

Supplementary Materials

The role of sulfuric acid, abiotic-organic acids, and biotic acids on serpentinite dissolution and trace metal release

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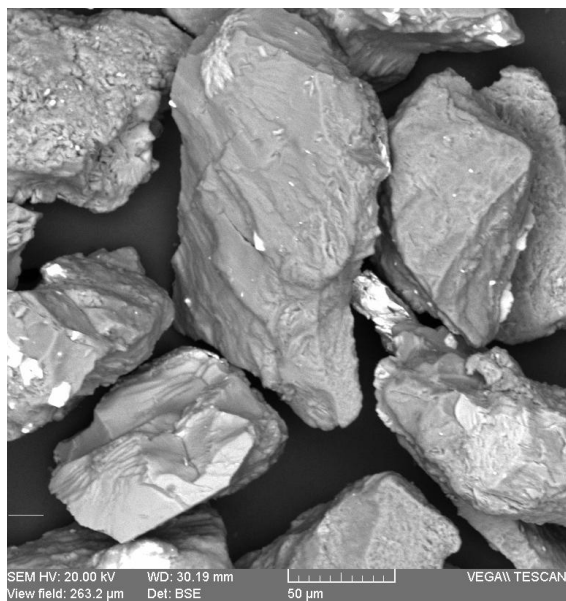
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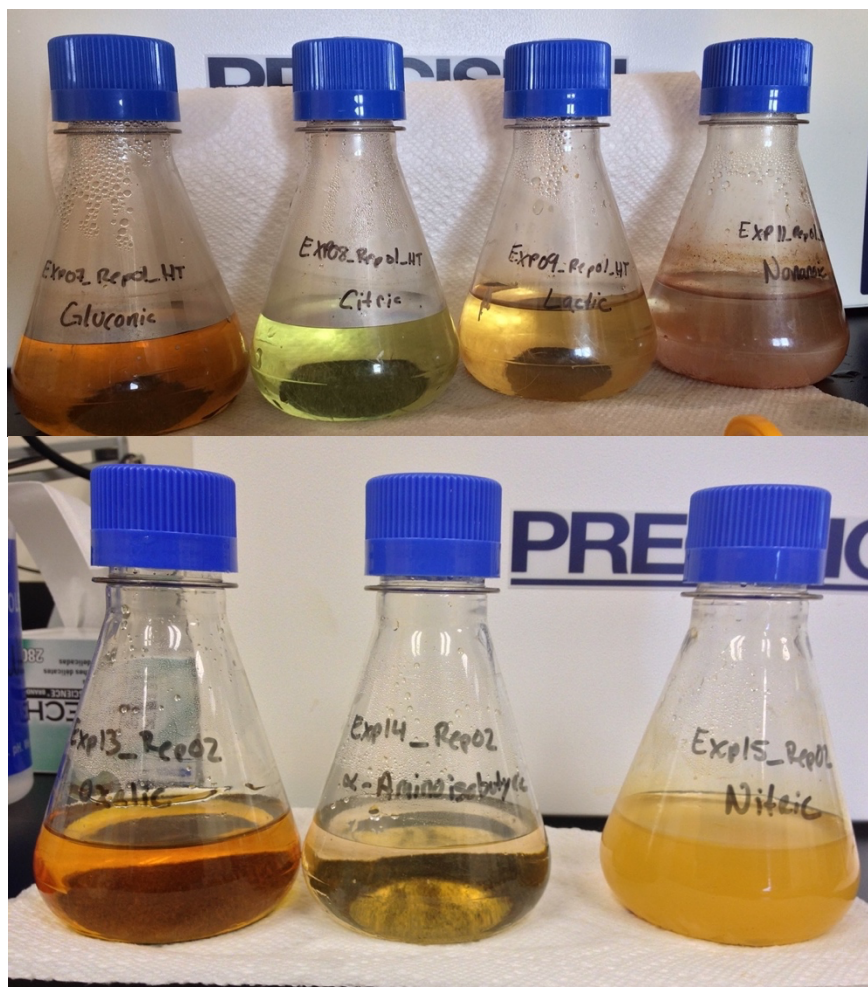
