Supplement of Biogeosciences Discuss., 12, 19819–19859, 2015
http://www.biogeosciences-discuss.net/12/19819/2015/
doi:10.5194/bgd-12-19819-2015-supplement

Supplement of

What is the P value of Siberian soils?

F. Brédoire et al.

Correspondence to: F. Brédoire (felix.bredoire@bordeaux.inra.fr)

Table S1: Detailed climatic features of the study sites. Data averaged on the period 1981–2010. The data presented for each site come from the closest weather stations.

Variable	Period	BAR	CHE	KRA	SAE	SAW	TOM
WMO index of the station		29838	29539	29915	29745	29736	29430
Distance site–station (km)		4	28	76	18	64	38
Air Temperature (°C)	MAT	2.7	1.3	2.9	2.3	1.2	0.9
	DJF	-14.1	-15.2	-15.1	-15.4	-17.6	-15.6
	MAM	3.4	2.0	3.4	3.4	2.8	1.6
	JJA	18.3	17.0	19.7	17.4	16.9	16.7
	SON	2.8	1.2	3.2	3.0	2.2	0.8
Precipitation (mm)	MAP	431.5	509.8	324.5	432.3	453.0	566.5
	DJF	69.8	84.5	53.2	54.3	66.1	104.7
	MAM	85.1	91.3	58.2	78.9	75.1	98.2
	JJA	166.6	184.8	135.3	182.2	168.8	202.9
	SON	107.7	146.4	76.1	106.1	115.9	157.2
Snow Height (cm)	climax*	48.8	42.5	18.8	38.0	54.3	70.6
Snow Cover Duration 1 cm (days)	year	157.2	167.6	141.9	144.5	149.5	178.1
Snow Cover Duration 20 cm (days)	year	108.3	118.3	25.2	88.3	116.4	145.5
Soil Temperature at 20 cm (°C)	DJF	-1.5		-6.0			-0.4
	MAM	4.3		4.0			2.4
	JJA	18.9		20.3			16.4
	SON	6.5		7.3			5.8
Nb of days with soil frozen at 20 cm	year	86.8		130.1			44.5
Average depth of soil frozen (m)	DJF	20–40		40–80			0–20

WMO: World Meteorological Organization; MAT: mean annual temperature; MAP: mean annual precipitations; D, J, F, M, A, M, J, J, A, S, O and N are the months of the year
*climax: maximum snow cover depth, mean snow depth between mid-February and mid-March

Table S2: Detailed forest stand characteristics. Mean and standard error of the mean for 3 plots per site.

	BAR		CHE		KRA		SAE		SAW		TOM	
	mean	se	mean	se	mean	se	mean	se	mean	se	mean	se
Surface described (m^2)[a]	100–325	—	800–1050	—	242–696	—	156–192	—	240–350	—	264–420	—
Density (tree/ha)	1664.0	271.9	387.3	39.5	767.0	235.4	1882.7	145.8	1144.0	147.1	1139.3	188.8
% aspen in density[b]	92.6	—	93.2	—	98.0	—	100.0	—	95.5	—	86.0	—
Basal Area ($m^2\,ha^{-1}$)	34.4	8.7	36.4	3.5	42.6	6.8	29.1	1.9	47.5	7.1	43.8	7.6
% aspen in basal area[b]	90.4	—	89.9	—	97.9	—	100.0	—	97.5	—	95.9	—
DBH (cm)	14.9	1.1	33.9	0.2	26.3	2.3	13.7	0.8	22.8	0.8	21.4	2.6
Height (m)	11.2	0.3	28.0	1.7	18.7	1.5	15.7	0.1	24.8	1.1	18.2	2.1
Age (years)	26.9	1.3	61.7	3.4	51.0	2.6	21.4	3.8	46.7	1.3	55.8	14.1
LAI (m^2 leaves m^{-2} soil)	4.9	0.6	3.8	0.3	3.8	0.3	5.1	0.6	5.0	0.4	2.9	0.5

Only pool and tree stages are included here (i.e. diameter at 1.3 m > 7 cm and height > 1.3 m). DBH: Diameter at breast height; LAI: Leaf area index.

[a]Surface described, plot set to include at least 30 *Populus tremula*

[b]Other tree species: mostly *Betula pendula* but also, very rarely, *Abies sibirica*, *Padus avium*, *Pinus sibirica* and *Pinus sylvestris*

Table S3: Composition of the understorey vegetation in forest (herbaceous, shrub and tree species with a height < 1.3 m and a diameter < 1 cm) and herbaceous species in grassland. Range of the number of species over 3 replicates and dominant species.

Veg. cover	Site	Nb of species	Dominant species*
Forest	BAR	14–18	*Populus tremula* L., *Heracleum sibiricum* L.
	CHE	21–27	*Athyrium filix-femina* (L.) Roth, *Betula pendula* Roth,
	SAE	20–44	*Populus tremula* L., *Carex pallescens* L., *Phlomis tuberosa* L.
	SAW	11–17	*Populus tremula* L., *Athyrium filix-femina* (L.) Roth, *Betula pendula* Roth, *Urtica dioica* L.
	TOM	16–29	*Populus tremula* L., *Athyrium filix-femina* (L.) Roth
Grassland	BAR	13–17	*Bromopsis inermis* (Leys.) Holub, *Cuscuta europaea* L., *Festuca pseudovina* Hack. ex Wiesb.
	CHE	19–26	*Bromopsis inermis* (Leys.) Holub, *Alopecurus pratensis* L.
	SAE	22–60	*Bromopsis inermis* (Leys.) Holub, *Seseli ledebourii* G. Don fil., *Filipendula vulgaris* Moench
	TOM	20–21	*Calamagrostis epigeios* (L.) Roth, *Bromopsis inermis* (Leys.) Holub, *Alopecurus pratensis* L.

* we retained species occurring in at least 2 of the 3 site replicates and with a mean score on the Braun-Blanquet scale > 1

Table S4: Litter and soil horizons description and their main physico-chemical properties. "Litter" means all the dead plant material deposited on the soil surface (senesced leaf litterfall, small branches and senesced understorey vegetation in forests; senesced herbaceous vegetation in grasslands) that is to say mainly OL and OF horizons, and eventually OH (at BAR, CHE, KRA and SAE) at the date of sampling.

	Depth	Forest						Grassland				
Variable	(cm)	BAR	CHE	KRA	SAE	SAW	TOM	BAR	CHE	KRA	SAE	TOM
Horizon type*	−5	AU	AU	O	AU	AY	AY	AU	AU	AU	Ad	AY
	−15	AU	AU_e	AU	AU	AEL	AEL	AU	AU_e	AU	AU	AEL
	−30	BEL	BEL	AU	B	EL	AEL	AU	EL	AU	B	BEL_g
	−60	B	BT	BEL	B	BEL	BEL_g	B	BT	B_{Ca}	BC_{Ca}	BT_g
	−100	BT	BT	BM	M	BT	BT_g	B_{Ca}	BT	B_{Ca}	M	BT_g
Thickness* (cm)	−5	7.7	9.0	8.0	8.7	5.8	7.2	10.0	10.0	8.5	8.3	10.0
	−15	15.5	16.7	11.3	13.2	14.7	12.8	12.5	10.0	11.5	13.8	10.3
	−30	25.3	15.8	23.0	24.5	33.2	29.3	24.2	23.5	15.5	21.5	32.7
	−60	36.8	41.2	28.3	30.0	13.3	24.8	37.2	30.8	34.5	33.3	21.8
	−100	34.7	37.3	49.3	43.7	53.0	45.8	36.2	45.7	50.0	43.0	45.2
Litter mass* ($kg\,m^{-2}$)		2.96	2.43	4.29	1.98	0.94	1.15	0.71	0.20	2.29	0.88	0.21
Density*	−5	1.0	0.8	0.7	0.5	0.7	0.9	1.0	1.0	0.9	0.9	0.9
	−15	1.2	1.0	1.0	0.8	1.0	1.1	1.3	1.1	1.0	1.1	1.2
	−30	1.2	1.2	1.2	1.1	1.3	1.2	1.3	1.1	1.2	1.3	1.3
	−60	1.3	1.4	1.4	1.3	1.5	1.5	1.7	1.4	1.4	1.3	1.5
	−100	1.4	1.5	1.6	1.1	1.6	1.4	1.7	1.4	1.5	1.4	1.4
0–2 µm (%)	−5	27.7	22.8	32.5	40.7	22.2	23.2	27.5	25.5	38.4	35.3	22.0
	−15	27.2	18.6	29.6	36.8	20.4	21.9	27.7	25.1	36.1	34.9	21.2
	−30	26.8	18.6	29.9	31.4	18.2	19.7	26.2	23.1	30.9	24.5	20.5
	−60	26.1	31.5	32.9	17.3	23.1	31.1	25.6	30.8	28.7	14.8	37.8
	−100	25.3	28.4	23.6	8.0	31.2	40.8	25.3	27.8	26.4	6.5	38.6
2–20 µm (%)	−5	23.2	36.2	17.4	26.5	37.9	38.8	20.7	34.4	21.1	23.8	38.9
	−15	23.0	37.0	15.3	25.3	38.2	38.7	21.0	34.7	7.3	23.9	40.5
	−30	22.8	36.2	14.9	25.1	38.3	39.1	19.5	34.9	23.7	19.2	40.1
	−60	23.4	27.6	14.6	13.2	36.2	32.6	22.7	27.2	15.7	11.2	30.3
	−100	21.9	28.3	12.0	5.5	31.5	30.6	16.1	27.6	17.2	5.6	32.1

*: mean of 3 replicates; FRLD: fine root length density; FRMD: fine root mass density

Table S4: Continued.

	Depth	Forest						Grassland				
Variable	(cm)	BAR	CHE	KRA	SAE	SAW	TOM	BAR	CHE	KRA	SAE	TOM
20–50 μm (%)	−5	35.3	32.8	14.5	14.9	34.4	30.2	35.5	32.3	15.3	17.0	30.8
	−15	35.7	34.9	14.8	15.6	36.6	31.0	32.7	32.0	27.3	17.6	31.7
	−30	35.2	34.8	14.2	15.2	37.5	31.3	34.8	33.7	16.5	15.3	30.8
	−60	37.3	31.5	13.5	8.8	35.4	27.4	33.7	31.7	16.3	8.7	25.7
	−100	39.8	32.9	16.0	3.4	32.7	24.6	34.4	34.1	17.3	3.1	25.6
50–200 μm (%)	−5	13.0	7.2	25.1	4.4	4.6	6.9	14.0	7.3	17.3	4.7	6.7
	−15	13.5	8.3	26.5	5.2	3.9	7.4	16.0	7.7	21.2	4.2	4.7
	−30	14.5	8.7	26.3	5.7	5.2	8.8	15.3	7.8	19.1	3.3	6.6
	−60	12.2	8.4	24.2	5.3	4.3	7.7	12.8	9.7	24.0	4.5	5.4
	−100	12.0	8.3	27.1	4.5	4.1	3.5	19.8	10.1	20.5	6.6	3.1
200–2000 μm (%)	−5	0.7	0.9	10.4	13.4	0.8	0.8	2.2	0.4	7.8	19.1	1.5
	−15	0.5	1.1	13.7	17.0	0.8	0.9	2.5	0.4	8.0	19.3	1.8
	−30	0.6	1.6	14.6	22.5	0.7	1.0	2.5	0.4	7.8	37.6	1.9
	−60	0.9	0.9	13.5	55.2	0.9	1.1	1.8	0.5	7.9	60.1	0.7
	−100	0.9	0.8	9.7	73.7	0.4	0.4	4.3	0.3	7.0	76.7	0.4
pH	Litter	6.81	6.81	7.27	6.86	6.86	6.59	6.65	6.36	6.79	6.86	6.31
	−5	6.10	5.73	6.86	6.17	6.07	5.37	6.50	5.95	7.16	6.47	5.45
	−15	6.12	5.40	6.34	5.97	5.45	5.25	7.20	6.27	7.80	6.58	5.54
	−30	6.52	5.67	6.32	6.15	5.25	5.25	7.73	6.29	8.30	7.28	5.63
	−60	6.34	6.18	7.99	7.09	5.39	5.60	7.88	6.41	9.10	8.12	6.02
	−100	6.34	7.60	8.52	8.36	5.70	6.53	8.00	6.43	8.95	8.55	7.32
Organic C ($g\,kg^{-1}$)	Litter	305.00	377.00	398.00	362.00	341.00	400.00	370.00	338.00	202.00	290.00	368.00
	−5	39.20	53.00	54.30	113.00	52.90	37.20	35.30	40.30	68.10	51.20	32.50
	−15	32.80	22.40	34.90	63.60	25.00	24.80	29.10	35.40	42.80	46.10	21.30
	−30	28.60	10.70	25.00	16.90	13.10	13.90	18.20	28.50	30.80	6.79	10.70
	−60	8.05	3.68	6.79	3.07	4.92	5.49	5.71	4.35	12.80	2.86	3.76
	−100	2.73	2.43	3.68	1.26	2.43	2.99	2.79	2.68	3.07	1.11	2.33

*: mean of 3 replicates; FRLD: fine root length density; FRMD: fine root mass density

Table S4: Continued.

