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Soil Research

Supplementary Material

Amending soils of different pH to decrease phosphorus losses

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Table S1. Mean soil pH in each soil with different types and rates of amendment applied. Differences in means were identified using Tukey's Honestly Significant Different (HSD) post hoc test. Amendment type and rate combinations within the same soil and the same letter are not significantly different ($P < 0.05$) from one another.

Amendment	Rate	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	Soil 6	Soil 7
control		5.2 f	5.1 f	6.0 f	6.9 d	6.2 e	6.8 c	6.4 e
Lime	0.5 Ca: 1 P	5.7 e	5.7 d	6.5 c	7.3 a	6.8 b	7.2 a	6.8 b
	1 Ca: 1 P	6.3 b	6.3 b	6.9 b	7.3 a	7.1 a	7.2 a	7.2 a
	5 Ca: 3 P	6.7 a	6.8 a	7.1 a	7.3 a	7.2 a	7.2 a	7.2 a
Gypsum	0.5 Ca: 1 P	4.8 g	4.9 g	5.8 g	6.6 e	5.9 fg	6.5 d	6.0 f
	1 Ca: 1 P	4.7 gh	4.8 g	5.7 g	6.5 e	5.9 fg	6.5 d	6.0 f
	5 Ca: 3 P	4.7 gh	4.8 g	5.7 g	6.5 e	5.9 f	6.5 d	6.0 f
Hydrotalcite	0.25 Al: 1 P	5.7 e	5.6 e	6.1 ef	6.9 cd	6.3 e	6.9 b	6.6 d
	0.5 Al: 1 P	5.8 d	5.7 d	6.1 e	7.0 bc	6.3 d	7.0 b	6.6 d
	1 Al: 1 P	6.0 c	5.9 c	6.2 d	7.0 b	6.5 c	7.0 b	6.7 c
Alum	0.25 Al: 1 P	4.7 h	4.7 h	5.6 h	6.4 f	5.8 g	6.4 d	5.7 g
	0.5 Al: 1 P	4.4 j	4.4 k	5.2 i	6.0 h	5.6 i	6.1 ef	5.3 i
	1 Al: 1 P	4.0 l	4.0 m	4.6 k	5.3 j	5.1 k	5.4 g	4.8 k
Iron sulphate	0.25 Fe: 1 P	4.6 i	4.6 i	5.5 h	6.2 g	5.6 h	6.2 e	5.6 h
	0.5 Fe: 1 P	4.2 k	4.2 l	5.0 j	5.7 i	5.3 k	5.5 g	5.1 j
	1 Fe: 1 P	3.7 m	3.8 n	4.2 l	4.9 k	4.7 m	5.0 h	4.4 l
Iron chloride	0.25 Fe: 1 P	4.5 i	4.5 j	5.3 i	6.1 h	5.6 hi	6.0 f	5.3 i
	0.5 Fe: 1 P	4.0 l	4.0 m	4.7 k	5.4 j	5.1 k	5.5 g	4.8 k
	1 Fe: 1 P	3.4 n	3.4 o	3.7 m	4.3 l	4.3 m	4.5 i	3.8 m
Overall mean		5.0	5.0	5.7	6.4	5.9	6.4	5.9
Coefficient of variation (%)		0.6	0.5	0.7	0.6	0.5	0.9	0.6

Table S2. Percentage change in mean pH associated with each rate of amendment applied to the seven soils.

Amendment	Rate	pH decrease (%)						
		Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	Soil 6	Soil 7
Control								
Lime	0.5 Ca: 1 P	-10	-11	-9	-6	-9	-5	-5
Lime	1 Ca: 1 P	-20	-22	-15	-6	-15	-5	-11
Lime	5 Ca: 3 P	-29	-32	-18	-7	-16	-6	-12
Gypsum	0.5 Ca: 1 P	9	6	4	5	5	5	8
Gypsum	1 Ca: 1 P	9	6	5	6	5	5	8
Gypsum	5 Ca: 3 P	9	6	5	6	5	5	8
Hydrotalcite	0.25 Al: 1 P	-9	-9	-1	0	-1	-2	-2
Hydrotalcite	0.5 Al: 1 P	-12	-11	-2	-1	-2	-2	-2
Hydrotalcite	1 Al: 1 P	-15	-15	-4	-2	-4	-2	-4
Alum	0.25 Al: 1 P	10	8	7	7	6	6	11
Alum	0.5 Al: 1 P	16	14	13	12	11	10	17
Alum	1 Al: 1 P	24	22	23	23	19	20	25
Iron sulphate	0.25 Fe: 1 P	12	11	8	10	9	9	13
Iron sulphate	0.5 Fe: 1 P	20	19	17	18	15	19	21
Iron sulphate	1 Fe: 1 P	28	27	29	29	24	27	31
Iron chloride	0.25 Fe: 1 P	13	13	12	12	10	12	17
Iron chloride	0.5 Fe: 1 P	23	23	22	22	18	20	25
Iron chloride	1 Fe: 1 P	35	34	39	37	31	34	42

