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Supplement of

Phosphorus dynamics during early soil development in a cold desert: insights from oxygen isotopes in phosphate

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Supporting Information

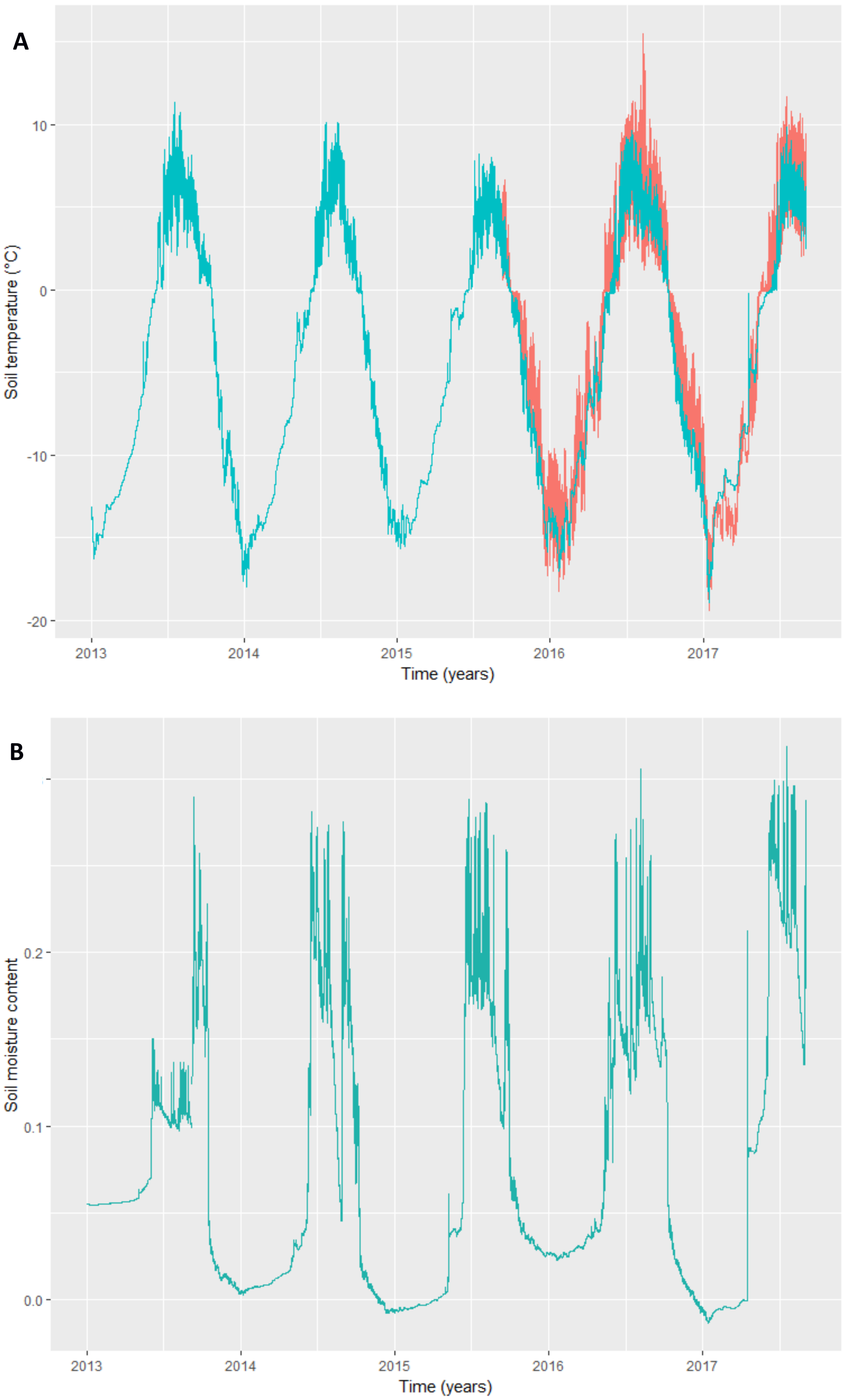
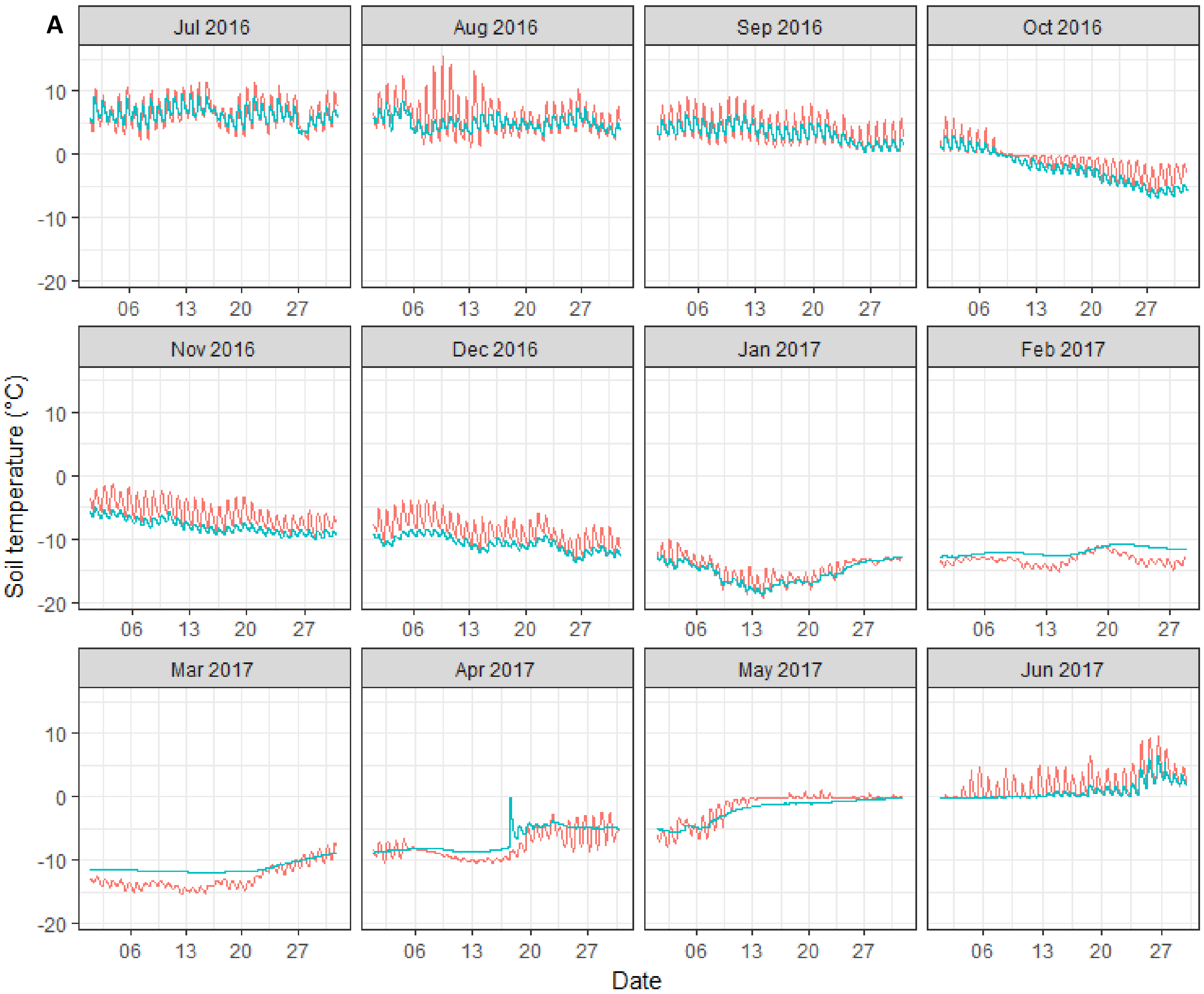


Figure S1: Long-term A: soil temperature data and B: volumetric soil moisture content in cm^3 cm^{-3} (5 cm below surface) á 15 mins. Both data loggers were situated in the base camp, 5700 m.a.s.l. in a lawn, or in a lawn covered with rock debris, for red and blue line respectively, ca 500-700m from the sampling site. B: Long-term data on the volumetric soil moisture content in cm^3 cm^{-3} (5 cm below surface).

