 ± 1.7	12.6 ± 2.8	296 ± 52	7.1 ± 4.6
	nozOF{3}	1	6	68.6	2.4	11.8	287	0.1
	A	6	–	27.3 ± 5.7	3.7 ± 2.0	2.1 ± 0.5	77 ± 20	5.7 ± 1.9
Hemimor Reg (Birch forest)	OL	2	1	7.3 ± 2.7	1.3 ± 0.1	3.4 ± 1.3	145 ± 12	0.6 ± 0.4
	zoOF{micro}{1}	2	3	31.0 ± 7.0	3.7 ± 0.2	7.4 ± 0.5	183 ± 6	12.1 ± 3.6
	nozOF{1}	2	4.5	58.9 ± 12.8	5.4 ± 0.1	4.7 ± 0.1	162 ± 10	9.5 ± 2.5
	A	2	–	25.5 ± 8.2	3.6 ± 2.3	1.5 ± 0.2	52 ± 1	4.5 ± 0.2

Hemimor Reg (Spruce-fir forest)	OL	11	0.7	3.3 ± 0.5	2.4 ± 0.5	1.5 ± 0.2	64 ± 4	4.5 ± 0.8
	zoOF{micro}{1}	11	2.3	6.4 ± 1.1	9.0 ± 2.6	3.4 ± 0.2	101 ± 5	6.2 ± 0.9
	zoOF{micro}{2}	4	3.9	21.9 ± 3.4	17.0 ± 3.6	3.6 ± 0.5	115 ± 12	27.1 ± 11.0
	nozOF+[zoOF{micro}]{1}	7	4.4	32.6 ± 8.0	18.6 ± 3.8	4.4 ± 0.5	111 ± 13	48.1 ± 17.7
	nozOF+[zoOF{micro}]{2}	2	5.5	45.5 ± 8.0	15.9 ± 4.6	3.9 ± 0.1	109 ± 3	65.2 ± 16.1
	nozOF{1}	8	5.6	35.5 ± 7.5	13.7 ± 2.0	3.4 ± 0.6	89 ± 10	100.0 ± 25.4
	nozOF{2}	1	8.5	72.2	13.4	4.5	127	75.6
	A	11	–	9.3 ± 1.4	2.0 ± 0.4	1.1 ± 0.1	31 ± 1	22.2 ± 4.6
Hemimormull Reg (Birch forest)	OL	8	0.6	3.5 ± 0.5	1.2 ± 0.5	1.5 ± 0.1	132 ± 7	1.8 ± 0.3
	zoOF{1}	8	1.9	10.0 ± 2.2	2.0 ± 0.5	4.9 ± 0.6	207 ± 14	3.2 ± 0.8
	nozOF+[zoOF{micro}]{1}	4	3.1	23.8 ± 6.8	7.2 ± 1.8	8.9 ± 1.0	214 ± 24	6.5 ± 1.2
	nozOF{1}	7	3.9	33.9 ± 4.6	8.3 ± 3.7	6.7 ± 0.6	182 ± 9	4.7 ± 1.3
	nozOF{2}	1	4	19.5	10.2	4.7	145	3.0
	A	8	–	16.1 ± 1.9	0.9 ± 0.3	2.3 ± 0.2	57 ± 3	7 ± 3.2
Hemimormull Reg (Spruce-fir forest)	OL	9	0.6	3.4 ± 0.3	1.2 ± 0.3	1.2 ± 0.2	77 ± 6	5.7 ± 0.9
	OL+zoOF	5	1.8	4.0 ± 0.8	1.1 ± 0.3	3.7 ± 0.4	87 ± 14	0.7 ± 0.4
	zoOF{1}	12	2.5	9.5 ± 2.3	4.4 ± 1.0	4.2 ± 0.6	118 ± 8	8.1 ± 2.1
	zoOF{micro}{1}	8	3.3	10.6 ± 1.9	4.0 ± 1.2	6.4 ± 0.8	142 ± 14	4.4 ± 1.9
	zoOF{micro}{2}	1	4.5	12.9	1.7	11.7	229	2.7
	zoOF{micro}{3}	1	6	15.3	0.1	10.4	243	1.2
	nozOF+[zoOF{micro}]{1}	8	5	27.8 ± 4.9	8.7 ± 1.8	5.5 ± 0.9	115 ± 13	30.2 ± 11.9
	nozOF+[zoOF{micro}]{2}	1	6	12.6	6.0	3.3	66	20.8
	nozOF{1}	6	4.7	48.9 ± 10.1	13.9 ± 4.9	6.2 ± 1.3	126 ± 18	71.6 ± 31.1
	A	14	–	10.8 ± 2.0	2.9 ± 0.7	1.1 ± 0.1	32 ± 2	21.3 ± 5.6
Eumormull Reg (Birch forest)	OL	1	0.5	1.3	3.1	1	131	0.9
	zoOF{1}	1	2	2.1	5.4	3.2	224	1.8
	nozOF+[zoOF{micro}]{1}	1	3	8.4	21.5	13.7	346	5.5
	nozOF{1}	1	4	36.0	24.2	9.2	175	6.0
	A	1	–	19.4	2.5	3.0	65	0.3