Variable	Depth (cm)	Forest BAR	Forest CHE	Forest KRA	Forest SAE	Forest SAW	Forest TOM	Grassland BAR	Grassland CHE	Grassland KRA	Grassland SAE	Grassland TOM
Total N ($g\,kg^{-1}$)	Litter	12.70	12.00	14.50	16.70	13.80	11.10	15.50	12.20	11.50	14.90	10.70
	−5	2.91	3.48	4.10	8.53	4.22	2.92	2.83	2.80	5.32	3.90	2.65
	−15	2.44	1.47	2.57	4.65	2.14	2.09	2.31	2.40	3.23	3.47	1.77
	−30	2.09	0.75	1.85	1.21	1.15	1.17	1.45	1.89	2.34	0.48	0.85
	−60	0.65	0.36	0.58	0.26	0.45	0.50	0.51	0.38	1.01	0.22	0.40
	−100	0.26	0.25	0.31	0.09	0.29	0.36	0.21	0.27	0.24	0.10	0.29
C:N	Litter	24.00	31.50	27.50	21.70	24.70	36.10	23.90	27.60	17.50	19.40	34.40
	−5	13.50	15.20	13.30	13.30	12.50	12.70	12.50	14.40	12.80	13.10	12.30
	−15	13.50	15.20	13.60	13.70	11.70	11.90	12.60	14.70	13.20	13.30	12.10
	−30	13.70	14.40	13.50	13.90	11.40	11.90	12.60	15.10	13.10	14.10	12.70
	−60	12.40	10.30	11.70	11.90	11.00	11.10	11.20	11.30	12.70	12.80	9.38
	−100	10.40	9.55	11.90	14.50	8.27	8.42	13.10	9.78	12.60	11.00	8.05
C:P	Litter	246.84	320.99	301.84	294.01	225.07	395.33	317.39	252.16	180.02	219.93	386.09
	−5	38.53	62.25	74.47	103.11	50.91	48.97	40.22	42.15	80.40	55.58	46.81
	−15	34.46	33.75	56.69	70.03	28.92	36.65	33.66	37.71	61.27	52.79	34.11
	−30	29.77	17.02	46.18	40.62	17.05	24.87	24.09	31.69	48.99	12.06	20.25
	−60	10.54	5.44	17.20	9.49	8.41	11.23	9.62	6.31	24.84	4.68	7.62
	−100	4.28	3.69	9.01	3.95	3.76	5.66	4.70	3.86	7.41	1.87	4.34
N:P	Litter	10.28	10.22	11.00	13.56	9.11	10.97	13.30	9.10	10.25	11.30	11.23
	−5	2.86	4.09	5.62	7.78	4.06	3.84	3.22	2.93	6.28	4.23	3.82
	−15	2.56	2.21	4.17	5.12	2.48	3.09	2.67	2.56	4.62	3.97	2.83
	−30	2.18	1.19	3.42	2.91	1.50	2.09	1.92	2.10	3.72	0.86	1.60
	−60	0.85	0.53	1.47	0.80	0.76	1.01	0.86	0.56	1.96	0.37	0.81
	−100	0.41	0.39	0.76	0.27	0.45	0.67	0.36	0.39	0.59	0.17	0.54
Total $CaCO_3$ ($g\,kg^{-1}$)	−5	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	−15	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
	−30	< 1	< 1	< 1	< 1	< 1	< 1	17.00	< 1	19.00	< 1	< 1
	−60	< 1	< 1	13.00	2.00	< 1	< 1	33.00	< 1	72.00	7.00	< 1
	−100	< 1	13.00	114.00	49.00	< 1	< 1	20.00	< 1	114.00	15.00	2.00

*: mean of 3 replicates; FRLD: fine root length density; FRMD: fine root mass density

Table S4: Continued.

	Depth	Forest						Grassland				
Variable	(cm)	BAR	CHE	KRA	SAE	SAW	TOM	BAR	CHE	KRA	SAE	TOM
Al oxides	Litter	34.10	21.87	14.82	27.80	24.83	18.16	26.68	40.77	63.38	49.29	35.58
(mmol kg^{-1})	−5	63.38	60.78	48.92	101.55	77.09	86.73	58.56	74.50	55.96	101.18	90.43
	−15	64.86	64.49	55.22	126.01	88.95	95.25	59.30	73.01	60.78	104.89	91.17
	−30	63.01	58.93	53.00	141.21	95.62	100.07	57.82	70.05	64.12	122.31	95.99
	−60	75.24	83.02	61.15	114.52	102.66	116.75	61.89	87.10	62.26	88.95	118.97
	−100	64.49	74.12	57.45	81.91	118.23	125.27	53.74	75.61	71.53	92.29	117.12
Fe oxides	Litter	15.40	14.33	6.63	15.76	19.88	12.00	10.92	20.23	23.99	22.20	22.92
(mmol kg^{-1})	−5	31.34	50.68	19.52	56.05	68.05	75.21	25.25	47.81	21.85	48.53	93.65
	−15	33.31	53.18	20.41	67.15	75.57	78.97	26.32	47.27	22.20	49.60	95.62
	−30	34.20	40.47	19.52	71.45	82.19	89.18	25.43	44.59	22.56	63.75	107.44
	−60	35.81	38.50	17.73	65.00	76.28	74.67	24.53	30.08	20.77	55.51	70.19
	−100	26.50	33.13	18.26	46.20	67.15	58.55	22.74	30.62	26.86	64.64	59.27
FRLD*	−5	1.440	2.023	1.995	2.165	0.922	0.772	2.345	4.212	4.025	2.823	2.792
(cm cm^{-3})	−15	0.773	0.841	1.119	0.944	0.369	0.820	1.301	1.943	1.830	1.025	1.056
	−30	0.689	0.395	0.615	0.477	0.163	0.219	0.831	1.167	1.611	0.670	0.294
	−60	0.412	0.176	0.259	0.405	0.004	0.011	0.437	0.551	0.628	0.277	0.070
	−100	0.328	0.070	0.222	0.083	0.000	0.023	0.112	0.258	0.344	0.018	0.048
FRMD*	−5	1.466	1.275	1.347	1.884	0.865	0.873	1.494	1.545	2.303	2.041	1.061
(mg cm^{-3})	−15	0.565	0.531	0.510	0.870	0.517	0.577	0.593	0.547	0.942	0.488	0.217
	−30	0.540	0.221	0.424	0.465	0.226	0.207	0.345	0.309	0.656	0.354	0.051
	−60	0.331	0.196	0.133	0.295	0.002	0.007	0.188	0.158	0.298	0.151	0.014
	−100	0.412	0.033	0.151	0.072	0.000	0.014	0.060	0.075	0.128	0.004	0.016

*: mean of 3 replicates; FRLD: fine root length density; FRMD: fine root mass density

Table S5: Parameters m and n from the model of $r(t)/R$ (Eq. 4). "Litter" means all the dead plant material deposited on the soil surface (senesced leaf litterfall, small branches and senesced understorey vegetation in forests; senesced herbaceous vegetation in grasslands) that is to say mainly OL and OF horizons, and eventually OH (at BAR, CHE, KRA and SAE) at the date of sampling.

	Depth	Forest						Grassland				
	(cm)	BAR	CHE	KRA	SAE	SAW	TOM	BAR	CHE	KRA	SAE	TOM
m	Litter	0.924	0.962	0.955	0.953	0.975	0.978	0.984	0.958	0.949	0.969	1.005
	−5	0.726	1.024	0.793	0.901	0.953	0.878	0.635	0.646	0.861	0.428	0.745
	−15	0.651	0.707	0.556	0.855	0.926	0.634	0.241	0.480	0.401	0.398	0.510
	−30	0.526	0.472	0.420	0.235	0.522	0.342	0.161	0.454	0.319	0.087	0.198
	−60	0.212	0.087	0.113	0.128	0.153	0.094	0.072	0.072	0.287	0.223	0.036
	−100	0.114	0.038	0.077	0.295	0.085	0.028	0.086	0.056	0.101	0.371	0.034
n	Litter	0.023	0.028	0.019	0.027	0.024	0.010	0.015	0.000	0.026	0.033	0.003
	−5	0.181	0.212	0.163	0.155	0.173	0.385	0.183	0.225	0.157	0.226	0.284
	−15	0.214	0.291	0.267	0.213	0.329	0.326	0.230	0.254	0.316	0.313	0.372
	−30	0.217	0.313	0.386	0.318	0.370	0.408	0.270	0.288	0.277	0.282	0.427
	−60	0.288	0.334	0.262	0.397	0.384	0.392	0.289	0.349	0.299	0.201	0.355
	−100	0.337	0.304	0.331	0.290	0.371	0.240	0.280	0.313	0.351	0.307	0.294

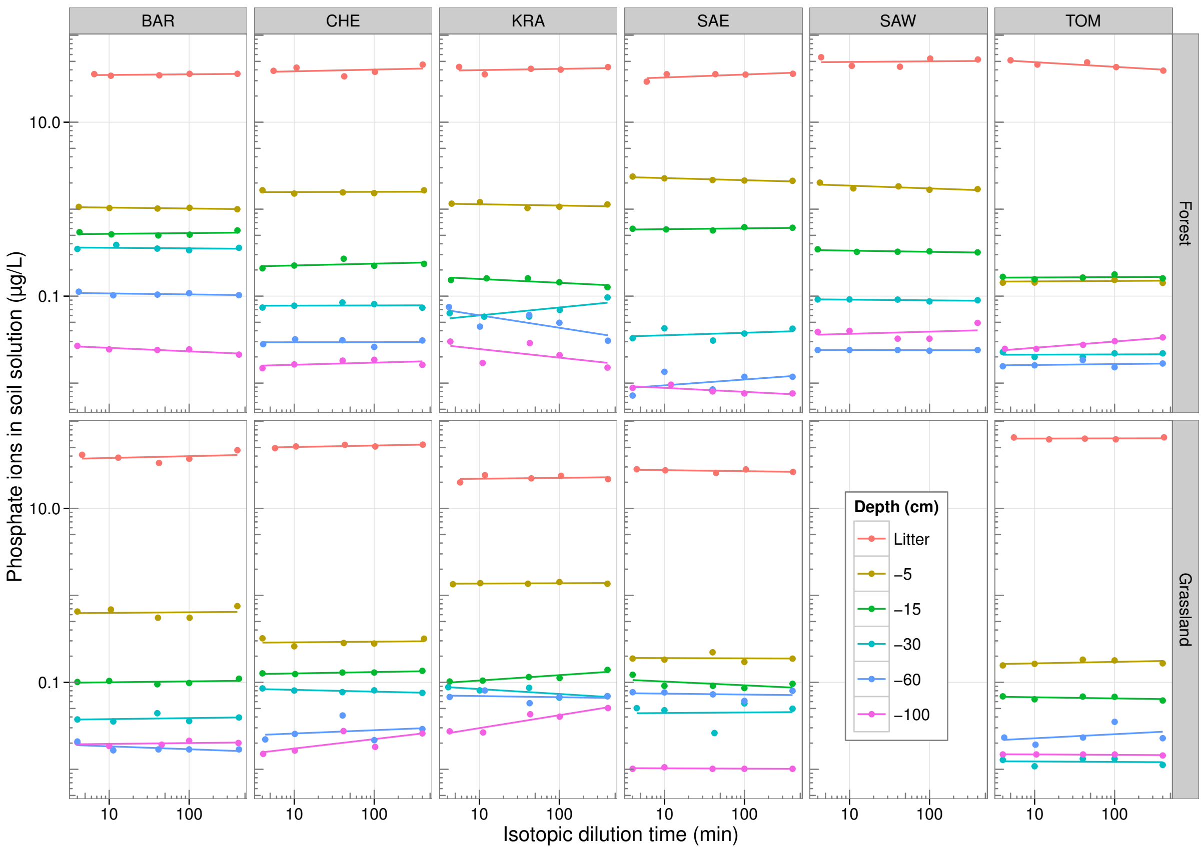

Figure S1: Measures of the concentration of phosphate ions in soil solution during the isotopic dilution. "Litter" means all the dead plant material deposited on the soil surface (senesced leaf litterfall, small branches and senesced understorey vegetation in forests; senesced herbaceous vegetation in grasslands) that is to say mainly OL and OF horizons, and eventually OH (at BAR, CHE, KRA and SAE) at the date of sampling.

Table S6: Spearman's rank correlation coefficient matrix between P variables and selected soil properties as well as fine root (diameter < 0.8 mm) densities, computed separately for each investigated soil depth. Bold coefficients are significant at $p < 0.05$. Depth is in cm. *Qw*: phosphate ions in solution; *m* and *n* are the fitting parameters of Eq. 4; *Pr*: diffusive phosphate ions; *E*: isotopically exchangeable phosphate ions; FRLD: fine root length density; FRMD: fine root mass density.