Figure S2: Sampling sites on the northern slope of Chamser Kangri peak (6645 m). Site M1/W1 and M2 with no vegetation cover; M2 and M3 with weakly or well-developed SBC, respectively; M3 sparingly inhabited by *Thylacospermum caespitosum* (20-50% surface cover); M4 with well-developed SBC and vegetation cover with *Poa attenuata and Thylacospermum* (70-80% surface cover).


A
Jul 2016
Aug 2016
Sep 2016
Oct 2016
Nov 2016
Dec 2016
Jan 2017
Feb 2017
Mar 2017
Apr 2017
May 2017
Jun 2017
10
0
-10
-20
06
13
20
27
Soil temperature (°C)
Date

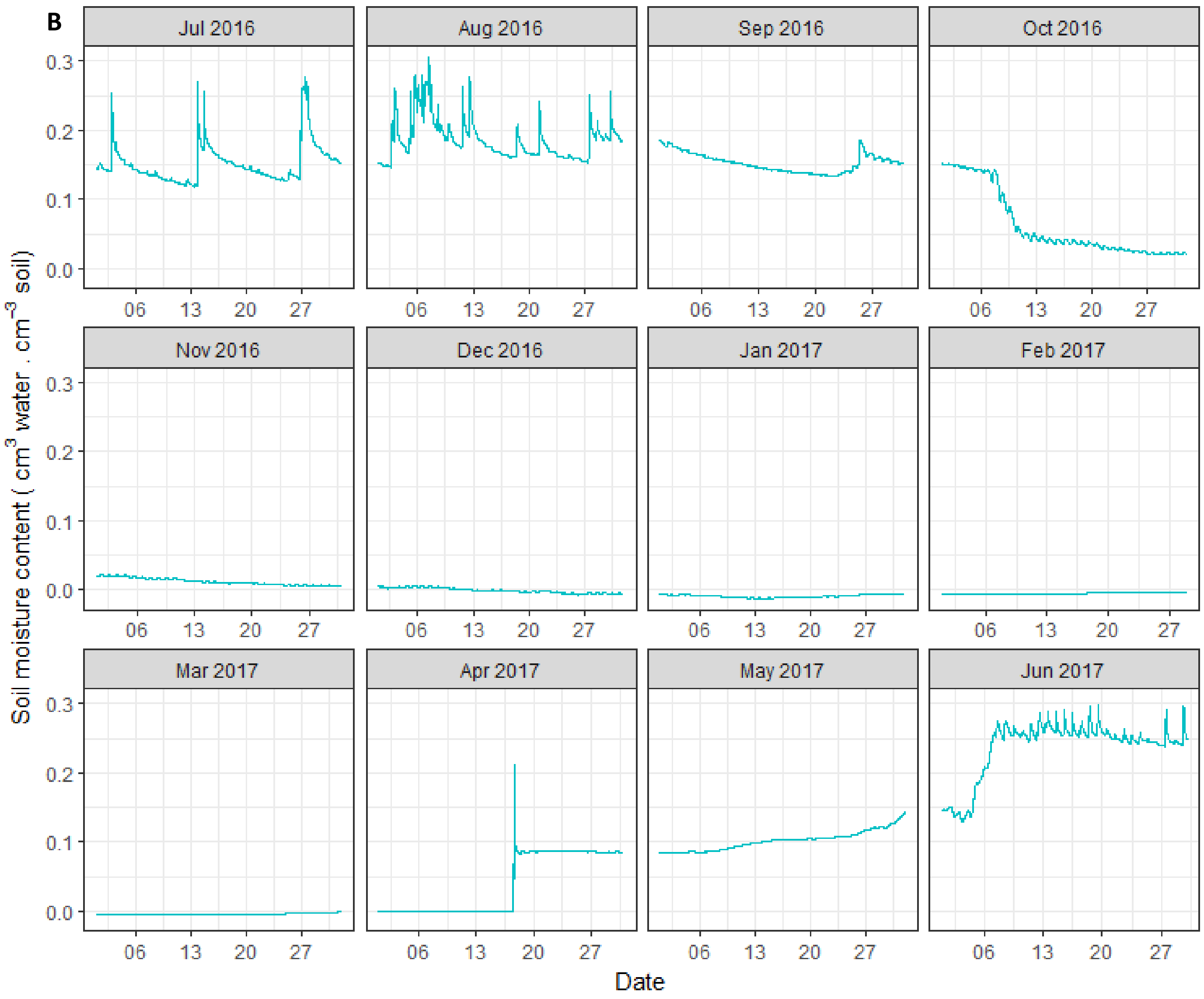


Figure S3: Monthly variation in soil temperature (A) and volumetric soil moisture content (B) 5 cm below surface. Data loggers were situated in the base camp, 5700 m.a.s.l., in a lawn, or in a lawn covered with rock debris, for red and blue line respectively, ca 500-700m from the sampling site.

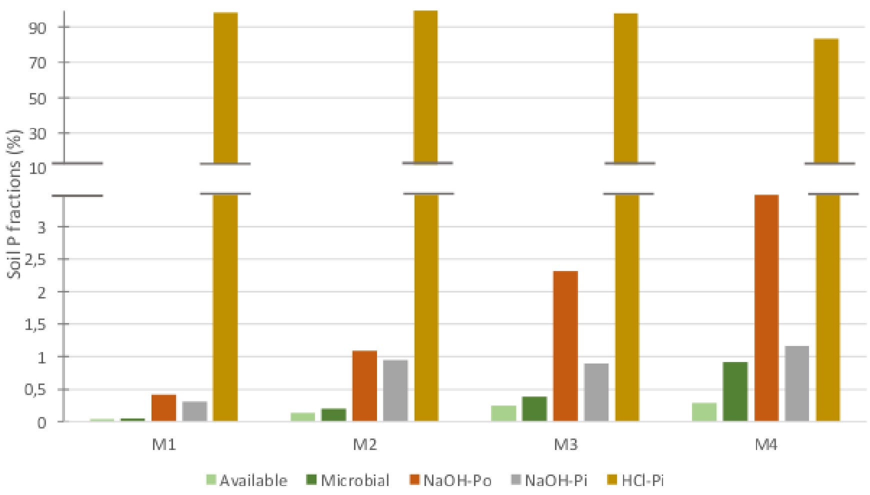


Figure S4: Percentage of P pools in percentage of total P.

Discussion of water isotopes results

Water isotopes. Regular diurnal precipitation in the form of snow, followed by melting in the morning hours suggest precipitation as the main factor determining the $\delta^{18}O_W$ in soil water at the older sites (M2-M4) with variable $\delta^{18}O_W$ enrichment by evaporation (Sprenger *et al.* 2017).