Eumormull Reg (Spruce-fir forest)	OL	7	0.6	4.7 ± 1.2	1.4 ± 0.2	1.1 ± 0.2	66 ± 6	4.0 ± 0.7
	OL+zoOF	2	2	3.8 ± 0.3	0.6 ± 0.4	2.2 ± 0.6	86 ± 1	1.8 ± 0.9
	zoOF{1}	9	2.5	4.4 ± 1.0	1.8 ± 0.4	3.2 ± 0.7	103 ± 12	4.0 ± 0.8
	zoOF{2}	3	4	3.7 ± 1.0	4.3 ± 1.4	4.0 ± 1.0	108 ± 18	3.7 ± 0.7
	zoOF{3}	2	5.5	16.2 ± 1.6	8.9 ± 0.7	7.5 ± 2.3	154 ± 32	6.9 ± 0.1
	zoOF{micro}{1}	4	4.1	13.9 ± 3.4	5.4 ± 1.3	6.7 ± 0.1	144 ± 13	5.7 ± 1.7
	nozOF+[zoOF{micro}]{1}	6	5.3	39.6 ± 7.4	5.3 ± 1.3	6.6 ± 0.8	141 ± 18	9.7 ± 4.7
	nozOF{1}	3	6.3	46.8 ± 4.5	13.1 ± 6.3	10.1 ± 1.5	171 ± 16	13.0 ± 7.1
	nozOF{2}	1	6	87.0	21.1	5.0	122	168.5
	A	9	–	16.3 ± 3.6	4.0 ± 0.8	1.7 ± 0.2	58 ± 9	29.9 ± 9.1

Note: *d* represents the average depth of the lower boundary of the forest litter from its surface, the depth range is presented in Table S2; *n* denotes the sample size. For codes used to identify the different horizons, refer to Table S1 and Fig.1 in the main text. Figures in curly brackets indicate the index number of the layer within the horizon, while a dash indicates the absence of data.

Table S5. MANOVA results for parameter differences between humus forms, habitat types, and soil horizons

Effect	Wilks' λ	*F*	*df* effect	*df* error	*p*	Effect size
	pH(water) and exchange complex					
Humus form	0.89	2.4	16	944.6	0.0019	0.04
Habitat	0.83	15.4	4	309.0	<0.0001	0.17
Horizon	0.08	202.0	8	618.0	<0.0001	0.72
Humus form × Habitat	0.93	1.3	16	944.6	0.1616	0.02
Humus form × Horizon	0.89	1.1	32	1141.1	0.3290	0.03
Habitat × Horizon	0.89	4.5	8	618.0	<0.0001	0.06
Humus form × Habitat × Horizon	0.89	1.2	32	1141.1	0.2281	0.03
	Carbon and nitrogen					
Humus form	0.98	0.8	8	602	0.5642	0.01
Habitat	0.95	8.0	2	301	0.0004	0.05
Horizon	0.12	288.1	4	602	<0.0001	0.66
Humus form × Habitat	0.95	1.8	8	602	0.0744	0.02
Humus form × Horizon	0.96	0.8	16	602	0.6842	0.02
Habitat × Horizon	0.99	1.0	4	602	0.3946	0.01
Humus form × Habitat × Horizon	0.98	0.4	16	602	0.9727	0.01
	Acid-soluble metals					
Humus form	0.54	5.6	36	1141.0	<0.0001	0.15
Habitat	0.73	12.6	9	304.0	<0.0001	0.27
Horizon	0.04	130.8	18	608.0	<0.0001	0.79
Humus form × Habitat	0.81	1.8	36	1141.0	0.0021	0.05
Humus form × Horizon	0.63	2.1	72	1856.7	<0.0001	0.07
Habitat × Horizon	0.72	6.1	18	608.0	<0.0001	0.15
Humus form × Habitat × Horizon	0.63	2.0	72	1856.7	<0.0001	0.07
	Exchangeable metals					
Humus form	0.54	10.5	20	1022.5	<0.0001	0.17
Habitat	0.86	9.9	5	308.0	<0.0001	0.14
Horizon	0.33	45.7	10	616.0	<0.0001	0.43
Humus form × Habitat	0.82	3.2	20	1022.5	<0.0001	0.06
Humus form × Horizon	0.81	1.7	40	1345.3	0.0049	0.05
Habitat × Horizon	0.94	2.0	10	616.0	0.0267	0.03
Humus form × Habitat × Horizon	0.86	1.1	40	1345.3	0.2567	0.03

Note. The factor gradations used in MANOVA are as follows: Humus form – Eumor, Humimor, Hemimor, Hemimormull, and Eumormull; Habitat – spruce-fir and birch forest; Horizon – OL, OF, and A. The calculated variables (BS and C/N) are not included in the MANOVA.