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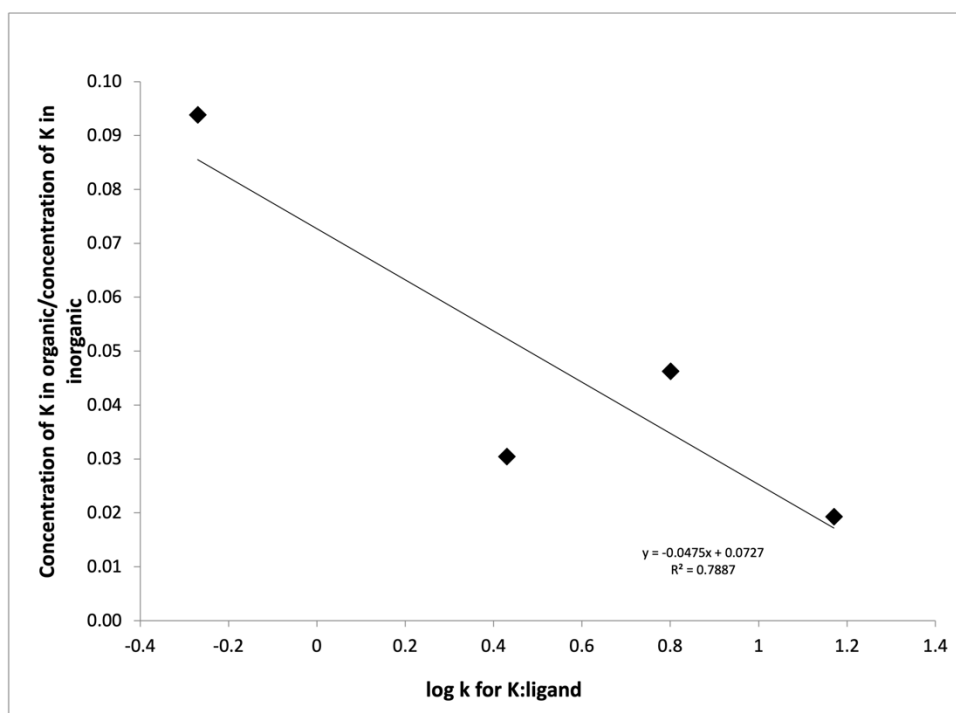
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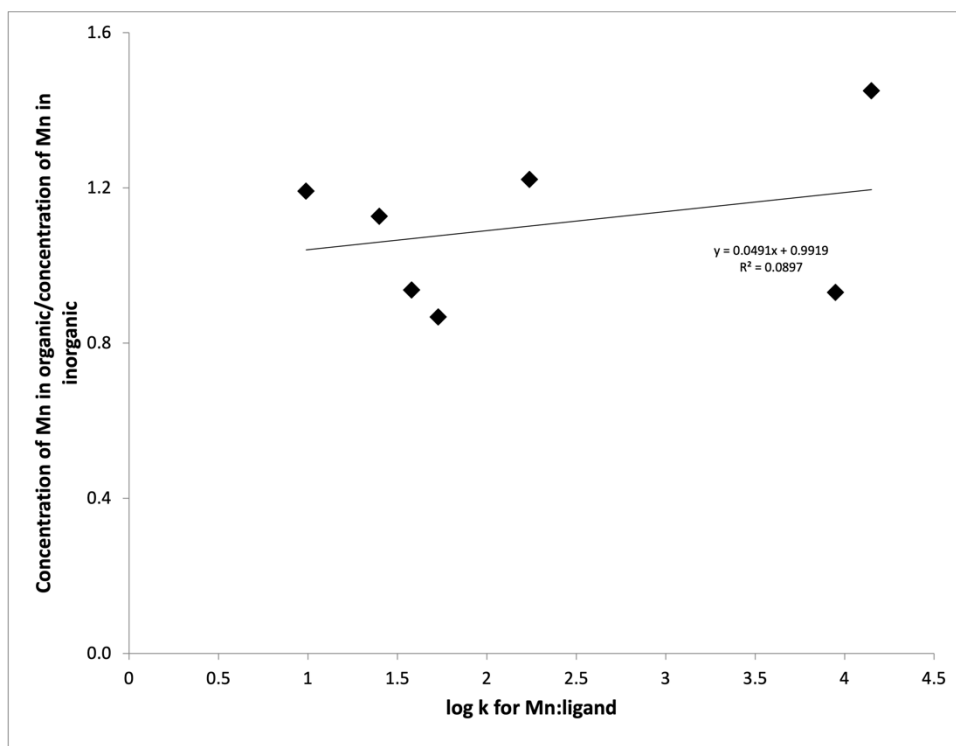
Supplementary Figure S1. Photomicrographs of unreacted serpentinite rock grains illustrating the degree of inclusions in the grains.