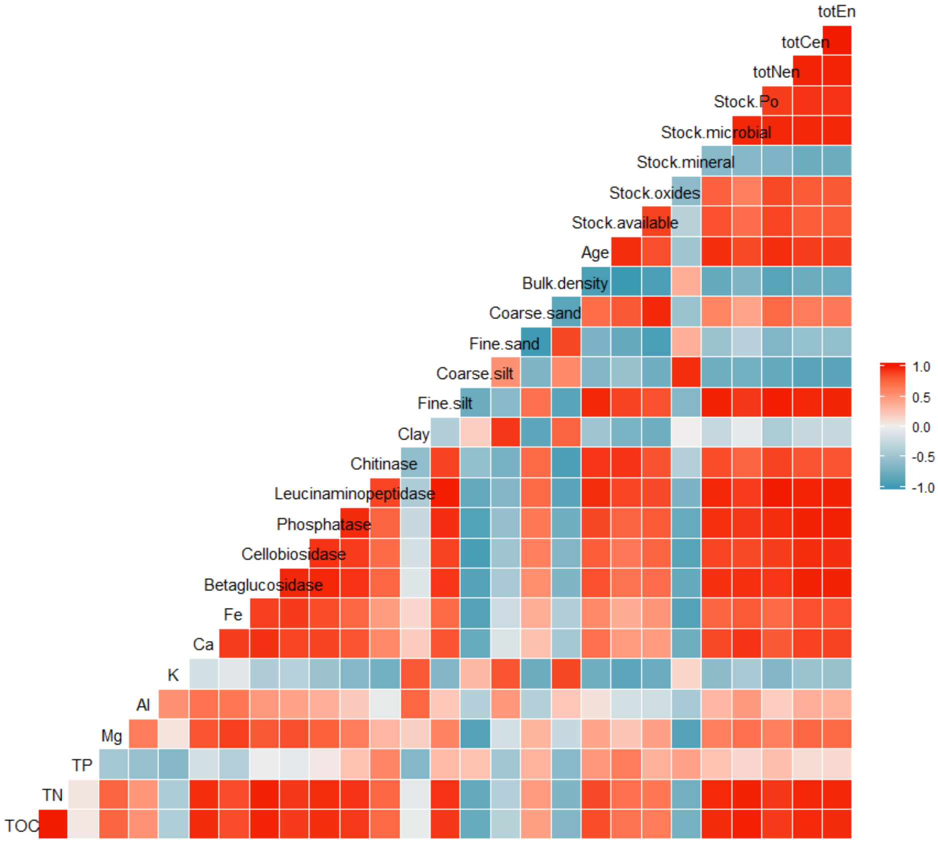
The observed enrichment by heavy isotopes of water in the stream ($\delta^{18}O_W$ = -12.4‰, δ^2H_W = -94.3‰) may be explained by a mixing of glacier melt ($\delta^{18}O_W$: -15.8‰, δ^2H_W: -116.3‰) with a melting snowpack, the latter having a higher stable water isotope ratio of -11.4‰ for $\delta^{18}O_W$ and -68‰ for δ^2H_W than the glacier melt. This is in agreement with previously reported data for cold arid regions of the Western Himalaya (Jeelani *et al.* 2017). The $\delta^{18}O_W$ values of the soil water at four forefield sites were highly variable. The lighter isotopic value for M1 can be explained by soil saturation with a mixed glacier and snowpack melt indicating a short residence time of the sampled water in the topsoil (young water). Accordingly, this value is also very close to the value we measured in the glacier stream water. In contrary, the isotopic enrichment of the older soils (M2-M4) may be attributed to a longer residence time of the soil water (old water) and to evaporative enrichment. This explanation is corroborated by the fluctuation of soil moisture during and previously the week of sampling (Figure S3).

Table S1: Individual sequentially extracted P-fractions in particular soils, average values (n=3) in mg P kg^{-1} of dry soil weight (top 0-5 cm).

Locality	**Available**	**Microbial**	**NaOH-Pi**	**NaOH-Po**	**HCl-P**	**Total P**
	mg P kg^{-1} of soil dry weight					
M1	0.3	0.4	2.3	0.4	726.6	**740.2**
M2	1.0	1.4	6.8	0.6	716.6	**720.5**
M3	2.3	3.6	8.3	6.1	909.7	**930.1**
M4	2.2	7.1	9.0	19.2	643.3	**770.7**