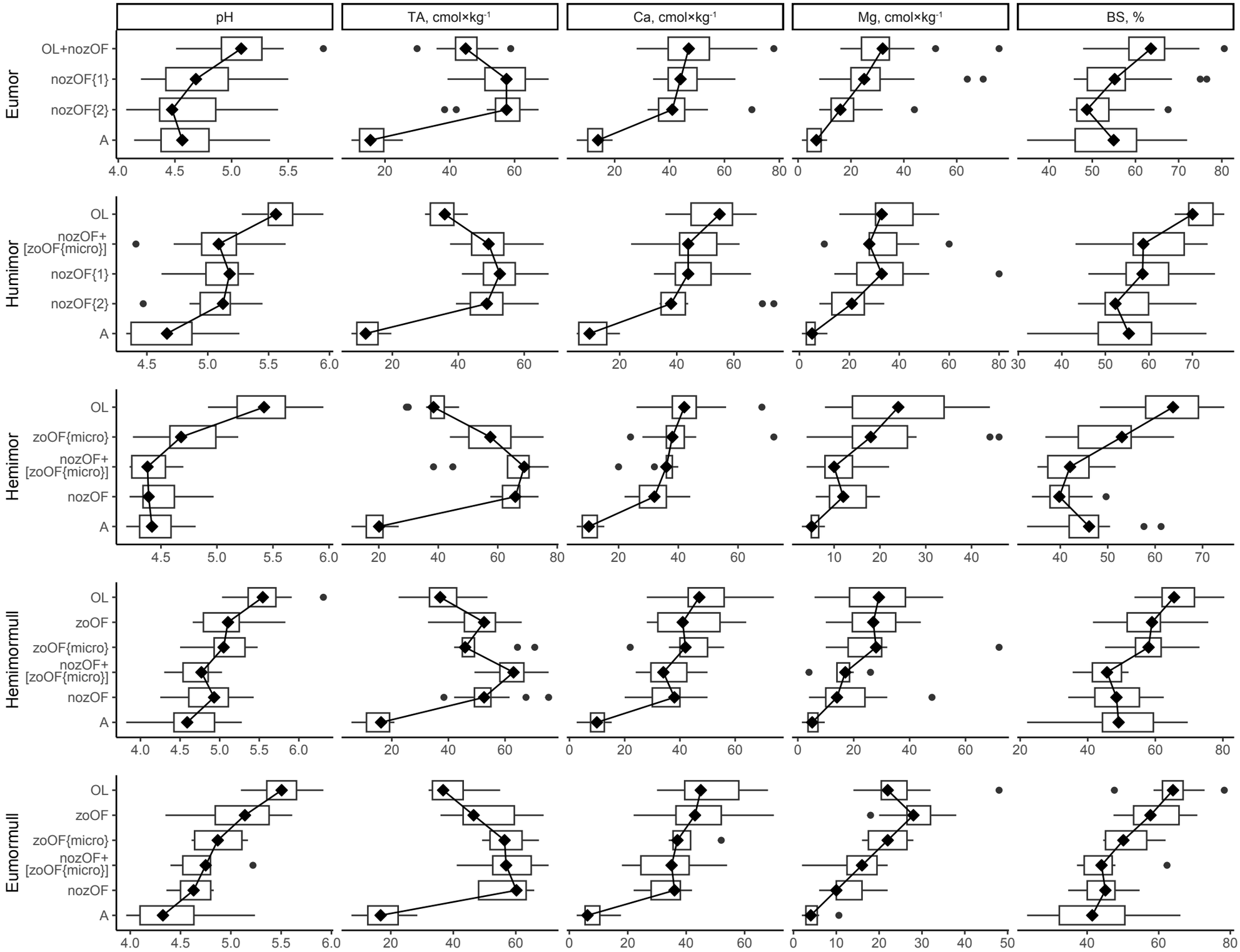

Figure S1. Distribution of pH, total acidity (TA), exchangeable calcium and magnesium, and the saturation of the exchange complex with bases (BS) by humus forms and horizons (layers). Horizon codes are explained in Table S1 and Fig.1 in the main text. The box and whisker plots show the median (rhombus), lower and upper quartiles (box), non-outlier range (whiskers), and outliers (dots).