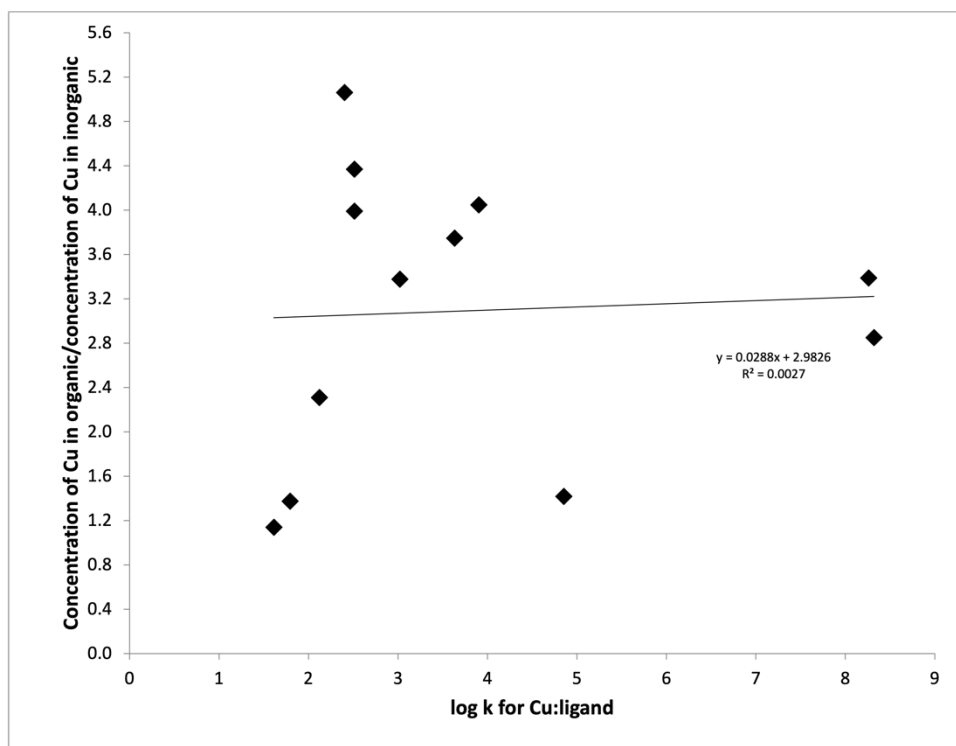
Supplementary Figure S2. Photographs of the dissolution experiments. Top photograph displays the color variation between different experiments while the bottom shows the difference in clarity.