Table S2: Pearson correlation, p-values (empty cells = no significance), and visualization of the positive and negative correlation in a heatmap

p-values																												
	TOC	TN	TP	Mg	Al	K	Ca	Fe	Betaglucos	Cellobiosic	Phosphata	Leucinamino	Chitinase	Clay	Fine silt	Coarse silt	Fine sand	Coarse sar	Bulk densit	Age	Stock avail	Stock oxide	Stock mine	Stock micro	Stock Po	totNen	totCen	totEn
TOC		0.8775	0.0048	0.0806	0.2113	< 2.2e-16	0.0003	< 2.2e-16	< 2.2e-16	< 2.2e-16		< 2.2e-16	0.0063	0.9153	< 2.2e-16	0.0014	0.2784	0.1458	0.0206	0.0004	0.014	0.026	0.0077	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16
TN	< 2.2e-16		0.0045	0.0961	0.1879	< 2.2e-16	0.0003	< 2.2e-16	< 2.2e-16	< 2.2e-16		< 2.2e-16	0.0052	0.8406	< 2.2e-16	0.001	0.2326	0.1158	0.0159	0.0003	0.0111	0.0186	0.0059	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16
TP	0.8775	0.8589		0.0696	0.0246	0.6099	0.2346	0.9481	0.8333	0.8943		0.4221	0.0482	0.0229	0.3393	0.4279	0.118	0.273	0.0351	0.1061	0.0256	0.2544	0.1528	0.426	0.6702	0.3813	0.7294	0.7117
Mg	0.0048	0.0045	0.1362		0.8272	0.0009	< 2.2e-16	0.0013	0.0005	0.0035		0.0249	0.2993	0.5782	0.0395	< 2.2e-16	0.5973	0.2847	0.4365	0.1736	0.4685	0.149	< 2.2e-16	0.0324	0.0127	0.0298	0.0057	0.0062
Al	0.0806	0.0961	0.0696	0.0251		0.0129	0.0169	0.1115	0.1576	0.2503		0.505	0.8763	0.0054	0.4794	0.2474	0.1009	0.2401	0.4772	0.8173	0.5781	0.5271	0.1562	0.31	0.1126	0.5364	0.2483	0.2664
K	0.2113	0.1879	0.0246	0.8272	0.0741		0.8079	0.2061	0.2597	0.0948		0.0243	0.0061	0.0015	0.0217	0.3318	0.0011	0.0035	0.0002	0.0043	0.0003	0.0023	0.6417	0.043	0.1658	0.0214	0.0865	0.0783
Ca	< 2.2e-16	< 2.2e-16	0.6099	0.0009	0.0129	0.6033		< 2.2e-16	0.0001	< 2.2e-16		0.0012	0.052	0.5351	0.0011	0.002	0.6856	0.41	0.1437	0.0112	0.1135	0.1311	0.0038	0.0002	< 2.2e-16	0.0015	< 2.2e-16	< 2.2e-16
Fe	0.0003	0.0003	0.2346	< 2.2e-16	0.0169	0.8079	< 2.2e-16		< 2.2e-16	0.0004		0.0052	0.128	0.6659	0.0072	< 2.2e-16	0.4975	0.2351	0.2213	0.0509	0.2219	0.0887	< 2.2e-16	0.0047	0.0017	0.0065	0.0006	0.0007
Betaglucosi	< 2.2e-16	< 2.2e-16	0.9481	0.0013	0.1115	0.2061	< 2.2e-16	< 2.2e-16		< 2.2e-16		< 2.2e-16	0.0054	0.7474	< 2.2e-16	< 2.2e-16	0.164	0.0664	0.0164	0.0006	0.0139	0.0095	0.0012	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16