Table S3. Mean soil water extractable P (WEP) concentration (mg L⁻¹) in each soil with different types and rates of amendment applied. Differences in means were identified using Tukey's Honestly Significant Different (HSD) post hoc test. Amendment type and rate combinations within the same soil and the same letter are not significantly different from one another (P<0.05).

Amendment	Rate	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	Soil 6	Soil 7
control		0.13 a	0.09 a	0.08 a	0.14 ab	0.31 a	0.49 ab	0.57 a
Lime	0.5 Ca: 1 P	0.12 ab	0.07 ab	0.07 abc	0.14 abc	0.27 bc	0.46 abc	0.59 a
	1 Ca: 1 P	0.09 bc	0.06 bcd	0.07 abc	0.15 a	0.26 bcd	0.37 cde	0.56 a
	5 Ca: 3 P	0.08 bcd	0.07 ab	0.08 abc	0.14 abcd	0.27 bc	0.46 abc	0.54 a
Gypsum	0.5 Ca: 1 P	0.09 bcd	0.07 abc	0.06 bcde	0.12 bcdef	0.26 bcd	0.41 bcde	0.41 b
	1 Ca: 1 P	0.08 bcd	0.05 bcde	0.04 defg	0.11 cdefg	0.25 cd	0.34 def	0.39 bc
	5 Ca: 3 P	0.08 bcd	0.05 bcde	0.04 defg	0.10 efg	0.23 de	0.35 cdef	0.36 bc
Hydrotalcite	0.25 Al: 1 P	0.06 cd	0.05 bcdef	0.09 a	0.13 abcde	0.28 bc	0.54 a	0.60 a
	0.5 Al: 1 P	0.07 cd	0.06 bcd	0.08 ab	0.14 abc	0.29 ab	0.44 abcd	0.56 a
	1 Al: 1 P	0.09 bcd	0.06 bcde	0.07 abc	0.09 efg	0.28 bc	0.39 cde	0.54 a
Alum	0.25 Al: 1 P	0.08 bcd	0.05 bcde	0.06 bcd	0.08 fgh	0.25 cd	0.38 cde	0.37 bc
	0.5 Al: 1 P	0.05 cde	0.02 defg	0.03 fgh	0.05 hi	0.21 ef	0.30 efg	0.28 de
	1 Al: 1 P	0.02 ef	0.03 cdefg	0.01 h	0.03 i	0.13 g	0.18 h	0.13 gh
Iron sulphate	0.25 Fe: 1 P	0.07 cd	0.01 g	0.05 cdef	0.10 defg	0.23 de	0.41 bcde	0.35 bc
	0.5 Fe: 1 P	0.05 def	0.02 efg	0.03 efg	0.08 gh	0.18 f	0.31efg	0.23 ef
	1 Fe: 1 P	0.01 ef	0.04 bcdefg	0.01 h	0.03 i	0.13 gh	0.21 gh	0.10 hi
Iron chloride	0.25 Fe: 1 P	0.07 bcd	0.07 ab	0.06 bcde	0.09 efg	0.25 cd	0.38 cde	0.33 cd
	0.5 Fe: 1 P	0.05 def	0.02 fg	0.03 gh	0.07 gh	0.20 ef	0.30 efg	0.19 fg
	1 Fe: 1 P	0.01 f	0.01 g	0.01 h	0.02 i	0.10 h	0.24 fgh	0.04 i
Overall mean		0.08	0.06	0.06	0.11	0.25	0.39	0.42
Coefficient of variation (%)		20.3	24.9	16.2	13.6	5.6	11.8	6.2

Table S4. Percentage change in mean water extractable P concentration (WEP) associated with each rate of amendment applied to the seven soils.