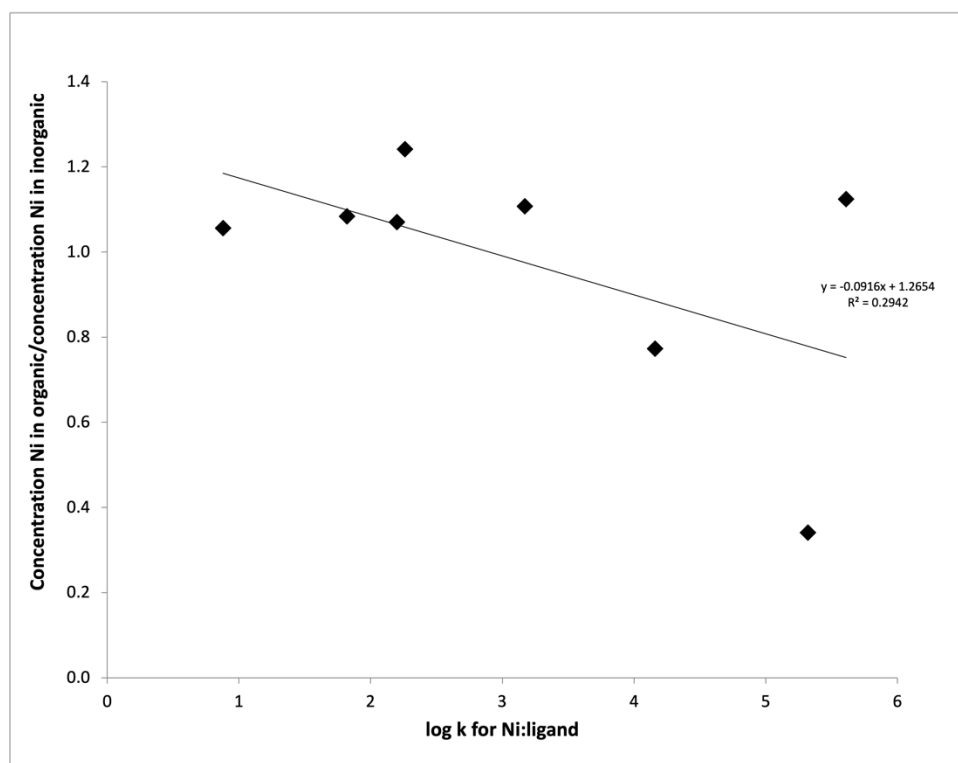
Supplementary Figure S3. Release ratios for K in organic solutions and nitric acid versus stability constant for the metal-ligand pair.



Supplementary Figure S4. Release ratios for Mn in organic solutions and nitric acid versus stability constant for the metal-ligand pair.



Supplementary Figure S5. Release ratios for Cu in organic solutions and nitric acid versus stability constant for the metal-ligand pair.



Supplementary Figure S6. Release ratios for Ni in organic solutions and nitric acid versus stability constant for the metal-ligand pair.

Supplementary Table S1. Sample conditions and pH.

Sample #	Acid	t (minutes)	T (°C)	pH
1	MSA	30	0	2.82
2	MSA	180	0	3.02
3	MSA	480	0	3.28
4	MSA	1440	0	3.84
5	MSA	2880	0	4.39
6	MSA	4320	0	4.66
7	MSA	10080	0	4.43
8	MSA	20160	0	5.02
9	MSA	40320	0	4.76
10	Acetic	30	0	2.84
11	Acetic	180	0	2.96
12	Acetic	480	0	3.27
13	Acetic	1440	0	3.87
14	Acetic	2880	0	4.14
15	Acetic	4320	0	4.42
16	Acetic	10080	0	4.49
17	Acetic	20160	0	4.65
18	Acetic	40320	0	4.52
19	Sulfuric	30	0	2.91
20	Sulfuric	180	0	2.90
21	Sulfuric	480	0	3.08
22	Sulfuric	1440	0	3.50
23	Sulfuric	2880	0	4.08
24	Sulfuric	4320	0	4.45
25	Sulfuric	10080	0	5.18
26	Sulfuric	20160	0	5.14
27	Sulfuric	40320	0	4.94
28	Fumaric	30	0	2.77
29	Fumaric	180	0	2.81
30	Fumaric	480	0	3
31	Fumaric	1440	0	3.11
32	Fumaric	2880	0	3.33
33	Fumaric	4320	0	3.46
34	Fumaric	10080	0	3.75
35	Fumaric	20160	0	3.66
36	Fumaric	40320	0	3.54
37	Glutamic	30	0	2.77
38	Glutamic	180	0	2.84
39	Glutamic	480	0	2.93
40	Glutamic	1440	0	3.14