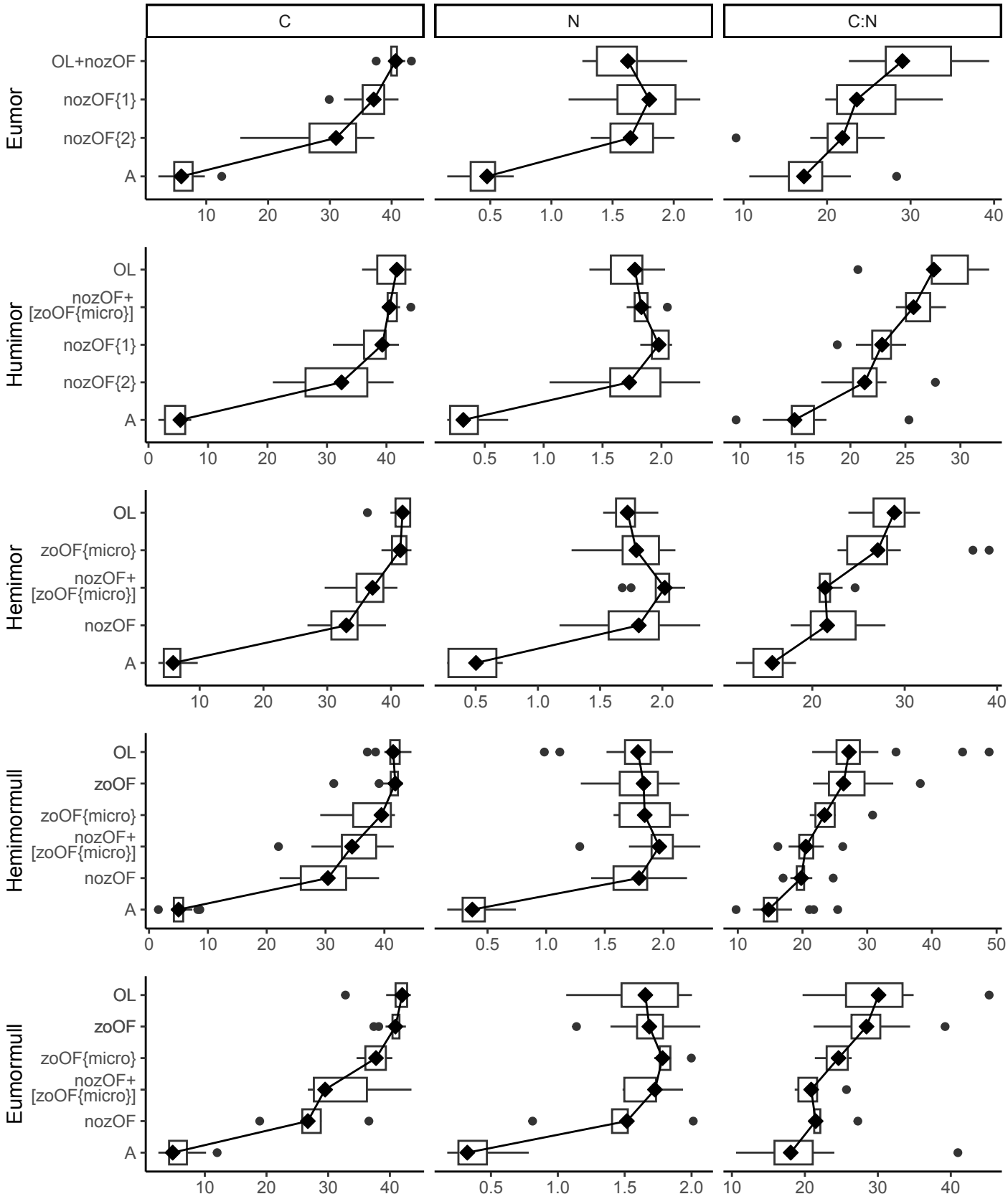

Figure S2. Distribution of organic carbon and total nitrogen by humus forms and horizons (layers). Horizon codes are explained in Table S1 and Fig.1 in the main text. The box and whisker plots show the median (rhombus), lower and upper quartiles (box), non-outlier range (whiskers), and outliers (dots).