Depth	Variable	P_{tot}	P_{org}	P_{inorg}	*Qw*	*m*	*n*	*Pr* (1 day)	*E* (1 day)
-5	pH	0.100	0.191	-0.109	0.382	-0.300	**-0.700**	0.182	0.182
	Clay fraction	0.282	0.500	-0.209	0.300	-0.227	-0.600	0.209	0.245
	Organic C	0.300	**0.682**	-0.200	**0.791**	0.500	**-0.773**	**0.655**	**0.673**
	$CaCO_3$	na	na	na	na	na	na	na	na
	Al oxides	0.355	0.336	-0.091	-0.191	0.000	0.336	-0.191	-0.164
	Fe oxides	0.036	0.045	-0.073	-0.209	0.373	0.509	-0.109	-0.109
	Al + Fe oxides	0.064	0.173	-0.191	-0.364	0.118	0.555	-0.309	-0.291
	P_{tot}	—	0.345	**0.627**	0.527	0.055	-0.409	0.464	0.527
	P_{org}	0.345	—	-0.364	0.318	0.227	-0.345	0.100	0.173
	P_{inorg}	**0.627**	-0.364	—	0.191	-0.055	0.009	0.364	0.336
	Qw	0.527	0.318	0.191	—	**0.609**	**-0.864**	**0.882**	**0.909**
	m	0.055	0.227	-0.055	**0.609**	—	-0.318	**0.709**	**0.709**
	n	-0.409	-0.345	0.009	**-0.864**	-0.318	—	**-0.673**	**-0.736**
	Pr (1 day)	0.464	0.100	0.364	**0.882**	**0.709**	**-0.673**	—	**0.982**
	E (1 day)	0.527	0.173	0.336	**0.909**	**0.709**	**-0.736**	**0.982**	—
	FRLD	-0.055	0.345	-0.364	-0.145	-0.518	0.018	-0.445	-0.418
	FRMD	0.236	0.482	-0.209	0.118	-0.464	-0.364	-0.055	-0.027
-15	pH	0.205	0.318	-0.045	-0.473	**-0.755**	-0.318	-0.227	-0.282
	Clay fraction	0.296	**0.609**	-0.291	-0.055	-0.373	-0.491	0.009	0.018
	Organic C	0.542	**0.773**	-0.100	0.109	-0.218	-0.536	0.045	0.064
	$CaCO_3$	na	na	na	na	na	na	na	na
	Al oxides	0.333	0.527	0.036	0.136	0.282	0.155	0.209	0.282
	Fe oxides	-0.091	0.027	0.027	0.091	0.455	0.500	0.173	0.227
	Al + Fe oxides	0.150	0.336	0.009	0.155	0.409	0.245	0.145	0.227
	P_{tot}	—	0.456	**0.688**	0.337	0.018	-0.579	0.296	0.333
	P_{org}	0.456	—	-0.091	-0.027	-0.164	-0.118	0.045	0.073
	P_{inorg}	**0.688**	-0.091	—	0.209	0.027	-0.309	0.255	0.273
	Qw	0.337	-0.027	0.209	—	**0.855**	-0.436	0.600	**0.664**
	m	0.018	-0.164	0.027	**0.855**	—	-0.009	0.545	**0.609**
	n	-0.579	-0.118	-0.309	-0.436	-0.009	—	0.064	0.000
	Pr (1 day)	0.296	0.045	0.255	0.600	0.545	0.064	—	**0.991**
	E (1 day)	0.333	0.073	0.273	**0.664**	**0.609**	0.000	**0.991**	—
	FRLD	-0.091	0.264	-0.336	**-0.636**	**-0.764**	-0.145	**-0.691**	**-0.736**
	FRMD	0.351	0.282	0.064	0.364	-0.018	-0.464	0.400	0.391
-30	pH	0.237	0.273	0.032	0.228	-0.346	**-0.793**	0.533	0.551
	Clay fraction	-0.246	0.136	-0.464	-0.036	-0.300	-0.391	0.355	0.282
	Organic C	0.400	**0.843**	0.009	0.474	0.328	-0.469	0.077	0.105
	$CaCO_3$	0.176	0.324	-0.040	0.027	-0.351	-0.512	0.081	0.081
	Al oxides	-0.410	-0.564	-0.209	-0.400	-0.355	0.318	-0.200	-0.291
	Fe oxides	-0.305	-0.536	0.018	-0.445	-0.127	0.600	-0.464	-0.536
	Al + Fe oxides	-0.465	**-0.636**	-0.209	-0.491	-0.245	0.500	-0.400	-0.491
	P_{tot}	—	**0.656**	**0.870**	**0.825**	0.565	**-0.661**	0.205	0.328
	P_{org}	**0.656**	—	0.282	**0.691**	0.573	-0.336	0.009	0.100
	P_{inorg}	**0.870**	0.282	—	0.573	0.391	-0.500	0.236	0.318
	Qw	**0.825**	**0.691**	0.573	—	**0.745**	-0.545	0.445	0.555
	m	0.565	0.573	0.391	**0.745**	—	-0.036	0.018	0.109
	n	**-0.661**	-0.336	-0.500	-0.545	-0.036	—	-0.473	-0.536
	Pr (1 day)	0.205	0.009	0.236	0.445	0.018	-0.473	—	**0.982**
	E (1 day)	0.328	0.100	0.318	0.555	0.109	-0.536	**0.982**	—
	FRLD	0.387	0.518	0.073	0.336	-0.173	**-0.773**	0.236	0.291
	FRMD	0.155	0.336	-0.118	0.427	0.018	**-0.655**	**0.636**	**0.618**

Table S6: Continued.

Depth	Variable	P_{tot}	P_{org}	P_{inorg}	Qw	m	n	Pr (1 day)	E (1 day)
-60	pH	-0.045	0.073	-0.200	0.436	0.400	**-0.636**	-0.491	-0.491
	Clay fraction	-0.145	-0.055	-0.082	0.045	-0.555	0.055	**0.782**	**0.782**
	Organic C	0.027	0.509	-0.073	0.273	0.209	-0.264	0.182	0.182
	$CaCO_3$	-0.312	0.069	-0.461	0.144	0.327	-0.471	**-0.649**	**-0.649**
	Al oxides	-0.264	-0.300	-0.127	-0.491	-0.191	**0.718**	0.100	0.100
	Fe oxides	-0.164	-0.127	-0.027	-0.482	-0.073	**0.664**	-0.018	-0.018
	Al + Fe oxides	-0.264	-0.245	-0.109	-0.564	-0.227	**0.718**	0.027	0.027
	P_{tot}	—	0.382	**0.973**	0.555	0.036	-0.427	0.291	0.291
	P_{org}	0.382	—	0.282	0.518	0.564	-0.327	-0.091	-0.091
	P_{inorg}	**0.973**	0.282	—	0.455	-0.109	-0.355	0.373	0.373
	Qw	0.555	0.518	0.455	—	0.509	**-0.809**	0.173	0.173
	m	0.036	0.564	-0.109	0.509	—	-0.291	-0.509	-0.509
	n	-0.427	-0.327	-0.355	**-0.809**	-0.291	—	0.100	0.100
	Pr (1 day)	0.291	-0.091	0.373	0.173	-0.509	0.100	—	**1.000**
	E (1 day)	0.291	-0.091	0.373	0.173	-0.509	0.100	**1.000**	—
	FRLD	0.318	0.100	0.164	0.327	0.191	-0.373	-0.145	-0.145
	FRMD	0.336	0.282	0.200	0.382	0.318	-0.273	-0.100	-0.100
-100	pH	**-0.615**	-0.518	-0.591	-0.364	0.400	-0.109	-0.391	-0.391
	Clay fraction	0.308	0.515	0.251	0.451	**-0.847**	-0.105	**0.852**	**0.852**
	Organic C	-0.228	0.378	-0.237	**0.679**	-0.287	0.164	0.342	0.342
	$CaCO_3$	**-0.673**	-0.359	**-0.676**	-0.284	0.387	-0.019	-0.387	-0.387
	Al oxides	0.041	0.073	0.009	0.018	-0.309	-0.164	0.427	0.427
	Fe oxides	0.164	-0.118	0.127	-0.127	-0.073	-0.055	0.291	0.291
	Al + Fe oxides	0.118	-0.009	0.073	0.000	-0.255	-0.145	0.436	0.436
	P_{tot}	—	0.260	**0.989**	0.132	-0.191	0.246	0.241	0.241
	P_{org}	0.260	—	0.209	0.409	**-0.709**	0.227	0.500	0.500
	P_{inorg}	**0.989**	0.209	—	0.091	-0.145	0.245	0.173	0.173
	Qw	0.132	0.409	0.091	—	-0.227	0.555	**0.736**	**0.736**
	m	-0.191	**-0.709**	-0.145	-0.227	—	0.300	**-0.655**	**-0.655**
	n	0.246	0.227	0.245	0.555	0.300	—	0.291	0.291
	Pr (1 day)	0.241	0.500	0.173	**0.736**	**-0.655**	0.291	—	**1.000**
	E (1 day)	0.241	0.500	0.173	**0.736**	**-0.655**	0.291	**1.000**	—
	FRLD	-0.114	-0.009	-0.055	0.173	0.191	0.273	-0.209	-0.209
	FRMD	-0.210	0.073	-0.136	0.100	0.209	0.264	-0.318	-0.318

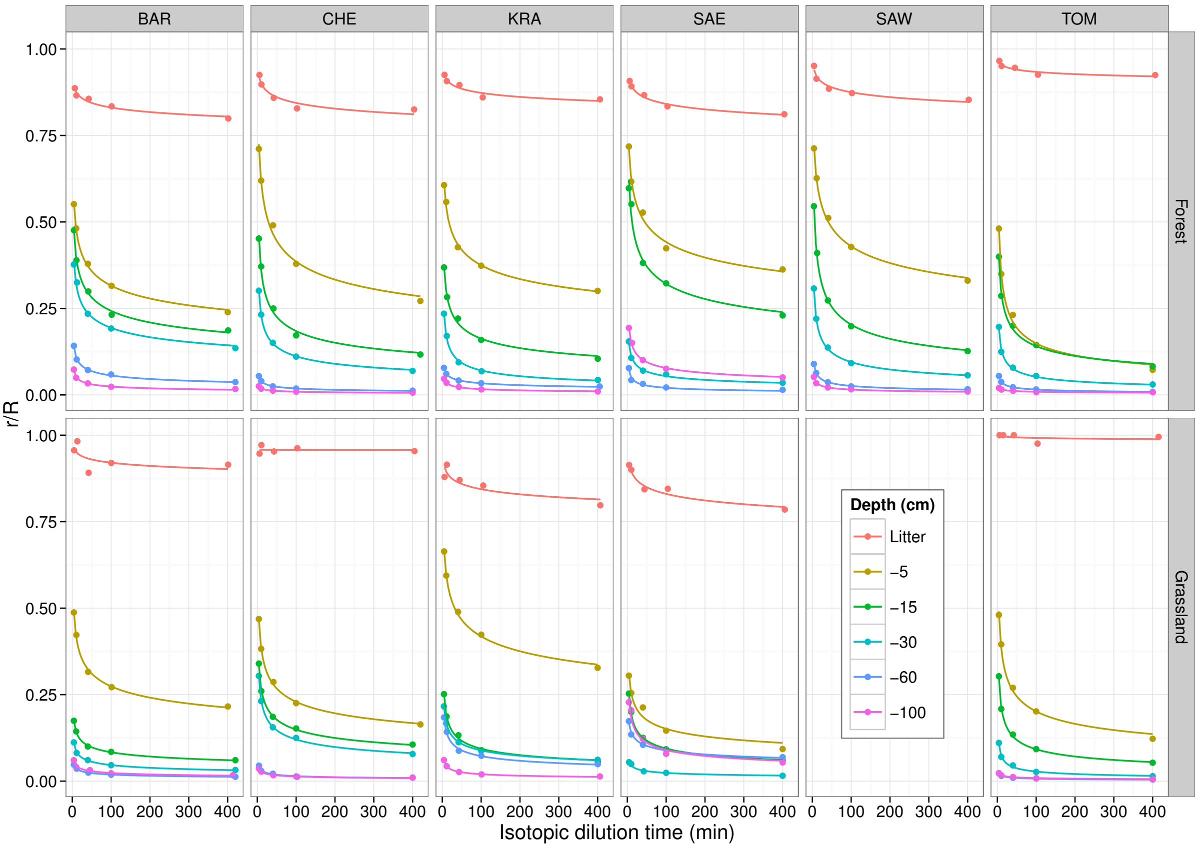

Figure S2: Fit of the model of $r(t)/R$ (Eq. 4). "Litter" means all the dead plant material deposited on the soil surface (senesced leaf litterfall, small branches and senesced understorey vegetation in forests; senesced herbaceous vegetation in grasslands) that is to say mainly OL and OF horizons, and eventually OH (at BAR, CHE, KRA and SAE) at the date of sampling.