Sample #	Acid	t (minutes)	T (°C)	pH
41	Glutamic	2880	0	3.41
42	Glutamic	4320	0	3.63
43	Glutamic	10080	0	3.81
44	Glutamic	20160	0	3.89
45	Glutamic	40320	0	3.80
46	Formic	30	0	2.85
47	Formic	180	0	2.86
48	Formic	480	0	3.03
49	Formic	1440	0	3.28
50	Formic	2880	0	3.45
51	Formic	4320	0	3.57
52	Formic	10080	0	3.59
53	Formic	20160	0	3.74
54	Formic	40320	0	3.64
55	Gluconic	30	0	2.81
56	Gluconic	180	0	2.85
57	Gluconic	480	0	3.00
58	Gluconic	1440	0	3.30
59	Gluconic	2880	0	3.60
60	Gluconic	4320	0	3.85
61	Gluconic	10080	0	4.36
62	Gluconic	20160	0	4.48
63	Gluconic	40320	0	4.13
64	Citric	30	0	2.75
65	Citric	180	0	2.94
66	Citric	480	0	2.98
67	Citric	1440	0	3.27
68	Citric	2880	0	3.42
69	Citric	4320	0	3.38
70	Citric	10080	0	3.25
71	Citric	20160	0	3.23
72	Citric	40320	0	3.13
73	Lactic	30	0	2.90
74	Lactic	180	0	2.91
75	Lactic	480	0	3.06
76	Lactic	1440	0	3.25
77	Lactic	2880	0	3.49
78	Lactic	4320	0	3.63
79	Lactic	10080	0	3.80
80	Lactic	20160	0	3.99
81	Lactic	40320	0	3.83

Sample #	Acid	t (minutes)	T (°C)	pH
82	Malic	30	0	2.82
83	Malic	180	0	2.79
84	Malic	480	0	2.94
85	Malic	1440	0	3.17
86	Malic	2880	0	3.38
87	Malic	4320	0	3.49
88	Malic	10080	0	3.46
89	Malic	20160	0	3.50
90	Malic	40320	0	3.30
91	Nonanoic	30	0	2.75
92	Nonanoic	180	0	2.84
93	Nonanoic	480	0	3.00
94	Nonanoic	1440	0	3.63
95	Nonanoic	2880	0	4.12
96	Nonanoic	4320	0	4.47
97	Nonanoic	10080	0	4.55
98	Nonanoic	20160	0	5.11
99	Nonanoic	40320	0	4.81
100	Glycolic	30	0	2.72
101	Glycolic	180	0	2.88
102	Glycolic	480	0	3.05
103	Glycolic	1440	0	3.28
104	Glycolic	2880	0	3.52
105	Glycolic	4320	0	3.66
106	Glycolic	10080	0	3.89
107	Glycolic	20160	0	4.07
108	Glycolic	40320	0	3.91
109	Oxalic	30	0	2.69
110	Oxalic	180	0	2.81
111	Oxalic	480	0	2.92
112	Oxalic	1440	0	3.01
113	Oxalic	2880	0	3.15
114	Oxalic	4320	0	3.11
115	Oxalic	10080	0	3.25
116	Oxalic	20160	0	3.67
117	Oxalic	40320	0	3.79
118	AIB	30	0	2.71
119	AIB	180	0	2.80
120	AIB	480	0	2.91
121	AIB	1440	0	3.10
122	AIB	2880	0	3.52

Sample #	Acid	t (minutes)	T (°C)	pH
123	AIB	4320	0	3.78
124	AIB	10080	0	3.96
125	AIB	20160	0	4.23
126	AIB	40320	0	4.10
127	Nitric	30	0	2.81
128	Nitric	180	0	2.99
129	Nitric	480	0	3.31
130	Nitric	1440	0	3.78
131	Nitric	2880	0	4.13
132	Nitric	4320	0	4.42
133	Nitric	10080	0	4.62
134	Nitric	20160	0	4.80
135	Nitric	40320	0	4.65
136	Valeric	30	0	2.82
137	Valeric	180	0	3.10
138	Valeric	480	0	3.37
139	Valeric	1440	0	3.88
140	Valeric	2880	0	4.04
141	Valeric	4320	0	4.26
142	Valeric	10080	0	4.28
143	Valeric	20160	0	4.45
144	Valeric	40320	0	4.33
145	MSA	30	22	2.81
146	MSA	180	22	2.86
147	MSA	480	22	3.02
148	MSA	1440	22	3.77
149	MSA	2880	22	4.48
150	MSA	4320	22	4.91
151	MSA	10080	22	4.83
152	MSA	20160	22	4.65
153	MSA	40320	22	4.65
154	Acetic	30	22	2.75
155	Acetic	180	22	3.01
156	Acetic	480	22	3.52
157	Acetic	1440	22	4.16
158	Acetic	2880	22	4.37
159	Acetic	4320	22	4.35
160	Acetic	10080	22	4.34
161	Acetic	20160	22	4.25
162	Acetic	40320	22	4.26