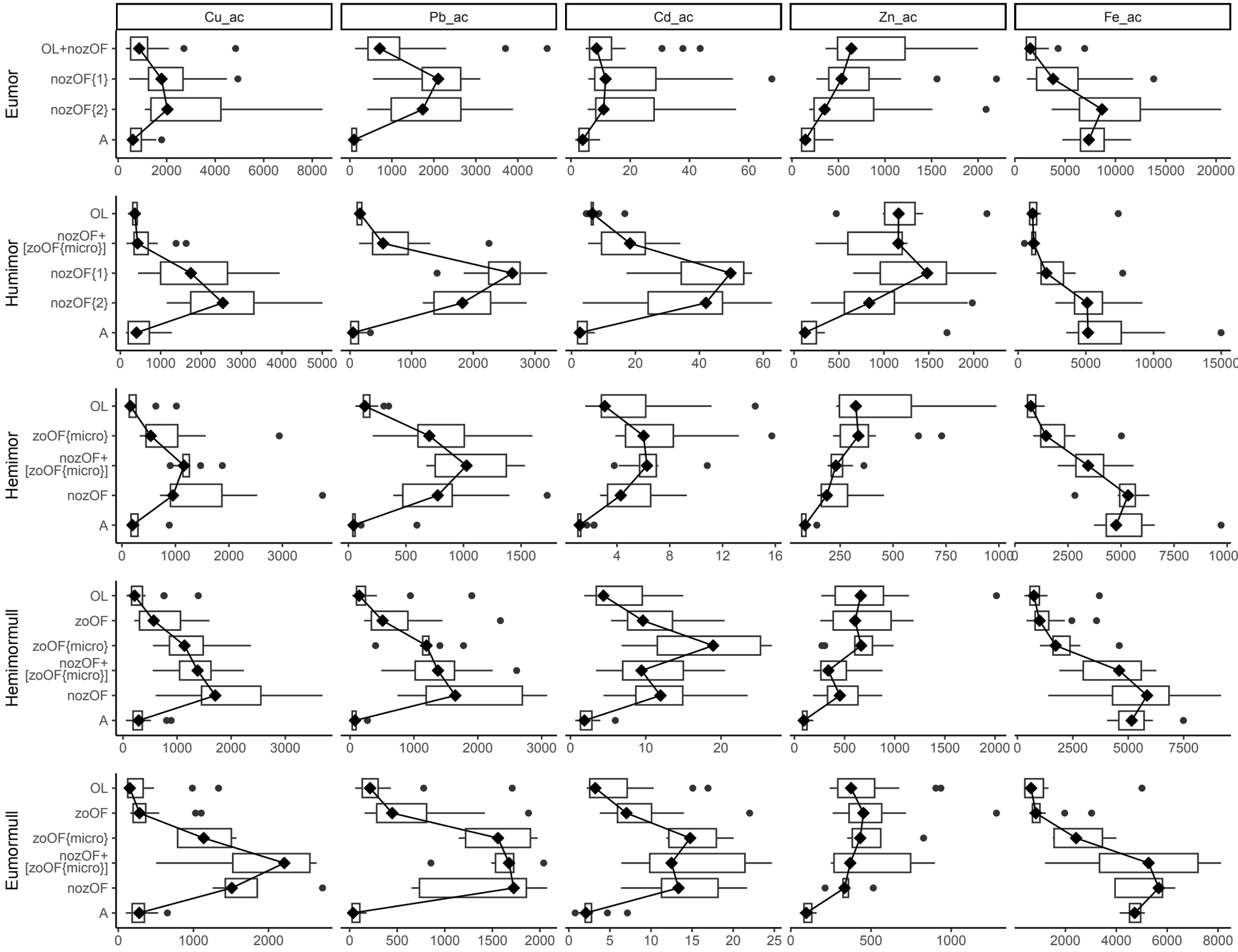

Figure S3. Distribution of acid-soluble metals (µg g^{-1}) by humus forms and horizons (layers). Horizon codes are explained in Table S1 and Fig.1 in the main text. The box and whisker plots show the median (rhombus), lower and upper quartiles (box), non-outlier range (whiskers), and outliers (dots).

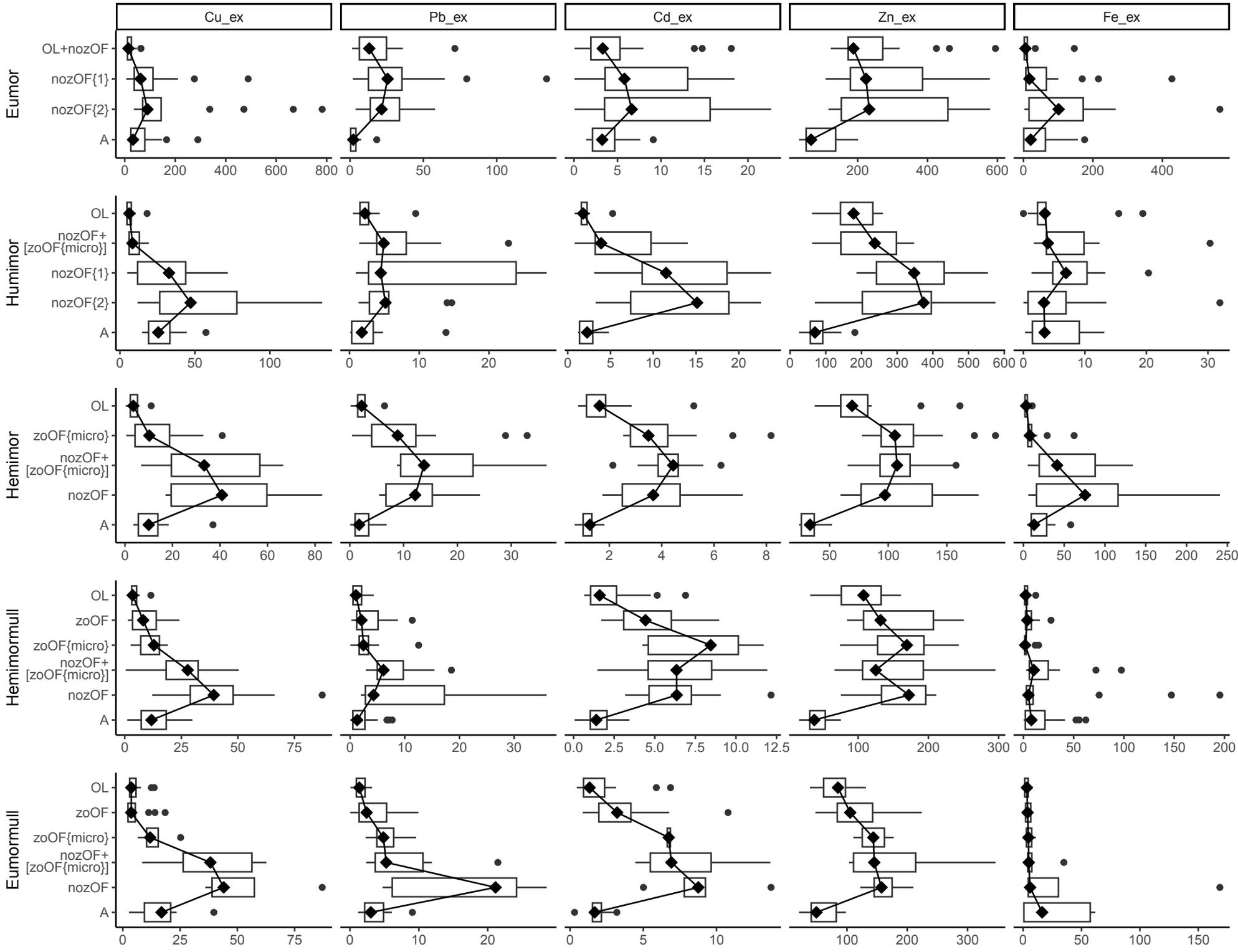

Figure S4. Distribution of exchangeable metals (µg g-1) by humus forms and horizons (layers). Horizon codes are explained in Table S1 and Fig.1 in the main text. The box and whisker plots show the median (rhombus), lower and upper quartiles (box), non-outlier range (whiskers), and outliers (dots).