Cellobiosida	< 2.2e-16	< 2.2e-16	0.8333	0.0005	0.1576	0.2597	0.0001	< 2.2e-16	< 2.2e-16			< 2.2e-16	0.0077	0.6113	< 2.2e-16	< 2.2e-16	0.1002	0.031	0.0201	0.0023	0.0214	0.0046	0.0001	0.0001	0.0002	< 2.2e-16	< 2.2e-16	< 2.2e-16
Phosphatas	< 2.2e-16	< 2.2e-16	0.8943	0.0035	0.2503	0.0948	< 2.2e-16	0.0004	< 2.2e-16	< 2.2e-16		< 2.2e-16	0.0045	0.4508	< 2.2e-16	< 2.2e-16	0.0647	0.0211	0.0047	0.0002	0.0045	0.0019	0.0016	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16
Leucinamin	< 2.2e-16	< 2.2e-16	0.4221	0.0249	0.505	0.0243	0.0012	0.0052	< 2.2e-16	< 2.2e-16	< 2.2e-16		0.2031	< 2.2e-16	0.0009	0.0202	0.0071	0.0002	< 2.2e-16		0.0002	0.0003	0.0121	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16
Chitinase	0.0063	0.0052	0.0482	0.2993	0.8763	0.0061	0.052	0.128	0.0054	0.0077	0.0045	0.0002		< 2.2e-16	0.0625	0.0088	0.0082	< 2.2e-16	< 2.2e-16		< 2.2e-16	0.0009	0.232	0.0004	0.0041	< 2.2e-16	0.001	0.001
Clay	0.9153	0.8406	0.0229	0.5782	0.0054	0.0015	0.5351	0.6659	0.7474	0.6113	0.4508	0.2031	0.0496		0.5622	< 2.2e-16	0.0004	0.0041	0.0995		0.0097	0.004	0.9716	0.4141	0.8599	0.1857	0.4423	0.4161
Fine silt	< 2.2e-16	< 2.2e-16	0.3393	0.0395	0.4794	0.0217	0.0011	0.0072	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	0.2273		0.0285	0.0124	0.0002	< 2.2e-16		< 2.2e-16	0.0006	0.0227	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16
Coarse silt	0.0014	0.001	0.4279	< 2.2e-16	0.2474	0.3318	0.002	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	0.0009	0.0625	0.5622	0.0025		0.0174	0.0566	0.0223		0.0757	0.0047	< 2.2e-16	0.004	0.0052	0.0013	0.0002	0.0002
Fine sand	0.2784	0.2326	0.118	0.5973	0.1009	0.0011	0.6856	0.4975	0.164	0.1002	0.0647	0.0202	0.0088	< 2.2e-16	0.0285	0.0779		0.0002	0.0137		0.001	< 2.2e-16	0.2488	0.0828	0.2836	0.0181	0.0671	0.0602
Coarse sanc	0.1458	0.1158	0.273	0.2847	0.2401	0.0035	0.41	0.2351	0.0664	0.031	0.0211	0.0071	0.0082	0.0004	0.0124	0.0174	< 2.2e-16		0.0093		0.0013	< 2.2e-16	0.084	0.0426	0.1647	0.0066	0.0245	0.0215