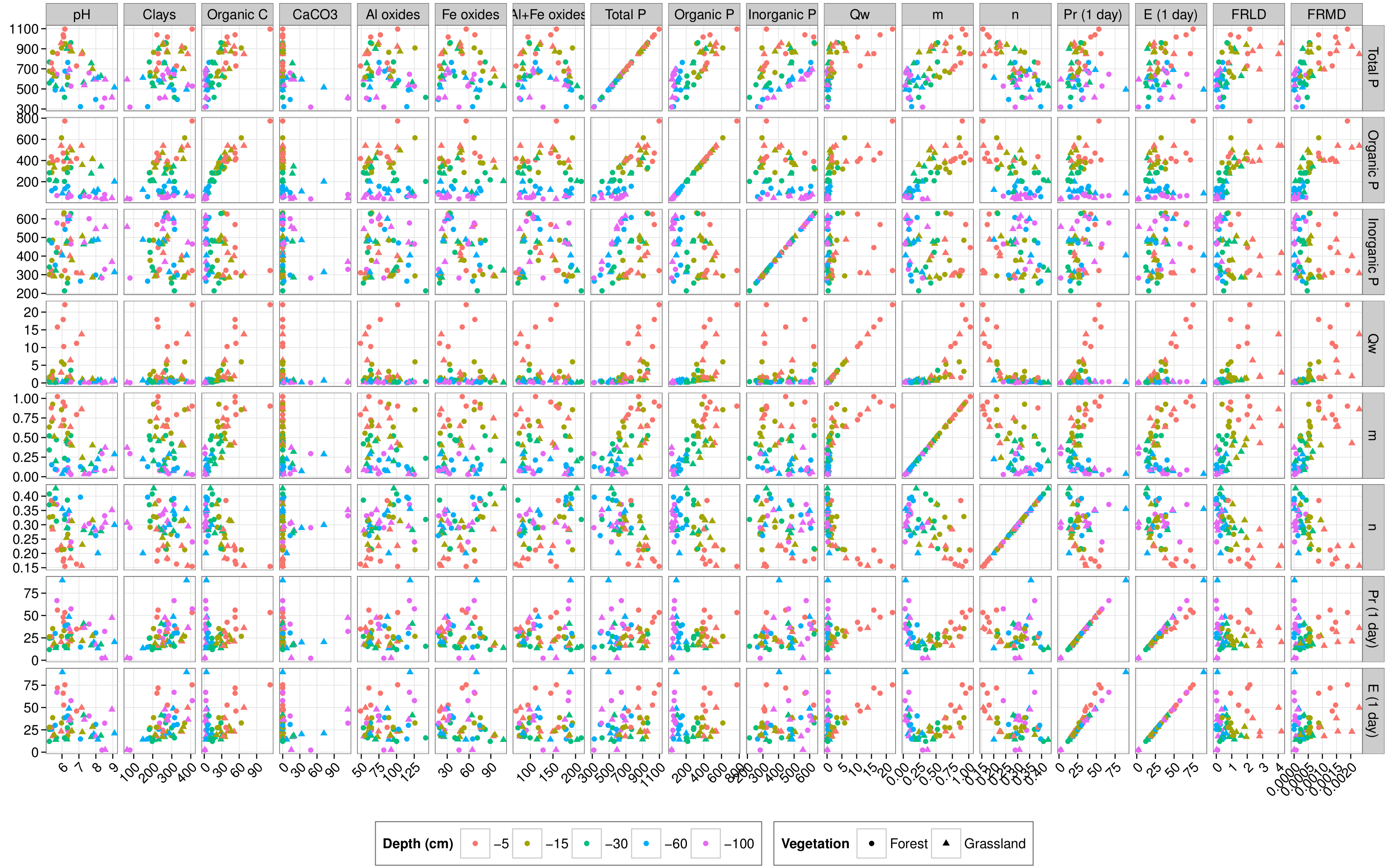

Figure S3: Matrix of scatter plots of P parameters against soil physico-chemical properties, other P parameters and fine root densities. *Qw*: phosphate ions in solution; *m* and *n* are the fitting parameters of Eq. 4; *Pr*: diffusive phosphate ions; *E*: isotopically exchangeable phosphate ions; FRLD: fine root length density; FRMD: fine root mass density.

Global data compilation—References

Abekoe, M. K. and Sahrawat, K. L. (2003). Long-term cropping effect on phosphorus fractions in an ultisol of the humid forest zone in West Africa. *Commun Soil Sci Plant Anal* 34, 427–437.

Achat, D. L., Bakker, M. R., Augusto, L., Derrien, D., Gallegos, N., Lashchinskiy, N., Milin, S., Nikitich, P., Raudina, T., Rusalimova, O., Zeller, B., and Barsukov, P. (2013). Phosphorus status of soils from contrasting forested ecosystems in southwestern Siberia: effects of microbiological and physicochemical properties. *Biogeosciences* 10, 733–752. DOI: 10.5194/bg-10-733-2013.

Achat, D. L., Pousse, N., Nicolas, M., Brédoire, F., and Augusto, L. (2016). Soil properties controlling inorganic phosphorus availability – Generic results from a national forest network and a global compilation of the literature. *In preparation.*

Achat, D. L., Augusto, L., Morel, C., and Bakker, M. R. (2011). Predicting available phosphate ions from physical–chemical soil properties in acidic sandy soils under pine forests. *J Soils Sediments* 11 (3), 452–466. DOI: 10.1007/s11368-010-0329-9.

Achat, D. L., Bakker, M. R., Augusto, L., Saur, E., Dousseron, L., and Morel, C. (2009). Evaluation of the phosphorus status of P-deficient podzols in temperate pine stands: combining isotopic dilution and extraction methods. *Biogeochemistry* 92 (3), 183–200. DOI: 10.1007/s10533-008-9283-7.

Achat, D. L., Daumer, M.-L., Sperandio, M., Santellani, A.-C., and Morel, C. (2014). Solubility and mobility of phosphorus recycled from dairy effluents and pig manures in incubated soils with different characteristics. *Nutri Cycl Agroecosyst* 99.1-3, 1–15. DOI: 10.1007/s10705-014-9614-0.

Agbenin, J. O. and Goladi, J. T. (1998). Dynamics of phosphorus fractions in a savanna Alfisol under continuous cultivation. *Soil Use and Management* 14, 59–64.

Agbenin, J. O. and Igbokwe, S. O. (2006). Effect of soil-dung manure incubation on the solubility and retention of applied phosphate by a weathered tropical semi-arid soil. *Geoderma* 133, 191–203. DOI: 10.1016/j.geoderma.2005.07.006.

Agbenin, J. O. and Tiessen, H. (1994). Phosphorus Transformations in a Toposequence of Lithosols and Cambisols from Semiarid Northeastern Brazil. *Geoderma* 62, 345–362. DOI: 10.1016/0016-7061(94)90098-1.

Aguiar, A. D. F., Candido, C. S., Carvalho, C. S., Monroe, P. H. M., and Moura, E. G. de (2013). Organic matter fraction and pools of phosphorus as indicators of the impact of land use in the Amazonian periphery. *Ecol Indic* 30, 158–164. DOI: 10.1016/j.ecolind.2013.02.010.

Almond, P. C. and Tonkin, P. J. (1999). Pedogenesis by upbuilding in an extreme leaching and weathering environment, and slow loess accretion, south Westland, New Zealand. *Geoderma* 92, 1–36. DOI: 10.1016/S0016-7061(99)00016-6.

Alt, F., Oelmann, Y., Herold, N., Schrumpf, M., and Wilcke, W. (2011). Phosphorus partitioning in grassland and forest soils of Germany as related to land-use type, management intensity, and land use-related pH. *J Plant Nutr Soil Sci* 174, 195–209. DOI: 10.1002/jpln.201000142.

Andersohn, C. (1996). Phosphate cycles in energy crop systems with emphasis on the availability of different phosphate fractions in the soil. *Plant Soil* 184, 11–21. DOI: 10.1007/Bf00029270.

Andriamaniraka, H., Rabeharisoa, L., Michellon, R., Moussa, N., and Morel, C. (2010). Influence de différents systèmes de culture sur la productivité de sols cultivés des Hautes Terres de Madagascar et conséquences pour le bilan de phosphore. *Étude et Gestion des Sols* 17.2, 119–130.

Aoki, M., Fujii, K., and Kitayama, K. (2012). Environmental Control of Root Exudation of Low-Molecular Weight Organic Acids in Tropical Rainforests. *Ecosystems* 15, 1194–1203. DOI: 10.1007/s10021-012-9575-6.

Aulakh, M. S., Kabba, B. S., Baddesha, H. S., Bahl, G. S., and Gill, M. P. S. (2003). Crop yields and phosphorus fertilizer transformations after 25 years of applications to a subtropical soil under groundnut-based cropping systems. *Field Crops Research* 83, 283–296.

Bah, A. R., Zaharah, A. R., Hussin, A., Husni, M. H., and Halimi, M. S. (2003). Phosphorus Status of Amended Soil as Assessed by Conventional and Isotopic Methods. *Commun Soil Sci Plant Anal* 34.17-18, 2659–2681. DOI: 10.1081/css-120024792.

Basamba, T. A., Barrios, E., Singh, B. R., and Rao, I. M. (2007). Impact of planted fallows and a crop rotation on nitrogen mineralization and phosphorus and organic matter fractions on a Colombian volcanic-ash soil. *Nutri Cycl Agroecosyst* 77, 127–141. DOI: 10.1007/s10705-006-9050-x.

Beck, M. A. and Elsenbeer, H. (1999). Biogeochemical cycles of soil phosphorus in southern Alpine spodosols. *Geoderma* 91, 249–260.

Beck, M. A. and Sanchez, P. A. (1996). Soil phosphorus movement and budget after 13 years of fertilized cultivation in the Amazon basin. *Plant Soil* 184, 23–31.

Blake, L., Johnston, A. E., Poulton, P. R., and Goulding, K. W. T. (2003). Changes in soil phosphorus fractions following positive and negative phosphorus balances for long periods. *Plant Soil* 254, 245–261. DOI: 10.1023/A:1025544817872.

Boldeskul, A. G. (2002). The forms of phosphorus compounds in brown soils of fir-broad-leaved forests of the southern Primor'e Region. *Eurasian Soil Sci* 35, 71–78.

Borda, T., Celi, L., Bünemann, E. K., Oberson, A., Frossard, E., and Barberis, E. (2014). Fertilization Strategies Affect Phosphorus Forms and Release from Soils and Suspended Solids. *Journal of Environment Quality* 43.3, 1024. DOI: 10.2134/jeq2013.11.0436.

Brandtberg, P. O., Davis, M. R., Clinton, P. W., Condron, L. M., and Allen, R. B. (2010). Forms of soil phosphorus affected by stand development of mountain beech (*Nothofagus*) forests in New Zealand. *Geoderma* 157, 228–234.

Bühler, S., Oberson, A., Rao, I. M., Friesen, D. K., and Frossard, E. (2002). Sequential Phosphorus Extraction of a P-Labeled Oxisol under Contrasting Agricultural Systems. *Soil Sci Soc Am J* 66.3, 868–877. DOI: 10.2136/sssaj2002.0868.

Bühler, S., Oberson, A., Sinaj, S., Friesen, D. K., and Frossard, E. (2003). Isotope methods for assessing plant available phosphorus in acid tropical soils. *Eur J Soil Sci* 54.3, 605–616. DOI: 10.1046/j.1365-2389.2003.00542.x.

Bünemann, E. K., Marschner, P., McNeill, A., and McLaughlin, M. (2007). Measuring rates of gross and net mineralisation of organic phosphorus in soils. *Soil Biol Biochem* 39.4, 900–913. DOI: 10.1016/j.soilbio.2006.10.009.

Bünemann, E. K., Steinebrunner, F., Smithson, P. C., Frossard, E., and Oberson, A. (2004). Phosphorus Dynamics in a Highly Weathered Soil as Revealed by Isotopic Labeling Techniques. *Soil Sci Soc Am J* 68.5, 1645–1655. DOI: 10.2136/sssaj2004.1645.

Bünemann, E., Oberson, A., Liebisch, F., Keller, F., Annaheim, K., Huguenin-Elie, O., and Frossard, E. (2012). Rapid microbial phosphorus immobilization dominates gross phosphorus fluxes in a grassland soil with low inorganic phosphorus availability. *Soil Biol Biochem* 51, 84–95. DOI: 10.1016/j.soilbio.2012.04.012.

Bünemann, E. K. (2003). Phosphorus dynamics in a ferralsol under maize-fallow rotations: The role of the soil microbial biomass. PhD thesis. ETH, Swiss Federal Institute of Technology.

Campbell, C. A., Schnitzer, M., Stewart, J. W. B., Biederbeck, V. O., and Selles, F. (1986). Effect of manure and P fertilizer on properties of a black chernozem in southern Saskatchewan. *Can J Soil Sci* 66, 601–613.

Cassagne, N., Remaury, M., Gauquelin, T., and Fabre, A. (2000). Forms and profile distribution of soil phosphorus in alpine Inceptisols and Spodosols (Pyrenees, France). *Geoderma* 95, 161–172.

Chacon, N. and Dezzeo, N. (2004). Phosphorus fractions and sorption processes in soil samples taken in a forest-savanna sequence of the Gran Sabana in southern Venezuela. *Biol Fertil Soils* 40, 14–19.

Chacon, N., Dezzeo, N., Munoz, B., and Rodriguez, J. M. (2005). Implications of soil organic carbon and the biogeochemistry of iron and aluminum on soil phosphorus distribution in flooded forests of the lower Orinoco River, Venezuela. *Biogeochemistry* 73, 555–566. DOI: 10.1007/s10533-004-1773-7.

Chapuis-Lardy, L., Ramiandrisoa, R. S., Randriamanantsoa, L., Morel, C., Rabeharisoa, L., and Blanchart, E. (2009). Modification of P availability by endogeic earthworms (Glossoscolecidae) in Ferralsols of the Malagasy Highlands. *Biol Fertil Soils* 45.4, 415–422. DOI: 10.1007/s00374-008-0350-y.

Chapuis-Lardy, L., Vanderhoeven, S., Dassonville, N., Koutika, L. S., and Meerts, P. (2006). Effect of the exotic invasive plant Solidago gigantea on soil phosphorus status. *Biol Fertil Soils* 42, 481–489. DOI: 10.1007/s00374-005-0039-4.

Chen, C. R., Condron, L. M., Davis, M. R., and Sherlock, R. R. (2003). Seasonal changes in soil phosphorus and associated microbial properties under adjacent grassland and forest in New Zealand. *For Ecol Manage* 177, 539–557.

Chen, C. R., Condron, L. M., Sinaj, S., Davis, M. R., Sherlock, R. R., and Frossard, E. (2003). Effects of plant species on phosphorus availability in a range of grassland soils. *Plant Soil* 256.1, 115–130. DOI: 10.1023/a:1026273529177.

Chen, C., Sinaj, S., Condron, L., Frossard, E., Sherlock, R., and Davis, M. (2003). Characterization of phosphorus availability in selected New Zealand grassland soils. *Nutri Cycl Agroecosyst* 65 (1), 89–100. DOI: 10.1023/A:1021889207109.

Chen, F. S., Li Xi, G. N., and Zhan, S. X. (2010). Topsoil phosphorus signature in five forest types along an urban-suburban-rural gradient in Nanchang, southern China. *Journal of Forestry Research* 21, 39–44.