Sample #	Acid	t (minutes)	T (°C)	pH
163	Sulfuric	30	22	2.76
164	Sulfuric	180	22	2.88
165	Sulfuric	480	22	3.02
166	Sulfuric	1440	22	3.58
167	Sulfuric	2880	22	4.25
168	Sulfuric	4320	22	4.62
169	Sulfuric	10080	22	4.88
170	Sulfuric	20160	22	4.62
171	Sulfuric	40320	22	4.69
172	Fumaric	30	22	2.68
173	Fumaric	180	22	2.78
174	Fumaric	480	22	3.02
175	Fumaric	1440	22	3.22
176	Fumaric	2880	22	3.35
177	Fumaric	4320	22	3.41
178	Fumaric	10080	22	3.43
179	Fumaric	20160	22	3.5
180	Fumaric	40320	22	3.61
181	Glutamic	30	22	2.68
182	Glutamic	180	22	2.73
183	Glutamic	480	22	2.88
184	Glutamic	1440	22	3.08
185	Glutamic	2880	22	3.55
186	Glutamic	4320	22	3.68
187	Glutamic	10080	22	3.67
188	Glutamic	20160	22	3.73
189	Glutamic	40320	22	3.74
190	Formic	30	22	2.72
191	Formic	180	22	2.87
192	Formic	480	22	3.16
193	Formic	1440	22	3.75
194	Formic	2880	22	4.01
195	Formic	4320	22	4.16
196	Formic	10080	22	4.17
197	Formic	20160	22	4.15
198	Formic	40320	22	4.1
199	Gluconic	30	22	2.82
200	Gluconic	180	22	3.11
201	Gluconic	480	22	3.44
202	Gluconic	1440	22	3.69
203	Gluconic	2880	22	3.73

Sample #	Acid	t (minutes)	T (°C)	pH
204	Gluconic	4320	22	3.72
205	Gluconic	10080	22	3.73
206	Gluconic	20160	22	3.68
207	Gluconic	40320	22	3.85
208	Citric	30	22	2.87
209	Citric	180	22	3.09
210	Citric	480	22	3.23
211	Citric	1440	22	3.21
212	Citric	2880	22	3.11
213	Citric	4320	22	3.08
214	Citric	10080	22	3.13
215	Citric	20160	22	3.45
216	Citric	40320	22	4.40
217	Lactic	30	22	2.94
218	Lactic	180	22	3.10
219	Lactic	480	22	3.37
220	Lactic	1440	22	3.75
221	Lactic	2880	22	3.80
222	Lactic	4320	22	3.80
223	Lactic	10080	22	3.87
224	Lactic	20160	22	3.88
225	Lactic	40320	22	4.00
226	Malic	30	22	2.85
227	Malic	180	22	2.95
228	Malic	480	22	3.14
229	Malic	1440	22	3.36
230	Malic	2880	22	3.40
231	Malic	4320	22	3.46
232	Malic	10080	22	3.39
233	Malic	20160	22	3.44
234	Malic	40320	22	3.83
235	Nonanoic	30	22	2.85
236	Nonanoic	180	22	3.00
237	Nonanoic	480	22	3.38
238	Nonanoic	1440	22	4.10
239	Nonanoic	2880	22	4.21
240	Nonanoic	4320	22	4.24
241	Nonanoic	10080	22	4.18
242	Nonanoic	20160	22	4.27
243	Nonanoic	40320	22	4.45