Bulk density	0.0206	0.0159	0.0351	0.4365	0.4772	0.0002	0.1437	0.2213	0.0164	0.0201	0.0047	0.0002	< 2.2e-16	0.0041	0.0002	0.0566	0.0002	0.0003			< 2.2e-16	< 2.2e-16	0.2331	0.0012	0.016	0.0001	0.0029	0.0024
Age	0.0004	0.0003	0.1061	0.1736	0.8173	0.0043	0.0112	0.0509	0.0006	0.0023	0.0002	< 2.2e-16	< 2.2e-16	0.0995	< 2.2e-16	0.0223	0.0137	0.0093	< 2.2e-16		< 2.2e-16	0.0005	0.1116	< 2.2e-16	0.0002	< 2.2e-16	< 2.2e-16	< 2.2e-16
Stock availa	0.014	0.0111	0.0256	0.4685	0.5781	0.0003	0.1135	0.2219	0.0139	0.0214	0.0045	0.0002	< 2.2e-16	0.0097	< 2.2e-16	0.0757	0.001	0.0013	< 2.2e-16	< 2.2e-16		0.2824	0.0006	0.0096	0.0001	0.0024	0.002	
Stock oxides	0.026	0.0186	0.2544	0.149	0.5271	0.0023	0.1311	0.0887	0.0095	0.0046	0.0019	0.0003	0.0009	0.004	0.0006	0.0047	< 2.2e-16	< 2.2e-16	< 2.2e-16	0.0005	< 2.2e-16		0.0039	0.0305	0.0002	0.0019	0.0016	
Stock miner	0.0077	0.0059	0.1528	< 2.2e-16	0.1562	0.6417	0.0038	< 2.2e-16	0.0012	0.0001	0.0016	0.0121	0.232	0.9716	0.0227	< 2.2e-16	0.2488	0.084	0.2331	0.1116	0.2824	0.0406		0.0262	0.015	0.0033	0.0035	
Stock microl	< 2.2e-16	< 2.2e-16	0.426	0.0324	0.31	0.043	0.0002	0.0047	< 2.2e-16	0.0001	< 2.2e-16	< 2.2e-16	0.0004	0.4141	< 2.2e-16	0.004	0.0828	0.0426	0.0012	< 2.2e-16	0.0006	0.0039	0.0288		< 2.2e-16	< 2.2e-16	< 2.2e-16	
Stock Po	< 2.2e-16	< 2.2e-16	0.6702	0.0127	0.1126	0.1658	< 2.2e-16	0.0017	< 2.2e-16	0.0002	< 2.2e-16	< 2.2e-16	0.0041	0.8599	< 2.2e-16	0.0052	0.2836	0.1647	0.016	0.0002	0.0096	0.0305	0.0262	< 2.2e-16		< 2.2e-16	< 2.2e-16	
totNen	< 2.2e-16	< 2.2e-16	0.3813	0.0298	0.5364	0.0214	0.0015	0.0065	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	0.1857	< 2.2e-16	0.0013	0.0181	0.0066	0.0001	< 2.2e-16	0.0001	0.0002	0.015	< 2.2e-16	< 2.2e-16		< 2.2e-16	
totCen	< 2.2e-16	< 2.2e-16	0.7294	0.0057	0.2483	0.0865	< 2.2e-16	0.0006	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	0.001	0.4423	< 2.2e-16	0.0002	0.0671	0.0245	0.0029	< 2.2e-16	0.0024	0.0019	0.0033	< 2.2e-16	< 2.2e-16	< 2.2e-16		
totEn	< 2.2e-16	< 2.2e-16	0.7117	0.0062	0.2664	0.0783	< 2.2e-16	0.0007	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	0.001	0.4161	< 2.2e-16	0.0002	0.0602	0.0215	0.0024	< 2.2e-16	0.002	0.0016	0.0035	< 2.2e-16	< 2.2e-16	< 2.2e-16	< 2.2e-16	