Chimdi, A., Esala, M., and Ylivainio, K. (2014). Sequential Fractionation Patterns of Soil Phosphorus Collected from Different Land Use Systems of Dire Inchine District, West Shawa Zone, Ethiopia. *American-Eurasian Journal of Scientific Research* 9, 51–57.

Chiu, C. Y., Pai, C. W., and Yang, K. L. (2005). Characterization of phosphorus in sub-alpine forest and adjacent grassland soils by chemical extraction and phosphorus-31 nuclear magnetic resonance spectroscopy. *Pedobiologia* 49, 655–663. DOI: 10.1016/j.pedobi.2005.06.007.

Ciampitti, I. A., Picone, L. I., Rubio, G., and Garcia, F. O. (2011). Pathways of Phosphorous Fraction Dynamics in Field Crop Rotations of the Pampas of Argentina. *Soil Sci Soc Am J* 75, 918–926. DOI: 10.2136/sssaj2010.0361.

Cleveland, C. C., Townsend, A. R., Schmidt, S. K., and Constance, B. C. (2003). Soil microbial dynamics and biogeochemistry in tropical forests and pastures, southwestern Costa Rica. *Ecol Appl* 13, 314–326. DOI: 10.1890/1051-0761(2003)013[0314:Smdabi]2.0.Co;2.

Compaoré, E., Frossard, E., Sinaj, S., Fardeau, J.-C., and Morel, J.-L. (2003). Influence of Land-Use Management on Isotopically Exchangeable Phosphate in Soils from Burkina Faso. *Commun Soil Sci Plant Anal* 34.1-2, 201–223. DOI: 10.1081/css-120017426.

Compton, J. E. and Cole, D. W. (2001). Fate and effects of phosphorus additions in soils under N-2-fixing red alder. *Biogeochemistry* 53, 225–247. DOI: 10.1023/A:1010646709944.

Condron, L. M., Davis, M. R., Newman, R. H., and Cornforth, I. S. (1996). Influence of conifers on the forms of phosphorus in selected New Zealand grassland soils. *Biol Fertil Soils* 21, 37–42. DOI: 10.1007/Bf00335991.

Couto, R. D., Santos, M. dos, Comin, J. J., Martini, L. C. P., Gatiboni, L. C., Martins, S. R., Belli, P., and Brunetto, G. (2015). Environmental Vulnerability and Phosphorus Fractions of Areas with Pig Slurry Applied to the Soil. *J Environ Qual* 44, 162–173. DOI: 10.2134/jeq2014.08.0359.

Crews, T. E. (1996). The supply of phosphorus from native, inorganic phosphorus pools in continuously cultivated Mexican agroecosystems. *Agriculture Ecosystems and Environment* 57, 197–208.

Crews, T. E. and Brookes, P. C. (2014). Changes in soil phosphorus forms through time in perennial versus annual agroecosystems. *Agriculture Ecosystems and Environment* 184, 168–181. DOI: 10.1016/j.agee.2013.11.022.

Cross, A. F. and Schlesinger, W. H. (2001). Biological and geochemical controls on phosphorus fractions in semiarid soils. *Biogeochemistry* 52, 155–172. DOI: 10.1023/A:1006437504494.

De Schrijver, A., Vesterdal, L., Hansen, K., De Frenne, P., Augusto, L., Achat, D. L., Staelens, J., Baeten, L., De Keersmaeker, L., De Neve, S., and Verheyen, K. (2012). Four decades of post-agricultural forest development have caused major redistributions of soil phosphorus fractions. *Oecologia* 169, 221–234. DOI: 10.1007/s00442-011-2185-8.

Delgado, A. and Torrent, J. (1997). Phosphate-rich soils in the European Union: estimating total plant-available phosphorus. *European Journal of Agronomy* 6.3-4, 205–214. DOI: 10.1016/s1161-0301(96)02048-5.

Demaria, P. (2004). Factors controlling phosphate exchangeability and release in agricultural soils. PhD thesis. ETH, Swiss Federal Institute of Technology.

Demaria, P., Sinaj, S., Flisch, R., and Frossard, E. (2013). Soil Properties and Phosphorus Isotopic Exchangeability in Cropped Temperate Soils. *Commun Soil Sci Plant Anal* 44.1-4, 287–300. DOI: 10.1080/00103624.2013.741896.

Derry, D. D., Voroney, R. P., and Briceno, J. A. (2005). Long-term effects of short-fallow frijol tapado on soil phosphorus pools in Costa Rica. *Agriculture Ecosystems and Environment* 110, 91–103. DOI: 10.1016/j.agee.2005.05.006.

Diekmann, L. O. (2004). *Soil nutrient dynamics during shifting cultivation in Campeche, Mexico.* Tech. rep., p. 85.

Dieter, D., Elsenbeer, H., and Turner, B. L. (2010). Phosphorus fractionation in lowland tropical rainforest soils in central Panama. *Catena* 82, 118–125. DOI: 10.1016/j.catena.2010.05.010.

Dobermann, A., George, T., and Thevs, N. (2002). Phosphorus fertilizer effects on soil phosphorus pools in acid upland soils. *Soil Sci Soc Am J* 66, 652–660.

Dodd, R. J. (2013). Use less, Lose less: Obtaining and maintaining an environmentally and agronomically sustainable farming system with phosphorus. PhD thesis. Lincoln University.

Dormaar, J. F. and Willms, W. D. (2000). A comparison of soil chemical characteristics in modified rangeland communities. *J Range Manage* 53, 453–458. DOI: 10.2307/4003759.

Duffera, M. and Robarge, W. P. (1999). Soil characteristics and management effects on phosphorus sorption by highland plateau soils of Ethiopia. *Soil Sci Soc Am J* 63, 1455–1462.

Elpat'evskii, P. V. (1998). Stores and dynamics of available phosphorus in brown forest soils of southern primorye forests in the Far East. *Eurasian Soil Sci* 31, 54–60.

Esberg, C., Toit, B. du, Olsson, R., Ilstedt, U., and Giesler, R. (2010). Microbial responses to P addition in six South African forest soils. *Plant Soil* 329, 209–225. DOI: 10.1007/s11104-009-0146-3.

Fabre, A., Pinay, G., and Ruffinoni, C. (1996). Seasonal changes in inorganic and organic phosphorus in the soil of a riparian forest. *Biogeochemistry* 35, 419–432. DOI: 10.1007/Bf02183034.

Fan, J., Wang, J. Y., Hu, X. F., and Chen, F. S. (2014). Seasonal dynamics of soil nitrogen availability and phosphorus fractions under urban forest remnants of different vegetation communities in Southern China. *Urban For Urban Greening* 13, 576–585. DOI: 10.1016/j.ufug.2014.03.002.

Fardeau, J. C., Morel, C., and Jappe, J. (1985). Cinétique d'échange des ions phosphate dans les systèmes sol-solution. Vérification expérimentale de l'équation théorique. In: *C.R. Acad. Sci. Paris, t 300, série III 8*, 371–376.
Fardeau, J. (1993). Le phosphore biodisponible du sol. Un système pluricompartimental à structure mamellaire. *Agronomie* 1, 1–13.
Fardeau, J., Morel, C., and Boniface, R. (1991). Cinétiques de transfert des ions phosphate du sol vers la solution du sol : paramètres caractéristiques. *Agronomie* 11.9, 787–797. DOI: 10.1051/agro:19910909.
Finzi, A. C. (2009). Decades of atmospheric deposition have not resulted in widespread phosphorus limitation or saturation of tree demand for nitrogen in southern New England. *Biogeochemistry* 92, 217–229. DOI: 10.1007/s10533-009-9286-z.
Frizano, J., Johnson, A. H., Vann, D. R., and Scatena, F. N. (2002). Soil phosphorus fractionation during forest development on landslide scars in the Luquillo Mountains, Puerto Rico. *Biotropica* 34, 17–26.
Frizano, J., Vann, D. R., Johnson, A. H., Johnson, C. M., Vieira, I. C. G., and Zarin, D. J. (2003). Labile phosphorus in soils of forest fallows and primary forest in the Bragantina region, Brazil. *Biotropica* 35, 2–11.
Frossard, E., Bolomey, S., Flura, T., and Sinaj, S. (2005). Phosphore du sol et stratégie de fertilisation. Le cas du lac de Baldegg. In: *Documents environnement.* Vol. 206.
Frossard, E., López-Hernández, D., and Brossard, M. (1996). Can isotopic exchange kinetics give valuable information on the rate of mineralization of organic phosphorus in soils? *Soil Biol Biochem* 28.7, 857–864. DOI: 10.1016/0038-0717(96)00063-6.
Frossard, E., Morel, J. L., Fardeau, J. C., and Brossard, M. (1994). Soil Isotopically Exchangeable Phosphorus: A Comparison between E and L Values. *Soil Sci Soc Am J* 58.3, 846–851. DOI: 10.2136/sssaj1994.03615995005800030031x.
Frossard, E., Stewart, J. W. B., and St-Arnaud, R. J. (1989). Distribution and mobility of phosphorus in grassland and forest soils of Saskatchewan. *Can J Soil Sci* 69.2, 401–416. DOI: 10.4141/cjss89-040.
Frossard, E., Achat, D., Bernasconi, S., Bünemann, E., Fardeau, J.-C., Jansa, J., Morel, C., Rabeharisoa, L., Randriamanantsoa, L., Sinaj, S., Tamburini, F., and Oberson, A. (2011). The Use of Tracers to Investigate Phosphate Cycling in Soil–Plant Systems. In: *Phosphorus in Action.* Vol. 100, 59–91. DOI: 10.1007/978-3-642-15271-9_3.
Gabbasova, I. M., Sirayeva, E. Z., Kol'tsova, G. A., and Khakimova, G. A. (1993). Content and composition of organic phosphates in the soils of Bashkiria. *Eurasian Soil Sci* 25, 36–48.
Galang, M. A., Markewitz, D., and Morris, L. A. (2010). Soil phosphorus transformations under forest burning and laboratory heat treatments. *Geoderma* 155, 401–408. DOI: 10.1016/j.geoderma.2009.12.026.
Gallet, A., Flisch, R., Ryser, J.-P., Frossard, E., and Sinaj, S. (2003). Effect of phosphate fertilization on crop yield and soil phosphorus status. *J Plant Nutr Soil Sci* 166.5, 568–578. DOI: 10.1002/jpln.200321081.
Garcia-Montiel, D. C., Neill, C., Melillo, J., Thomas, S., Steudler, P. A., and Cerri, C. C. (2000). Soil phosphorus transformations following forest clearing for pasture in the Brazilian Amazon. *Soil Sci Soc Am J* 64, 1792–1804.
Gazizullin, A. K. and Sabirov, A. T. (1991). Iron oxides in major types of Forest soils of the Middle Volga Region. *Soviet Soil Science* 23, 84–102.
Giardina, C. P., Sanford, R. L., and Dockersmith, I. C. (2000). Changes in soil phosphorus and nitrogen during slash-and-burn clearing of a dry tropical forest. *Soil Sci Soc Am J* 64, 399–405.
Gichangi, E. M., Mnkeni, P. N. S., and Brookes, P. C. (2009). Effects of goat manure and inorganic phosphate addition on soil inorganic and microbial biomass phosphorus fractions under laboratory incubation conditions. *Soil Sci Plant Nutr* 55, 764–771. DOI: 10.1111/j.1747-0765.2009.00415.x.
Gleason, S. M., Read, J., Ares, A., and Metcalfe, D. J. (2009). Phosphorus economics of tropical rainforest species and stands across soil contrasts in Queensland, Australia: understanding the effects of soil specialization and trait plasticity. *Funct Ecol* 23, 1157–1166. DOI: 10.1111/j.1365-2435.2009.01575.x.
Gorbachev, V. N. and Popova, E. P. (1984). Characteristics of soil formation on loesslike loams in the southern taiga of central Siberia. *Soviet Soil Science* 16, 12–18.
Gressel, N., Mccoll, J. G., Preston, C. M., Newman, R. H., and Powers, R. F. (1996). Linkages between phosphorus transformations and carbon decomposition in a forest soil. *Biogeochemistry* 33, 97–123. DOI: 10.1007/Bf02181034.
Guardini, R., Comin, J. J., Schmitt, D. E., Tiecher, T., Bender, M. A., Santos, D. R. dos, Mezzari, C. P., Oliveira, B. S., Gatiboni, L. C., and Brunetto, G. (2012). Accumulation of phosphorus fractions in typic Hapludalf soil after long-term application of pig slurry and deep pig litter in a no-tillage system. *Nutri Cycl Agroecosyst* 93, 215–225. DOI: 10.1007/s10705-012-9511-3.
Gundale, M. J., Sutherland, S., and DeLuca, T. H. (2008). Fire, native species, and soil resource interactions influence the spatio-temporal invasion pattern of Bromus tectorum. *Ecography* 31, 201–210. DOI: 10.1111/j.0906-7590.2008.5303.x.

Haefele, S. M., Wopereis, M. C. S., Schloebohm, A. M., and Wiechmann, H. (2004). Long-term fertility experiments for irrigated rice in the West African Sahel: effect on soil characteristics. *Field Crops Research* 85, 61–77. DOI: 10.1016/S0378-4290(03)00153-9.

Hamon, R. E. and McLaughlin, M. J. (2002). Interferences in the determination of isotopically exchangeable P in soils and a method to minimise them. *Aust J Soil Res* 40.8, 1383–1397. DOI: 10.1071/sr02045.