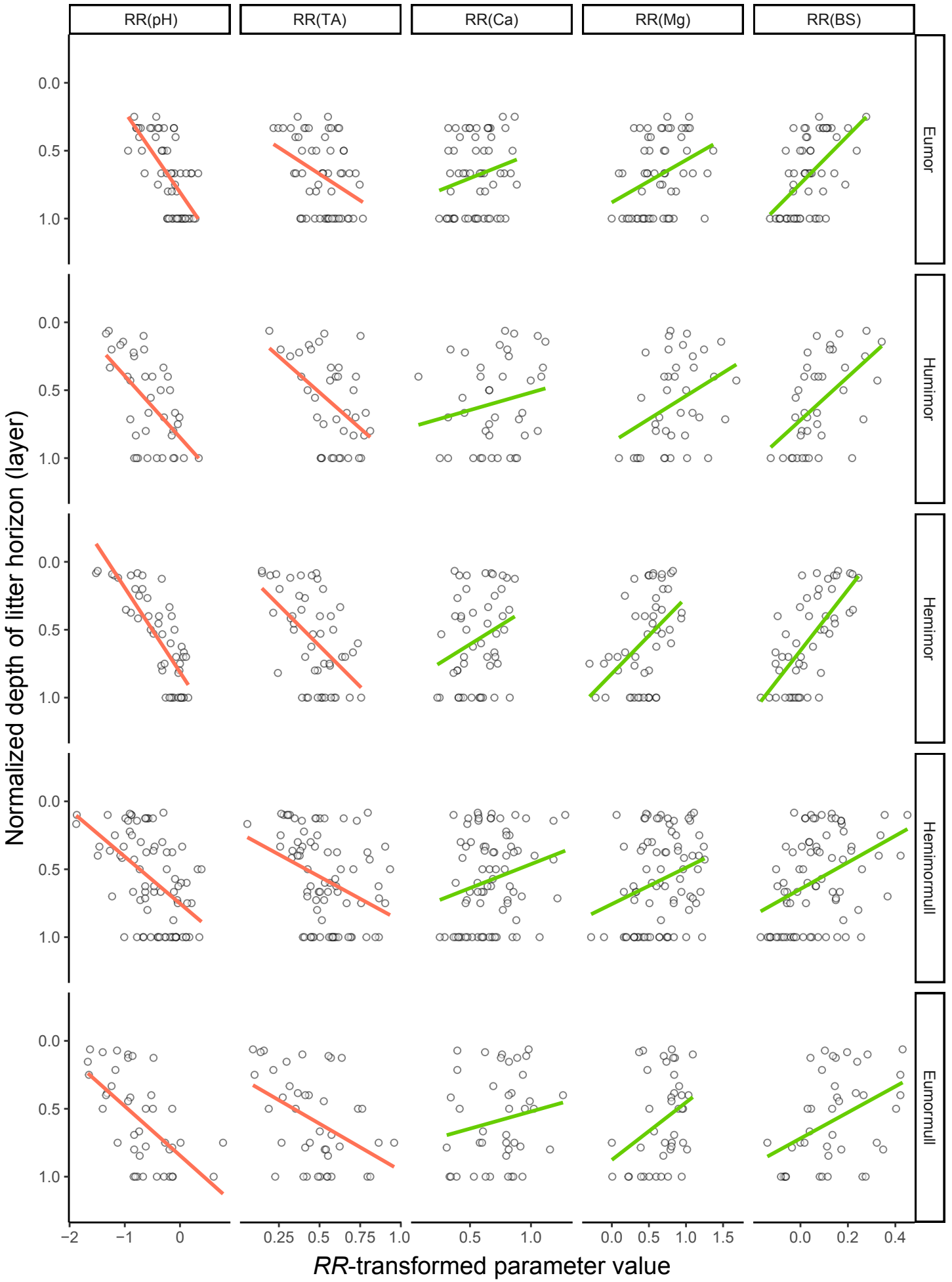

Fig. S5. Depth distribution of pH, total acidity (TA), exchangeable calcium and magnesium, and the saturation of the exchange complex with bases (BS) in different humus forms. See Table 2 in the main text for regression equation coefficients. The red line represents a negative slope, while the green line depicts a positive slope.