totEn
totCen
totNen
Stock.Po
Stock.microbial
Stock.mineral
Stock.oxides
Stock.available
Age
Bulk.density
Coarse.sand
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Fine.silt
Clay
Chitinase
Leucinaminopeptidase
Phosphatase
Cellobiosidase
Betaglucosidase
Fe
Ca
K
Al
Mg
TP
TN
TOC
1.0
0.5
0.0
-0.5
-1.0

Table S3: Fe pools in sites M1 to M3 characterized by sequential extraction (Claff et al., 2010); nd = not detected

Site	replicate	Soluble Fe salts ($MgCl_2$-extractable)	Carbonates and poorly ordered oxides (1M HCl-extractable)	Fe bound to readily available organic compounds ($PyroPO_4$-extractable)	Crystalline iron oxides (CBD-extractable)	Pyrite (conc HNO_3-extractable)
			Fe mg/g DS			
M1	1	nd	1.17	0.39	0.73	0.39
M1	2	nd	1.20	0.39	0.79	0.35
M1	3	nd	1.08	0.36	0.67	0.36
M2	1	nd	1.57	0.51	1.20	0.49
M2	2	nd	1.58	0.48	1.09	0.66
M2	3	nd	1.49	0.66	1.06	0.58
M3	1	nd	1.47	0.53	1.03	0.63
M3	2	nd	1.41	0.40	0.82	0.57
M3	3	nd	1.43	0.38	0.74	0.67

Table S4: Variation of $\delta^{18}O_{Pexpected}$ in the box model per unit variation of $\delta^{18}O$ of microbial P

	% variation of $\delta^{18}O_{Pexpected}$	
site	**M1**	**M2**
increase	15	8
decrease	-16	-8