Hartono, A., Funakawa, S., and Kosaki, T. (2006). Transformation of added phosphorus to acid upland soils with different soil properties in Indonesia. *Soil Sci Plant Nutr* 52, 734–744. DOI: 10.1111/j.1747-0765.2006.00087.x.

Hashimoto, Y. and Watanabe, Y. (2014). Combined applications of chemical fractionation, solution P-31-NMR and P K-edge XANES to determine phosphorus speciation in soils formed on serpentine landscapes. *Geoderma* 230, 143–150. DOI: 10.1016/j.geoderma.2014.04.001.

Heinrich, P. A. and Patrick, J. W. (1985). Phosphorus Acquisition in the Soil Root-System of Eucalyptus-Pilularis Sm Seedlings .1. Characteristics of the Soil System. *Aust J Soil Res* 23, 223–236. DOI: 10.1071/Sr9850223.

Hernández, G., Cuenca, G., and García, A. (2000). Behaviour of arbuscular-mycorrhizal fungi on Vigna luteola growth and its effect on the exchangeable (^{32}P) phosphorus of soil. *Biol Fertil Soils* 31.3-4, 232–236. DOI: 10.1007/s003740050650.

Hu, X. F., Chen, F. S., Nagle, G., Fang, Y. T., and Yu, M. Q. (2011). Soil phosphorus fractions and tree phosphorus resorption in pine forests along an urban-to-rural gradient in Nanchang, China. *Plant Soil* 346, 97–106. DOI: 10.1007/s11104-011-0799-6.

Ilstedt, U., Giesler, R., Nordgren, A., and Malmer, A. (2003). Changes in soil chemical and microbial properties after a wildfire in a tropical rainforest in Sabah, Malaysia. *Soil Biol Biochem* 35, 1071–1078. DOI: 10.1016/S0038-0717(03)00152-4.

Imai, N., Kitayama, K., and Titin, J. (2010). Distribution of phosphorus in an above-to-below-ground profile in a Bornean tropical rain forest. *J Trop Ecol* 26, 627–636. DOI: 10.1017/S0266467410000350.

Izquierdo, J. E., Houlton, B. Z., and Huysen, T. L. van (2013). Evidence for progressive phosphorus limitation over long-term ecosystem development: Examination of a biogeochemical paradigm. *Plant Soil* 367, 135–147. DOI: 10.1007/s11104-013-1683-3.

Keller, M., Oberson, A., Annaheim, K. E., Tamburini, F., Mader, P., Mayer, J., Frossard, E., and Bunemann, E. K. (2012). Phosphorus forms and enzymatic hydrolyzability of organic phosphorus in soils after 30 years of organic and conventional farming. *J Plant Nutr Soil Sci* 175, 385–393. DOI: 10.1002/jpln.201100177.

Khan, K. S. and Joergensen, R. G. (2012). Relationships between P fractions and the microbial biomass in soils under different land use management. *Geoderma* 173, 274–281. DOI: 10.1016/j.geoderma.2011.12.022.

Kitayama, K., Aiba, S. I., Takyu, M., Majalap, N., and Wagai, R. (2004). Soil phosphorus fractionation and phosphorus-use efficiency of a Bornean tropical montane rain forest during soil aging with podozolization. *Ecosystems* 7, 259–274. DOI: 10.1007/s10021-003-0229-6.

Kolahchi, Z. and Jalali, M. (2012). Speciation of Phosphorus in Phosphorus-Amended and Leached Calcareous Soils Using Chemical Fractionation. *Pol J Environ Stud* 21, 395–400.

Kolawole, G. O., Tijani-Eniola, H., and Tian, G. (2004). Phosphorus fractions in fallow systems of West Africa: Effect of residue management. *Plant Soil* 263, 113–120. DOI: 10.1023/B:Plso.0000047730.58844.B5.

Kristiansen, S. M., Amelung, W., and Zech, W. (2001). Phosphorus forms as affected by abandoned anthills (Formica polyctena Forster) in forest soils: sequential extraction and liquid-state P-31-NMR spectroscopy. *J Plant Nutr Soil Sci* 164, 49–55. DOI: 10.1002/1522-2624(200102)164:1<49::Aid-Jpln49>3.0.Co;2-X.

Krivonosova, G. M. and Basevich, T. V. (1980). Content and forms of organic phosphates in the soils of the steppe zone of the Ukraine [USSR]. *Soviet Soil Science* 12, 290–294.

Kuczak, C. N., Fernandes, E. C. M., Lehmann, J., Rondon, M. A., and Luizao, F. J. (2006). Inorganic and organic phosphorus pools in earthworm casts (Glossoscolecidae) and a Brazilian rainforest Oxisol. *Soil Biol Biochem* 38, 553–560. DOI: 10.1016/j.soilbio.2005.06.007.

Kunito, T., Tsunekawa, M., Yoshida, S., Park, H. D., Toda, H., Nagaoka, K., and Saeki, K. (2012). Soil Properties Affecting Phosphorus Forms and Phosphatase Activities in Japanese Forest Soils: Soil Microorganisms May Be Limited by Phosphorus. *Soil Sci* 177, 39–46. DOI: 10.1097/SS.0b013e3182378153.

Kvarnstrom, E., Morel, C., Fardeau, J.-C., Morel, J.-L., and Esa, S. (2000). Changes in the phosphorus availability of a chemically precipitated urban sewage sludge as a result of different dewatering processes. *Waste Manage Res* 18.3, 249–258. DOI: 10.1177/0734242x0001800306.

Lan, Z. M., Lin, X. J., Wang, F., Zhang, H., and Chen, C. R. (2012). Phosphorus availability and rice grain yield in a paddy soil in response to long-term fertilization. *Biol Fertil Soils* 48, 579–588. DOI: 10.1007/s00374-011-0650-5.

Lee, D., Han, X. G., and Jordan, C. F. (1990). Soil-Phosphorus Fractions, Aluminum, and Water-Retention as Affected by Microbial Activity in an Ultisol. *Plant Soil* 121, 125–136. DOI: 10.1007/Bf00013105.

Lehmann, J., Gunther, D., Mota, M. S. da, Almeida, M. P. de, Zech, W., and Kaiser, K. (2001). Inorganic and organic soil phosphorus and sulfur pools in an Amazonian multistrata agroforestry system. *Agrofor Syst* 53, 113–124. DOI: 10.1023/A:1013364201542.

Levy, E. T. and Schlesinger, W. H. (1999). A comparison of fractionation methods for forms of phosphorus in soils. *Biogeochemistry* 47, 25–38. DOI: 10.1023/A:1006105420235.

Li, L., Liang, X. Q., Ye, Y. S., Zhao, Y., Zhang, Y. X., Jin, Y., Yuan, J. L., and Chen, Y. X. (2015). Effects of repeated swine manure applications on legacy phosphorus and phosphomonoesterase activities in a paddy soil. *Biol Fertil Soils* 51, 167–181. DOI: 10.1007/s00374-014-0956-1.

Li, Y. F., Luo, A. C., Wei, X. H., and Yao, X. G. (2008). Changes in Phosphorus Fractions, pH, and Phosphatase Activity in Rhizosphere of Two Rice Genotypes. *Pedosphere* 18, 785–794. DOI: 10.1016/S1002-0160(08)60074-0.

Li, Y. Y., Yang, R., Gao, R., Wei, H. A., Chen, A. L., and Li, Y. (2015). Effects of long-term phosphorus fertilization and straw incorporation on phosphorus fractions in subtropical paddy soil. *Journal of Integrative Agriculture* 14, 365–373. DOI: 10.1016/S2095-3119(13)60684-X.

Liu, Q., Loganathan, P., Hedley, M. J., and Skinner, M. F. (2004). The mobilisation and fate of soil and rock phosphate in the rhizosphere of ectomycorrhizal Pinus radiata seedlings in an Allophanic soil. *Plant Soil* 264, 219–229. DOI: 10.1023/B:Plso.0000047758.77661.57.

Lopez-Hernandez, D., Brossard, M., and Frossard, E. (1998). P-Isotopic exchange values in relation to Po mineralisation in soils with very low P-sorbing capacities. *Soil Biol Biochem* 30.13, 1663–1670. DOI: 10.1016/s0038-0717(97)00255-1.

Magid, J. (1993). Vegetation Effects on Phosphorus Fractions in Set-Aside Soils. *Plant Soil* 149, 111–119. DOI: 10.1007/Bf00010768.

Makarov, M. I., Malysheva, T. I., Vladychenskii, A. S., and Zech, W. (2002). Phosphorus compounds in primitive soils on mantle loam under various phytocenoses. *Eurasian Soil Sci* 35, 924–933.

Makarov, M. I., Volkov, A. V., Malysheva, T. I., and Onipchenko, V. G. (2001). Phosphorus, nitrogen, and carbon in the soils of subalpine and alpine altitudinal belts of the Teberda Nature Reserve. *Eurasian Soil Sci* 34, 52–60.

Malik, M. A., Khan, K. S., Fayyaz-ul-Hassan, and Umair, A. (2014). Dynamics of Phosphorus Pools in Subtropical Alkaline Soils. *International Journal of Agriculture and Biology* 16, 293–299.

Markewitz, D., Figueiredo, R. D., Carvalho, C. J. R. de, and Davidson, E. A. (2012). Soil and tree response to P fertilization in a secondary tropical forest supported by an Oxisol. *Biol Fertil Soils* 48, 665–678. DOI: 10.1007/s00374-011-0659-9.

McGrath, D. A., Duryea, M. L., and Cropper, W. P. (2001). Soil phosphorus availability and fine root proliferation in Amazonian agroforests 6 years following forest conversion. *Agriculture Ecosystems and Environment* 83, 271–284. DOI: 10.1016/S0167-8809(00)00176-6.

McGroddy, M. E., Silver, W. L., Oliveira, R. C. de, Mello, W. Z. de, and Keller, M. (2008). Retention of phosphorus in highly weathered soils under a lowland Amazonian forest ecosystem. *Journal of Geophysical Research—Biogeosciences* 113. DOI: ArtnG0401210.1029/2008jg000756.

Mckenzie, R. H., Stewart, J. W. B., Dormaar, J. F., and Schaalje, G. B. (1992a). Long-term crop-rotation and fertilizer effects on phosphorus transformations .1. In a chernozemic Soil. *Can J Soil Sci* 72, 569–579.

Mckenzie, R. H., Stewart, J. W. B., Dormaar, J. F., and Schaalje, G. B. (1992b). Long-term crop-rotation and fertilizer effects on phosphorus transformations .2. In a luvisolic Soil. *Can J Soil Sci* 72, 581–589.

Meason, D. F., Idol, T. W., Friday, J. B., and Scowcroft, P. G. (2009). Effects of fertilisation on phosphorus pools in the volcanic soil of a managed tropical forest. *For Ecol Manage* 258, 2199–2206. DOI: 10.1016/j.foreco.2009.04.001.

Menzies, N. W., Skilton, J. A., and Guppy, C. N. (1999). Phosphorus storage on effluent irrigated land. *J Environ Qual* 28, 750–754.

Messiga, A. J., Ziadi, N., Plénet, D., Parent, L.-E., and Morel, C. (2010). Long-term changes in soil phosphorus status related to P budgets under maize monoculture and mineral P fertilization. *Soil Use and Management* 26.3, 354–364. DOI: 10.1111/j.1475-2743.2010.00287.x.

Messiga, A. J., Ziadi, N., Bélanger, G., and Morel, C. (2012). Process-based mass-balance modeling of soil phosphorus availability in a grassland fertilized with N and P. *Nutri Cycl Agroecosyst* 92.3, 273–287. DOI: 10.1007/s10705-012-9489-x.

Messiga, A. J., Ziadi, N., Mollier, A., Parent, L.-E., Schneider, A., and Morel, C. (2015). Process-based mass-balance modeling of soil phosphorus availability: Testing different scenarios in a long-term maize monoculture. *Geoderma* 243-244, 41–49. DOI: 10.1016/j.geoderma.2014.12.009.

Miller, A. J., Schuur, E. A. G., and Chadwick, O. A. (2001). Redox control of phosphorus pools in Hawaiian montane forest soils. *Geoderma* 102, 219–237. DOI: 10.1016/S0016-7061(01)00016-7.

Mirabello, M. J., Yavitt, J. B., Garcia, M., Harms, K. E., Turner, B. L., and Wright, S. J. (2013). Soil phosphorus responses to chronic nutrient fertilisation and seasonal drought in a humid lowland forest, Panama. *Soil Research* 51, 215–221. DOI: 10.1071/SR12188.

Morel, C. (2001). The effects of soil solution P and time on the transfer of P ions in soils from the IMPHOS European Network. In: *The effect of phosphate fertilizer management strategies on soil phosphorus status and crop yields in some European countries*, 103–102.

Morel, C., Cachot, C., Martinez, J., Peu, P., Elsass, F., Robert, M., and Fardeau, J. (2004). Évolution sur 12 ans de la solubilité, mobilité et lixiviation du phosphate dans un sol ayant massivement reçu du lisier. *Étude et Gestion des sols* 11.4.

Morel, C. and Hinsinger, P. (1999). Root-induced mmodification of the exchange of phosphate ion between soil solution and soil solid phase. *Plant Soil* 211.1, 103–110. DOI: 10.1023/a:1004485432261.

Morel, C., Tiessen, H., Moir, J. O., and Stewart, J. W. B. (1994). Phosphorus Transformations and Availability under Cropping and Fertilization Assessed by Isotopic Exchange. *Soil Sci Soc Am J* 58.5, 1439–1445. DOI: 10.2136/sssaj1994.03615995005800050023x.