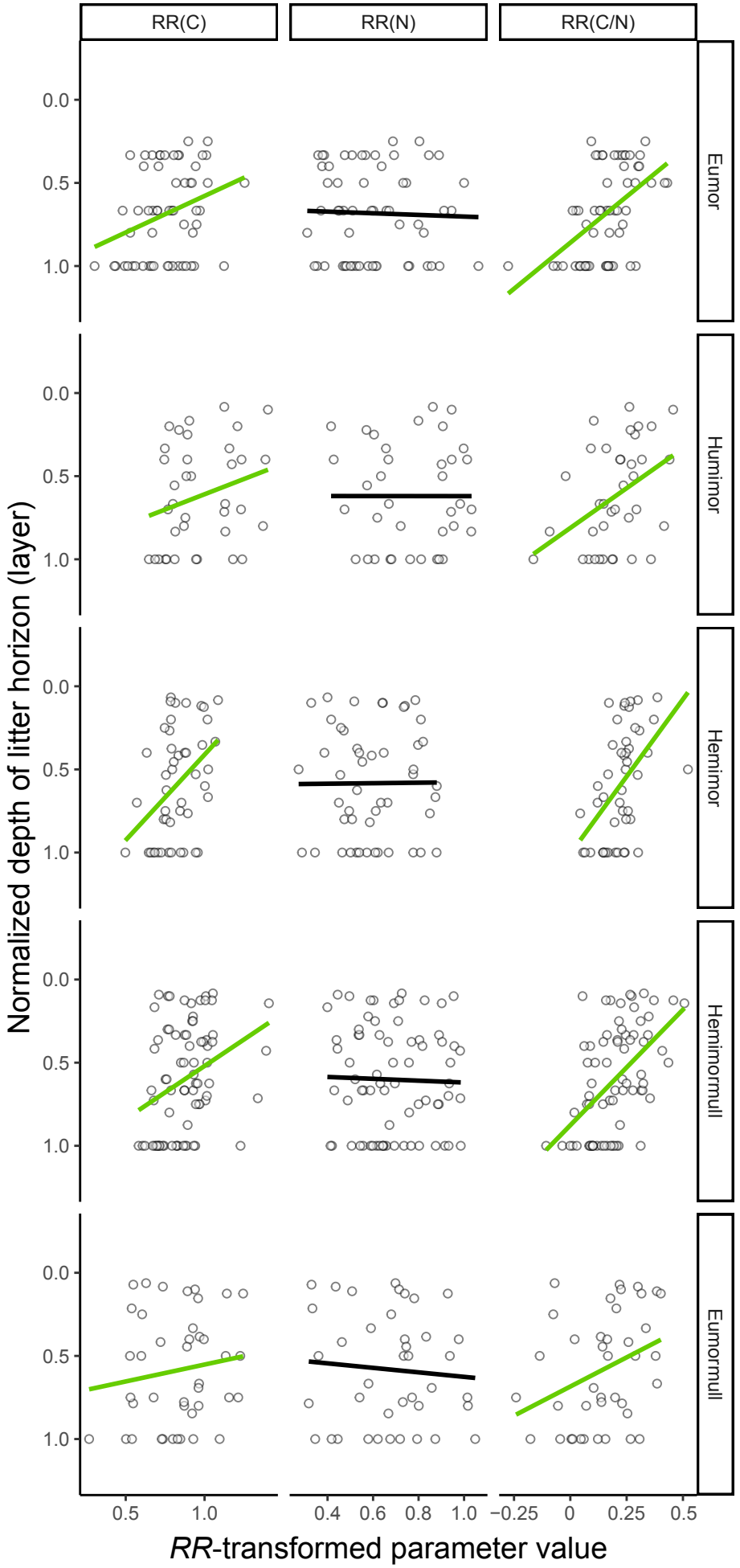

Fig. S6. Depth distribution of organic carbon and total nitrogen in different humus forms. See Table 2 in the main text for regression equation coefficients. The red line represents a negative slope, while the green line depicts a positive slope and the black line denotes a zero slope.