Sample #	Acid	t (minutes)	T (°C)	pH
244	Glycolic	30	22	2.92
245	Glycolic	180	22	3.16
246	Glycolic	480	22	3.51
247	Glycolic	1440	22	3.71
248	Glycolic	2880	22	3.71
249	Glycolic	4320	22	3.75
250	Glycolic	10080	22	3.76
251	Glycolic	20160	22	3.78
252	Glycolic	40320	22	3.89
253	Oxalic	30	22	2.87
254	Oxalic	180	22	2.98
255	Oxalic	480	22	2.98
256	Oxalic	1440	22	3.11
257	Oxalic	2880	22	3.19
258	Oxalic	4320	22	3.37
259	Oxalic	10080	22	4.08
260	Oxalic	20160	22	4.92
261	Oxalic	40320	22	5.38
262	AIB	30	22	2.81
263	AIB	180	22	2.88
264	AIB	480	22	3.16
265	AIB	1440	22	3.57
266	AIB	2880	22	3.71
267	AIB	4320	22	3.79
268	AIB	10080	22	3.89
269	AIB	20160	22	4.00
270	AIB	40320	22	4.14
271	Nitric	30	22	2.80
272	Nitric	180	22	2.96
273	Nitric	480	22	3.09
274	Nitric	1440	22	3.97
275	Nitric	2880	22	4.68
276	Nitric	4320	22	4.84
277	Nitric	10080	22	4.65
278	Nitric	20160	22	4.37
279	Nitric	40320	22	4.46
280	Valeric	30	22	2.71
281	Valeric	180	22	3.02
282	Valeric	480	22	3.65
283	Valeric	1440	22	4.34
284	Valeric	2880	22	4.48

Sample #	Acid	t (minutes)	T (°C)	pH
285	Valeric	4320	22	4.49
286	Valeric	10080	22	4.43
287	Valeric	20160	22	4.24
288	Valeric	40320	22	4.12
289	MSA	30	62	2.66
290	MSA	180	62	2.92
291	MSA	480	62	3.63
292	MSA	1440	62	4.18
293	MSA	2880	62	4.23
294	MSA	4320	62	4.36
295	MSA	10080	62	5.62
296	MSA	20160	62	6.47
297	MSA	40320	62	6.75
298	Acetic	30	62	2.89
299	Acetic	180	62	3.77
300	Acetic	480	62	4.23
301	Acetic	1440	62	3.98
302	Acetic	2880	62	4.04
303	Acetic	4320	62	4.32
304	Acetic	10080	62	5.05
305	Acetic	20160	62	5.47
306	Acetic	40320	62	5.66
307	Sulfuric	30	62	2.72
308	Sulfuric	180	62	2.95
309	Sulfuric	480	62	3.28
310	Sulfuric	1440	62	4.34
311	Sulfuric	2880	62	4.28
312	Sulfuric	4320	62	4.49
313	Sulfuric	10080	62	5.72
314	Sulfuric	20160	62	6.63
315	Sulfuric	40320	62	7.02
316	Fumaric	30	62	2.61
317	Fumaric	180	62	2.82
318	Fumaric	480	62	3.01
319	Fumaric	1440	62	3.25
320	Fumaric	2880	62	3.44
321	Fumaric	4320	62	3.53
322	Fumaric	10080	62	3.87
323	Fumaric	20160	62	4.17
324	Fumaric	40320	62	4.51
325	Glutamic	30	62	2.68

Sample #	Acid	t (minutes)	T (°C)	pH
326	Glutamic	180	62	2.92
327	Glutamic	480	62	3.18
328	Glutamic	1440	62	3.59
329	Glutamic	2880	62	3.70
330	Glutamic	4320	62	3.67
331	Glutamic	10080	62	3.79
332	Glutamic	20160	62	4.45
333	Glutamic	40320	62	5.31
334	Formic	30	62	2.72
335	Formic	180	62	3.16
336	Formic	480	62	3.37
337	Formic	1440	62	3.52
338	Formic	2880	62	3.69
339	Formic	4320	62	3.73
340	Formic	10080	62	4.01
341	Formic	20160	62	4.61
342	Formic	40320	62	5.32
343	Gluconic	30	62	2.86
344	Gluconic	180	62	3.38
345	Gluconic	480	62	3.70
346	Gluconic	1440	62	4.07
347	Gluconic	2880	62	4.12
348	Gluconic	4320	62	4.05
349	Gluconic	10080	62	4.56
350	Gluconic	20160	62	5.80
351	Gluconic	40320	62	6.02
352	Citric	30	62	2.91
353	Citric	180	62	3.21
354	Citric	480	62	3.25
355	Citric	1440	62	3.37
356	Citric	2880	62	4.38
357	Citric	4320	62	5.00
358	Citric	10080	62	6.15
359	Citric	20160	62	6.63
360	Citric	40320	62	7.00
361	Lactic	30	62	2.92
362	Lactic	180	62	3.43
363	Lactic	480	62	3.60
364	Lactic	1440	62	3.87
365	Lactic	2880	62	3.82
366	Lactic	4320	62	3.81
367	Lactic	10080	62	4.28