Morel, C., Tunney, H., Plénet, D., and Pellerin, S. (2000). Transfer of Phosphate Ions between Soil and Solution: Perspectives in Soil Testing. *J Environ Qual* 29.1, 50–59. DOI: 10.2134/jeq2000.00472425002900010007x.

Mortala, N. A. (2013). *Comportamiento de las formas de fósforo en un Ultisol con diferentes manejos de implantación forestal.* Tech. rep., p. 116.

Neufeldt, H., Silva, J. E. da, Ayarza, M. A., and Zech, W. (2000). Land-use effects on phosphorus fractions in Cerrado oxisols. *Biol Fertil Soils* 31, 30–37. DOI: 10.1007/s003740050620.

Newbery, D. M., Alexander, I. J., and Rother, J. A. (1997). Phosphorus dynamics in a lowland African rain forest: The influence of ectomycorrhizal trees. *Ecol Monogr* 67, 367–409.

Nguyen, H., Schoenau, J. J., Van Rees, K., Nguyen, D., and Qian, R. (2001). Long-term nitrogen, phosphorus and potassium fertilization of cassava influences soil chemical properties in North Vietnam. *Can J Soil Sci* 81, 481–488.

Nikonov, V. V. (1979). Characteristics of soil formation in the northern taiga spruce biogeocenoses of the Kola peninsula. *Soviet Soil Science* 11, 501–511.

Oberson, A., Fardeau, J. C., Besson, J. M., and Sticher, H. (1993a). Soil phosphorus dynamics in cropping systems managed according to conventional and biological agricultural methods. *Biol Fertil Soils* 16.2, 111–117. DOI: 10.1007/bf00369411.

Oberson, A., Fardeau, J. C., Besson, J. M., and Sticher, H. (1993b). Soil-Phosphorus Dynamics in Cropping Systems Managed According to Conventional and Biological Agricultural Methods. *Biol Fertil Soils* 16, 111–117. DOI: 10.1007/Bf00369411.

Oberson, A., Friesen, D., Tiessen, H., Morel, C., and Stahel, W. (1999). Phosphorus status and cycling in native savanna and improved pastures on an acid low-P Colombian Oxisol. *Nutri Cycl Agroecosyst* 55.1, 77–88. DOI: 10.1023/a:1009813008445.

Oehl, F. (1999). Microbially mediated phosphorus transformation processes in cultivated soils. PhD thesis. ETH, Swiss Federal Institute of Technology.

Oehl, F., Frossard, E., Fliessbach, A., Dubois, D., and Oberson, A. (2004). Basal organic phosphorus mineralization in soils under different farming systems. *Soil Biol Biochem* 36.4, 667–675. DOI: 10.1016/j.soilbio.2003.12.010.

Ohalloran, I. P., Stewart, J. W. B., and Dejong, E. (1987). Changes in P-Forms and Availability as Influenced by Management-Practices. *Plant Soil* 100, 113–126. DOI: 10.1007/Bf02370935.

Otabbong, E., Persson, J., Iakimenko, O., and Sadovnikova, L. (1997). The Ultuna long-term soil organic matter experiment .2. Phosphorus status and distribution in soils. *Plant Soil* 195, 17–23. DOI: 10.1023/A:1004276732679.

Owusu-Bennoah, E. and Acquaye, D. K. (1996). Greenhouse evaluation of agronomic potential of different sources of phosphate fertilizer in a typical concretionary soil of northern Ghana. *Fertil Res* 44, 101–106.

Paniagua, A., Mazzarino, M. J., Kass, D., Szott, L., and Fernandez, C. (1995). Soil-Phosphorus Fractions under 5 Tropical Agroecosystems on a Volcanic Soil. *Aust J Soil Res* 33, 311–320. DOI: 10.1071/Sr9950311.

Pare, D. and Bernier, B. (1989). Origin of the Phosphorus Deficiency Observed in Declining Sugar Maple Stands in the Quebec Appalachians. *Can J For Res* 19, 24–34. DOI: 10.1139/X89-004.

Patzold, S., Hejcman, M., Barej, J., and Schellberg, J. (2013). Soil phosphorus fractions after seven decades of fertilizer application in the Rengen Grassland Experiment. *J Plant Nutr Soil Sci* 176, 910–920. DOI: 10.1002/jpln.201300152.

Pavinato, P. S., Merlin, A., and Rosolem, C. A. (2009). Phosphorus fractions in Brazilian Cerrado soils as affected by tillage. *Soil Tillage Res* 105, 149–155. DOI: 10.1016/j.still.2009.07.001.

Perroni, Y., Garcia-Oliva, F., Tapia-Torres, Y., and Souza, V. (2014). Relationship between soil P fractions and microbial biomass in an oligotrophic grassland-desert scrub system. *Ecol Res* 29, 463–472. DOI: 10.1007/s11284-014-1138-1.

Pinochet, D., Epple, G., and MacDonald, R. (2001). Organic and inorganic phosphorus fractions in a soil transect of volcanic and metamorphic origin. *R.C. Suelo Nutr. Veg.* 1, 58–69.

Pizzeghello, D., Berti, A., Nardi, S., and Morari, F. (2011). Phosphorus forms and P-sorption properties in three alkaline soils after long-term mineral and manure applications in north-eastern Italy. *Agriculture Ecosystems and Environment* 141.1-2, 58–66. DOI: 10.1016/j.agee.2011.02.011.

Quesada, C. A., Lloyd, J., Schwarz, M., Patino, S., Baker, T. R., Czimczik, C., Fyllas, N. M., Martinelli, L., Nardoto, G. B., Schmerler, J., Santos, A. J. B., Hodnett, M. G., Herrera, R., Luizao, F. J., Arneth, A., Lloyd, G., Dezzeo, N., Hilke, I., Kuhlmann, I., Raessler, M., Brand, W. A., Geilmann, H., Moraes, J. O., Carvalho, F. P., Araujo, R. N., Chaves, J. E., Cruz, O. F., Pimentel, T. P., and Paiva, R. (2010). Variations in chemical and physical properties of Amazon forest soils in relation to their genesis. *Biogeosciences* 7, 1515–1541. DOI: 10.5194/bg-7-1515-2010.

Quintero, C. E., Gutierrez-Boem, F. H., Befani, M. R., and Boschetti, N. G. (2007). Effects of soil flooding on P transformations in soils of the Mesopotamia region, Argentina. *J Plant Nutr Soil Sci* 170, 500–505. DOI: 10.1002/jpln.200625015.

Rabeharisoa, R. (2004). Gestion de la fertilité et de la fertilisation phosphatée des sols ferrallitiques des hautes terres de Madagascar. PhD thesis. Université d'Antanarivo.

Randriamanantsoa, L., Frossard, E., Oberson, A., and Bünemann, E. K. (2015). Gross organic phosphorus mineralization rates can be assessed in a Ferralsol using an isotopic dilution method. *Geoderma* 257-258, 86–93. DOI: 10.1016/j.geoderma.2015.01.003.

Randriamanantsoa, L., Morel, C., Rabeharisoa, L., Douzet, J.-M., Jansa, J., and Frossard, E. (2013). Can the isotopic exchange kinetic method be used in soils with a very low water extractable phosphate content and a high sorbing capacity for phosphate ions? *Geoderma* 200-201, 120–129. DOI: 10.1016/j.geoderma.2013.01.019.

Reddy, D. D., Rao, S. A., and Singh, M. (2005). Changes in P fractions and sorption in an Alfisol following crop residues application. *J Plant Nutr Soil Sci* 168, 241–247. DOI: 10.1002/jpln.200421444.

Reddy, K. S., Rao, A. S., and Takkar, P. N. (1996). Transformation of fertilizer P in a Vertisol amended with farmyard manure. *Biol Fertil Soils* 22, 279–282. DOI: 10.1007/s003740050111.

Redel, Y. D., Rubio, R., Rouanet, J. L., and Borie, F. (2007). Phosphorus bioavailability affected by tillage and crop rotation on a Chilean volcanic derived Ultisol. *Geoderma* 139, 388–396. DOI: 10.1016/j.geoderma.2007.02.018.

Redel, Y., Rubio, R., Godoy, R., and Borie, F. (2008). Phosphorus fractions and phosphatase activity in an Andisol under different forest ecosystems. *Geoderma* 145, 216–221. DOI: 10.1016/j.geoderma.2008.03.007.

Richter, D. D., Allen, H. L., Li, J. W., Markewitz, D., and Raikes, J. (2006). Bioavailability of slowly cycling soil phosphorus: major restructuring of soil P fractions over four decades in an aggrading forest. *Oecologia* 150, 259–271. DOI: 10.1007/s00442-006-0510-4.

Roberts, T. L., Stewart, J. W. B., and Bettany, J. R. (1985). The Influence of Topography on the Distribution of Organic and Inorganic Soil-Phosphorus across a Narrow Environmental Gradient. *Can J Soil Sci* 65, 651–665.

Rose, T. J., Hardiputra, B., and Rengel, Z. (2010). Wheat, canola and grain legume access to soil phosphorus fractions differs in soils with contrasting phosphorus dynamics. *Plant Soil* 326, 159–170. DOI: 10.1007/s11104-009-9990-4.

Rubio, G., Faggioli, V., Scheiner, J. D., and Gutierrez-Boem, F. H. (2012). Rhizosphere phosphorus depletion by three crops differing in their phosphorus critical levels. *J Plant Nutr Soil Sci* 175. DOI: 10.1002/jpln.201200307.

Ruckamp, D., Amelung, W., Theisz, N., Bandeira, A. G., and Martius, C. (2010). Phosphorus forms in Brazilian termite nests and soils: Relevance of feeding guild and ecosystems. *Geoderma* 155, 269–279. DOI: 10.1016/j.geoderma.2009.12.010.

Saa, A., Trasar-Cepeda, M. C., and Carballas, T. (1998). Soil P status and phosphomonoesterase activity of recently burnt and unburnt soil following laboratory incubation. *Soil Biol Biochem* 30, 419–428. DOI: 10.1016/S0038-0717(97)00120-X.

Salcedo, I. H., Bertino, F., and Sampaio, E. V. S. B. (1991). Reactivity of Phosphorus in Northeastern Brazilian Soils Assessed by Isotopic Dilution. *Soil Sci Soc Am J* 55.1, 140–145. DOI: 10.2136/sssaj1991.03615995005500010025x.

Saltali, K., Kilic, K., and Kocyigit, R. (2007). Changes in sequentially extracted phosphorus fractions in adjacent arable and grassland ecosystems. *Arid Land Research and Management* 21, 81–89. DOI: 10.1080/15324980601074602.

Sattell, R. R. and Morris, R. A. (1992). Phosphorus Fractions and Availability in Sri-Lankan Alfisols. *Soil Sci Soc Am J* 56, 1510–1515.

Satti, P., Mazzarino, M. J., Roselli, L., and Crego, P. (2007). Factors affecting soil P dynamics in temperate volcanic soils of southern Argentina. *Geoderma* 139, 229–240. DOI: 10.1016/j.geoderma.2007.02.005.

Scharer, M. (2003). The influence of processes controlling phosphorus availability on phosphorus losses in grassland soils. PhD thesis. ETH, Swiss Federal Institute of Technology.

Schoenau, J. J., Stewart, J. W. B., and Bettany, J. R. (1989). Forms and Cycling of Phosphorus in Prairie and Boreal Forest Soils. *Biogeochemistry* 8, 223–237.

Scott, D. A. and Bliss, C. M. (2012). Phosphorus Fertilizer Rate, Soil P Availability, and Long-Term Growth Response in a Loblolly Pine Plantation on a Weathered Ultisol. *Forests* 3, 1071–1085. DOI: 10.3390/f3041071.

Scott, J. T. and Condron, L. M. (2003). Dynamics and availability of phosphorus in the rhizosphere of a temperate silvopastoral system. *Biol Fertil Soils* 39, 65–73. DOI: 10.1007/s00374-003-0678-2.

Sharpley, A. N., Jones, C. A., Gray, C., Cole, C. V., Tiessen, H., and Holzhey, C. S. (1985). *A detailed phosphorus characterization of seventy-eight soils.* Tech. rep., p. 30.

Sharpley, A. N., McDowell, R. W., and Kleinman, P. J. A. (2004). Amounts, forms, and solubility of phosphorus in soils receiving manure. *Soil Sci Soc Am J* 68, 2048–2057.

Sheklabadi, M., Mahmoudzadeh, H., Mahboubi, A. A., Gharabaghi, B., and Ahrens, B. (2014). Land use effects on phosphorus sequestration in soil aggregates in western Iran. *Environ Monit Assess* 186, 6493–6503. DOI: 10.1007/s10661-014-3869-4.

Shiels, A. B. and Sanford, R. L. (2001). Soil nutrient differences between two krummholz-form tree species and adjacent alpine tundra. *Geoderma* 102, 205–217. DOI: 10.1016/S0016-7061(01)00015-5.

Sinaj, S., Frossard, E., and Fardeau, J. C. (1997). Isotopically Exchangeable Phosphate in Size Fractionated and Unfractionated Soils. *Soil Sci Soc Am J* 61.5, 1413–1417. DOI: 10.2136/sssaj1997.03615995006100050019x.

Singh, M., Reddy, K. S., Singh, V. P., and Rupa, T. R. (2007). Phosphorus availability to rice (Oriza sativa L.)-wheat (Triticum estivum L.) in a Vertisol after eight years of inorganic and organic fertilizer additions. *Bioresour Technol* 98, 1474–1481. DOI: 10.1016/j.biortech.2006.02.045.