Amendment	Rate	WEP decrease (%)						
		Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	Soil 6	Soil 7
Control								
Lime	0.5 Ca: 1 P	12	25	15	1	11	7	-3
Lime	1 Ca: 1 P	28	34	15	-6	16	25	3
Lime	5 Ca: 3 P	36	25	11	4	11	5	5
Gypsum	0.5 Ca: 1 P	32	28	32	20	15	17	28
Gypsum	1 Ca: 1 P	42	43	49	26	19	31	32
Gypsum	5 Ca: 3 P	36	43	53	31	26	29	37
Hydrotalcite	0.25 Al: 1 P	51	46	-4	9	9	-11	-5
Hydrotalcite	0.5 Al: 1 P	47	36	8	3	5	9	2
Hydrotalcite	1 Al: 1 P	34	39	14	35	9	20	6
Alum	0.25 Al: 1 P	36	40	30	43	20	23	34
Alum	0.5 Al: 1 P	59	74	64	62	32	39	52
Alum	1 Al: 1 P	87	67	87	82	57	62	77
Iron sulphate	0.25 Fe: 1 P	47	94	38	29	24	16	39
Iron sulphate	0.5 Fe: 1 P	62	77	60	48	40	37	59
Iron sulphate	1 Fe: 1 P	92	56	88	80	59	57	82
Iron chloride	0.25 Fe: 1 P	44	19	33	35	19	22	41
Iron chloride	0.5 Fe: 1 P	63	83	70	49	35	38	67
Iron chloride	1 Fe: 1 P	92	93	88	85	69	51	93

Table S5. Annual yield of dissolved reactive P (DRP) potentially lost from each of the soils per ha assuming an annual runoff of 400 mm. Runoff data taken from Clifo (National Institute of Water and Atmospheric Research 2020) for Reporoa from 1970 to 2019.

Amendment	Rate	Field application rate (tha ⁻¹)	Application cost (USD ha ⁻¹)	DRP loss (kg ha ⁻¹ yr ⁻¹)						
				Soil 1	Soil 2	Soil 3	Soil 4	Soil 5	Soil 6	Soil 7
Control		0	0	0.53	0.36	0.34	0.57	1.23	1.96	2.28
Lime	0.5 Ca: 1 P	1.9	230	0.46	0.27	0.29	0.57	1.09	1.83	2.35
Lime	1 Ca: 1 P	3.8	461	0.38	0.24	0.29	0.61	1.03	1.47	2.22
Lime	5 Ca: 3 P	6.4	768	0.34	0.27	0.30	0.55	1.09	1.86	2.17
Gypsum	0.5 Ca: 1 P	3.3	1656	0.36	0.26	0.23	0.46	1.04	1.63	1.65
Gypsum	1 Ca: 1 P	6.6	3312	0.31	0.21	0.17	0.43	1.00	1.34	1.56
Gypsum	5 Ca: 3 P	11.0	5503	0.34	0.21	0.16	0.39	0.91	1.39	1.43
Hydrotalcite	0.25 Al: 1 P	2.9	2317	0.26	0.20	0.35	0.52	1.12	2.17	2.39
Hydrotalcite	0.5 Al: 1 P	5.8	4631	0.28	0.23	0.31	0.56	1.17	1.78	2.23
Hydrotalcite	1 Al: 1 P	11.6	9262	0.35	0.22	0.29	0.37	1.12	1.57	2.15
Alum	0.25 Al: 1 P	1.6	304	0.34	0.22	0.23	0.33	0.99	1.50	1.50
Alum	0.5 Al: 1 P	3.3	607	0.21	0.10	0.12	0.22	0.83	1.19	1.10
Alum	1 Al: 1 P	6.6	1214	0.07	0.12	0.04	0.10	0.53	0.74	0.52
Iron sulphate	0.25 Fe: 1 P	1.9	527	0.28	0.02	0.21	0.41	0.93	1.63	1.40
Iron sulphate	0.5 Fe: 1 P	3.8	1055	0.20	0.08	0.14	0.30	0.73	1.24	0.93
Iron sulphate	1 Fe: 1 P	7.7	2111	0.04	0.16	0.04	0.12	0.51	0.84	0.41
Iron chloride	0.25 Fe: 1 P	2.6	1101	0.29	0.29	0.23	0.38	1.00	1.53	1.34
Iron chloride	0.5 Fe: 1 P	5.2	2203	0.19	0.06	0.10	0.29	0.80	1.22	0.75
Iron chloride	1 Fe: 1 P	10.4	4406	0.04	0.03	0.04	0.08	0.39	0.97	0.16