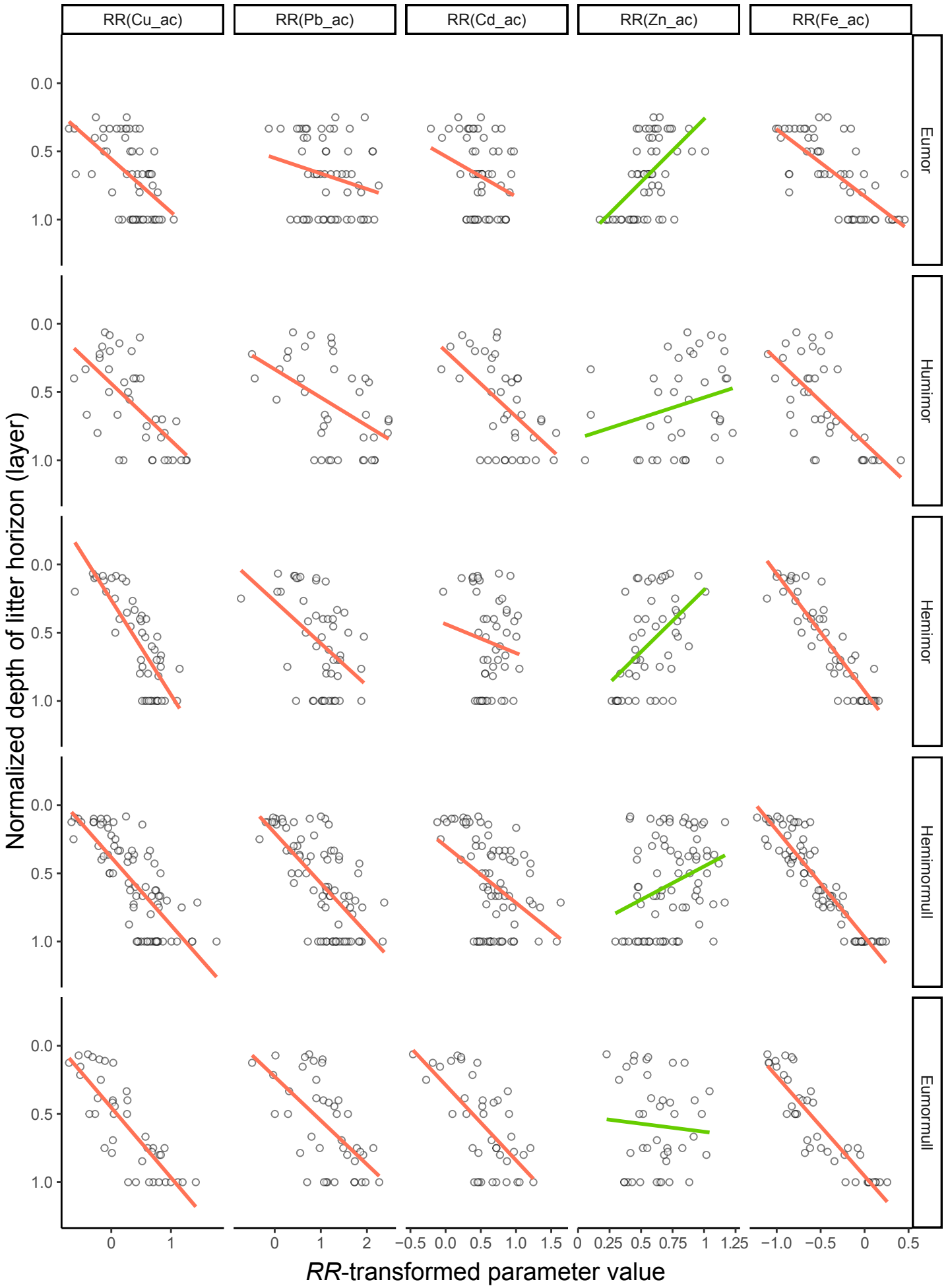

Fig. S7. Depth distribution of acid-soluble metals in different humus forms. See Table 2 in the main text for regression equation coefficients. The red line represents a negative slope, while the green line depicts a positive slope.

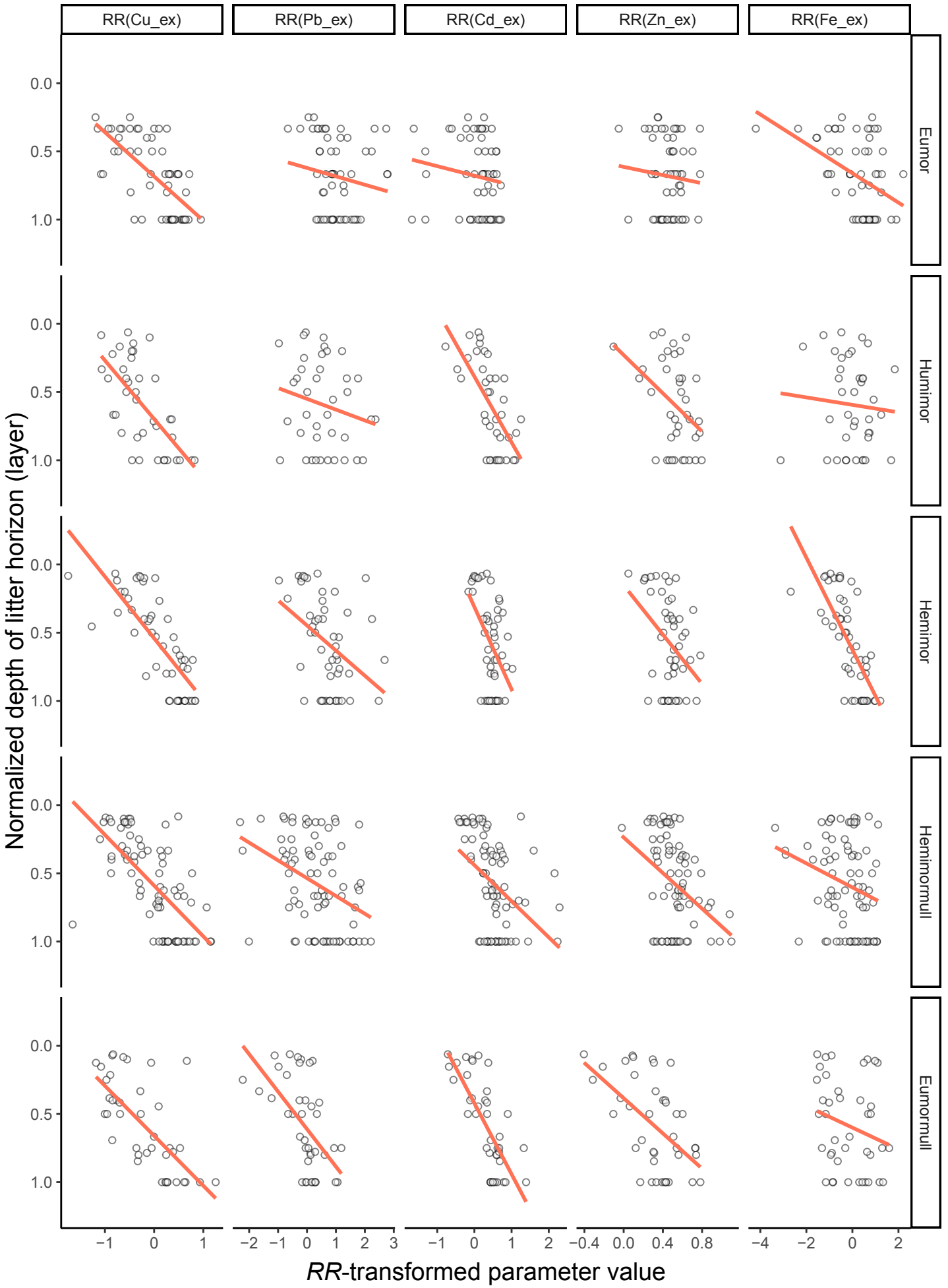

Fig. S8. Depth distribution of exchangeable metals in different humus forms. See Table 2 in the main text for regression equation coefficients. The red line represents a negative slope, while the green line depicts a positive slope.