Slazak, A., Freese, D., Matos, E. D., and Huttl, R. F. (2010). Soil organic phosphorus fraction in pine-oak forest stands in Northeastern Germany. *Geoderma* 158, 156–162. DOI: 10.1016/j.geoderma.2010.04.023.

Soinne, H., Raty, M., and Hartikainen, H. (2010). Effect of air-drying on phosphorus fractions in clay soil. *J Plant Nutr Soil Sci* 173, 332–336. DOI: 10.1002/jpln.200900225.

Solomon, D. and Lehmann, J. (2000). Loss of phosphorus from soil in semi-arid northern Tanzania as a result of cropping: evidence from sequential extraction and ^{31}P-NMR spectroscopy. *Eur J Soil Sci* 51, 699–708.

Solomon, D., Lehmann, J., Mamo, T., Fritzsche, F., and Zech, W. (2002). Phosphorus forms and dynamics as influenced by land use changes in the sub-humid Ethiopian highlands. *Geoderma* 105, 21–48.

Spears, J. D. H., Lajtha, K., Caldwell, B. A., Pennington, S. B., and Vanderbilt, K. (2001). Species effects of Ceanothus velutinus versus Pseudotsuga menziesii, Douglas-fir, on soil phosphorus and nitrogen properties in the Oregon cascades. *For Ecol Manage* 149, 205–216. DOI: 10.1016/S0378-1127(00)00555-7.

Spohn, M., Ermak, A., and Kuzyakov, Y. (2013). Microbial gross organic phosphorus mineralization can be stimulated by root exudates — A 33P isotopic dilution study. *Soil Biol Biochem* 65, 254–263. DOI: 10.1016/j.soilbio.2013.05.028.

Stroia, C., Morel, C., and Jouany, C. (2007). Dynamics of diffusive soil phosphorus in two grassland experiments determined both in field and laboratory conditions. *Agriculture Ecosystems and Environment* 119.1-2, 60–74. DOI: 10.1016/j.agee.2006.06.007.

Su, J., Wang, H., Kimberley, M. O., Beecroft, K., Magesan, G. N., and Hu, C. (2007). Fractionation and mobility of phosphorus in a sandy forest soil amended with biosolids. *Environ Sci Pollut Res* 14, 529–535. DOI: 10.1065/espr2007.08.443.

Suarez, E. R., Pelletier, D. M., Fahey, T. J., Groffman, P. M., Bohlen, P. J., and Fisk, M. C. (2003). Effects of exotic earthworms on soil phosphorus cycling in two broadleaf temperate forests. *Ecosystems* 7, 28–44. DOI: 10.1007/s10021-003-0128-x.

Sugihara, S., Funakawa, S., Nishigaki, T., Kilasara, M., and Kosaki, T. (2012). Dynamics of fractionated P and P budget in soil under different land management in two Tanzanian croplands with contrasting soil textures. *Agriculture Ecosystems and Environment* 162, 101–107. DOI: 10.1016/j.agee.2012.07.019.

Sugihara, S., Shibata, M., Mvondo Ze, A. D., Araki, S., and Funakawa, S. (2014). Effect of vegetation on soil C, N, P and other minerals in Oxisols at the forest-savanna transition zone of central Africa. *Soil Sci Plant Nutr* 60, 45–59. DOI: 10.1080/00380768.2013.866523.

Sui, Y. B., Thompson, M. L., and Shang, C. (1999). Fractionation of phosphorus in a mollisol amended with biosolids. *Soil Sci Soc Am J* 63, 1174–1180.

Sun, H. Y., Wu, Y. H., Yu, D., and Zhou, J. (2013). Altitudinal Gradient of Microbial Biomass Phosphorus and Its Relationship with Microbial Biomass Carbon, Nitrogen, and Rhizosphere Soil Phosphorus on the Eastern Slope of Gongga Mountain, SW China. *PLoS ONE* 8. DOI: ARTNe7295210.1371/journal.pone.0072952.

Svetlova, Y. I. and Gradusov, B. P. (1985). Mineral and chemical composition of soils from the southern taiga subzone of the Ural region. *Soviet Soil Science* 17, 97–102.

Takeda, M., Nakamoto, T., Miyazawa, K., and Murayama, T. (2009). Phosphorus transformation in a soybean-cropping system in Andosol: effects of winter cover cropping and compost application. *Nutri Cycl Agroecosyst* 85, 287–297. DOI: 10.1007/s10705-009-9267-6.

Taranto, M. T., Adams, M. A., and Polglase, P. J. (2000). Sequential fractionation and characterisation (P-31-NMR) of phosphorus-amended soils in Banksia integrifolia (L.f.) woodland and adjacent pasture. *Soil Biol Biochem* 32, 169–177. DOI: 10.1016/S0038-0717(99)00138-8.

Tchienkoua and Zech, W. (2003). Chemical and spectral characterization of soil phosphorus under three land uses from an Andic Palehumult in West Cameroon. *Agriculture Ecosystems and Environment* 100, 193–200. DOI: 10.1016/S0167-8809(03)00195-6.

Thomas, S. M., Johnson, A. H., Frizano, J., Vann, D. R., Zarin, D. J., and Joshi, A. (1999). Phosphorus fractions in montane forest soils of the Cordillera de Piuchue, Chile: biogeochemical implications. *Plant Soil* 211, 139–148. DOI: 10.1023/A:1004686213319.

Tiessen, H., Abekoe, M. K., Salcedo, I. H., and Owusu-Bennoah, E. (1993). Reversibility of phosphorus sorption by ferruginous nodules. *Plant Soil* 153.1, 113–124. DOI: 10.1007/bf00010550.

Tiessen, H., Salcedo, I. H., and Sampaio, E. V. S. B. (1992). Nutrient and Soil Organic-Matter Dynamics under Shifting Cultivation in Semiarid Northeastern Brazil. *Agriculture Ecosystems and Environment* 38, 139–151. DOI: 10.1016/0167-8809(92)90139-3.

Tolchelnikov, Y. and Gurov, A. (1985). Seasonal dynamics of iron aluminum and silicon compounds in sandy soils of southern taiga in the european USSR. *Soviet Soil Science* 17, 32–48.

Townsend, A. R., Asner, G. P., Cleveland, C. C., Lefer, M. E., and Bustamante, M. M. C. (2002). Unexpected changes in soil phosphorus dynamics along pasture chronosequences in the humid tropics. *Journal of Geophysical Research—Atmospheres* 107. DOI: Artn806710.1029/2001jd000650.

Tran, T. S., Giroux, M., and Fardeau, J. C. (1988). Effects of Soil Properties on Plant-Available Phosphorus Determined by the Isotopic Dilution Phosphorus-32 Method. *Soil Sci Soc Am J* 52.5, 1383–1390. DOI: 10.2136/sssaj1988.03615995005200050033x.

Trasar-Cepeda, M. C., Gilsotres, F., and Guitianojea, F. (1990). Relation between Phosphorus Fractions and Development of Soils from Galicia (Nw Spain). *Geoderma* 47, 139–150. DOI: 10.1016/0016-7061(90)90051-A.

Turan, M., Ataoglu, N., and Sahin, F. (2007). Effects of Bacillus FS-3 on growth of tomato (Lycopersicon esculentum L.) plants and availability of phosphorus in soil. *Plant Soil and Environment* 53, 58–64.

Turrion, M. B., Glaser, B., Solomon, D., Ni, A., and Zech, W. (2000). Effects of deforestation on phosphorus pools in mountain soils of the Alay Range, Khyrgyzia. *Biol Fertil Soils* 31, 134–142. DOI: 10.1007/s003740050636.

Ubugunov, L. L., Ubugunova, V. I., and Mangataev, T. D. (1998). Phosphate reserves of the most typical alluvial soils of the Selenga river basin. *Eurasian Soil Sci* 31, 61–66.

Valdespino, P., Romualdo, R., Cadenazzi, L., and Campo, J. (2009). Phosphorus cycling in primary and secondary seasonally dry tropical forests in Mexico. *Ann For Sci* 66. DOI: Artn10710.1051/Forest:2008075.

Vaychis, M. V. (1988). Specific characteristics of Brown Forest soil formation on ancient alluvium. *Soviet Soil Science* 20, 50–56.

Verma, S., Subehia, S. K., and Sharma, S. P. (2005). Phosphorus fractions in an acid soil continuously fertilized with mineral and organic fertilizers. *Biol Fertil Soils* 41, 295–300. DOI: 10.1007/s00374-004-0810-y.

Vinegla, B., Garcia-Ruiz, R., Lietor, J., Ochoa, V., and Carreira, J. A. (2006). Soil phosphorus availability and transformation rates in relictic pinsapo fir forests from southern Spain. *Biogeochemistry* 78, 151–172. DOI: 10.1007/s10533-005-3698-1.

Vu, D. T., Tang, C., and Armstrong, R. D. (2008). Changes and availability of P fractions following 65 years of P application to a calcareous soil in a Mediterranean climate. *Plant Soil* 304, 21–33. DOI: 10.1007/s11104-007-9516-x.

Wagar, B. I., Stewart, J. W. B., and Moir, J. O. (1986). Changes with Time in the Form and Availability of Residual Fertilizer Phosphorus on Chernozemic Soils. *Can J Soil Sci* 66, 105–119.

Wang, G. P., Liu, J. S., Wang, J. D., and Yu, J. B. (2006). Soil phosphorus forms and their variations in depressional and riparian freshwater wetlands (Sanjiang Plain, Northeast China). *Geoderma* 132, 59–74. DOI: 10.1016/j.geoderma.2005.04.021.

Wang, X., Lester, D. W., Guppy, C. N., Lockwood, P. V., and Tang, C. (2007). Changes in phosphorus fractions at various soil depths following long-term P fertiliser application on a black vertosol from south-eastern Queensland. *Aust J Soil Res* 45, 524–532. DOI: 10.1071/SR07069.

Weiss, L., Shiels, A. B., and Walker, L. R. (2005). Soil impacts of bristlecone pine (Pinus longaeva) tree islands on alpine tundra, Charleston Peak, Nevada. *Western North American Naturalist* 65, 536–540.

Wright, R. B., Lockaby, B. G., and Walbridge, M. R. (2001). Phosphorus availability in an artificially flooded southeastern floodplain forest soil. *Soil Sci Soc Am J* 65, 1293–1302.

Xavier, F. A. D., Almeida, E. F., Cardoso, I. M., and Mendonca, E. D. (2011). Soil phosphorus distribution in sequentially extracted fractions in tropical coffee-agroecosystems in the Atlantic Forest biome, Southeastern Brazil. *Nutri Cycl Agroecosyst* 89, 31–44. doi: 10.1007/s10705-010-9373-5.

Xu, G., Sun, J. N., Xu, R. F., Lv, Y. C., Shao, H. B., Yan, K., Zhang, L. H., and Blackwell, M. S. A. (2011). Effects of air-drying and freezing on phosphorus fractions in soils with different organic matter contents. *Plant Soil and Environment* 57, 228–234.

Xue, Q. Y., Shamsi, I. H., Sun, D. S., Ostermann, A., Zhang, Q. C., Zhang, Y. S., and Lin, X. Y. (2013). Impact of manure application on forms and quantities of phosphorus in a Chinese Cambisol under different land use. *J Soils Sediments* 13, 837–845. doi: 10.1007/s11368-012-0627-5.

Yavitt, J. B., Harms, K. E., Garcia, M. N., Mirabello, M. J., and Wright, S. J. (2011). Soil fertility and fine root dynamics in response to 4 years of nutrient (N, P, K) fertilization in a lowland tropical moist forest, Panama. *Austral Ecol* 36, 433–445. doi: 10.1111/j.1442-9993.2010.02157.x.

Zhang, J., Li, M., Liu, S., Liu, Y. J., Zhang, L. Q., Cao, Q., and Sun, D. Z. (2011). Seasonal variations and bioavailability of inorganic phosphorus in soils of Yeyahu Wetland in Beijing, China. *International Journal of Sediment Research* 26, 181–192.

Zhang, L., Wu, Y., Wu, N., Luo, P., Liu, L., and Hu, H. Y. (2011). Impacts of Vegetation Type on Soil Phosphorus Availability and Fractions near the Alpine Timberline of the Tibetan Plateau. *Pol J Ecol* 59, 307–316.

Zhang, Q., Wang, G. H., Feng, Y. K., Sun, Q. Z., Witt, C., and Dobermann, A. (2006). Changes in soil phosphorus fractions in a calcareous paddy soil under intensive rice cropping. *Plant Soil* 288, 141–154. doi: 10.1007/s11104-006-9100-9.

Zhang, T. Q., MacKenzie, A. F., Liang, B. C., and Drury, C. F. (2004). Soil test phosphorus and phosphorus fractions with long-term phosphorus addition and depletion. *Soil Sci Soc Am J* 68, 519–528.

Zheng, Z. M., MacLeod, J. A., and Lafond, J. (2004). Phosphorus status of a Humic Cryaquept profile in a frigid continental climate as influenced by cropping practices. *Biol Fertil Soils* 39, 467–473. doi: 10.1007/s00374-004-0735-5.

Zohar, I., Shaviv, A., Young, M., Kendall, C., Silva, S., and Paytan, A. (2010). Phosphorus dynamics in soils irrigated with reclaimed waste water or fresh water - A study using oxygen isotopic composition of phosphate. *Geoderma* 159, 109–121. doi: 10.1016/j.geoderma.2010.07.002.

Zubillaga, M. S. and Giuffre, L. (1999). Soil phosphorus mobilization in different taxonomic orders. *J Plant Nutr Soil Sci* 162, 201–205. doi: 10.1002/(Sici)1522-2624(199903)162:2<201::Aid-Jpln201>3.0.Co;2-9.