Sample #	Acid	t (minutes)	T (°C)	pH
368	Lactic	20160	62	5.34
369	Lactic	40320	62	5.99
370	Malic	30	62	2.75
371	Malic	180	62	3.10
372	Malic	480	62	3.29
373	Malic	1440	62	3.35
374	Malic	2880	62	3.73
375	Malic	4320	62	4.21
376	Malic	10080	62	5.12
377	Malic	20160	62	5.76
378	Malic	40320	62	6.40
379	Nonanoic	30	62	2.84
380	Nonanoic	180	62	4.05
381	Nonanoic	480	62	4.37
382	Nonanoic	1440	62	4.62
383	Nonanoic	2880	62	4.48
384	Nonanoic	4320	62	4.67
385	Nonanoic	10080	62	5.74
386	Nonanoic	20160	62	6.05
387	Nonanoic	40320	62	6.54
388	Glycolic	30	62	2.93
389	Glycolic	180	62	3.36
390	Glycolic	480	62	3.54
391	Glycolic	1440	62	3.89
392	Glycolic	2880	62	3.81
393	Glycolic	4320	62	3.80
394	Glycolic	10080	62	4.39
395	Glycolic	20160	62	5.46
396	Glycolic	40320	62	6.04
397	Oxalic	30	62	2.88
398	Oxalic	180	62	3.09
399	Oxalic	480	62	3.67
400	Oxalic	1440	62	4.65
401	Oxalic	2880	62	5.22
402	Oxalic	4320	62	5.34
403	Oxalic	10080	62	5.76
404	Oxalic	20160	62	5.92
405	Oxalic	40320	62	6.14
406	AIB	30	62	2.78
407	AIB	180	62	3.11
408	AIB	480	62	3.81

Sample #	Acid	t (minutes)	T (°C)	pH
409	AIB	1440	62	4.03
410	AIB	2880	62	3.97
411	AIB	4320	62	4.02
412	AIB	10080	62	4.62
413	AIB	20160	62	5.74
414	AIB	40320	62	6.38
415	Nitric	30	62	2.83
416	Nitric	180	62	3.86
417	Nitric	480	62	4.26
418	Nitric	1440	62	4.46
419	Nitric	2880	62	4.34
420	Nitric	4320	62	4.53
421	Nitric	10080	62	5.64
422	Nitric	20160	62	6.29
423	Nitric	40320	62	6.66
424	Valeric	30	62	3.19
425	Valeric	180	62	3.98
426	Valeric	480	62	4.13
427	Valeric	1440	62	4.06
428	Valeric	2880	62	4.04
429	Valeric	4320	62	4.07
430	Valeric	10080	62	4.56
431	Valeric	20160	62	5.04
432	Valeric	40320	62	5.41

Supplementary Table S2. p-values which describe the y-intercepts of each acid compared to nitric acid for each acid-cation pair for Model 2 for Research Question 2.

Element	AIB	Acetic	Citric	Formic	Fumaric	Gluconic	Glutamic	Glycolic	Lactic
Al	0.04210	0.18300	< 2e-16	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ba	0.21100	< 2e-16	0.19300	0.00000	0.00000	0.14900	0.00000	0.22800	0.21600
Ca	0.28800	0.66200	0.00000	0.45900	0.44000	0.19500	0.61800	0.25500	0.46500
Cd	0.67000	0.01270	0.00128	0.03150	0.02360	0.43000	0.89700	0.00741	0.06190
Ce	0.03980	0.00335	< 2e-16	0.00030	0.00487	0.01410	0.00000	0.00537	0.00037
Co	0.00668	0.00425	0.00000	0.00000	0.00000	0.20400	0.01400	0.00176	0.00048
Cr	0.00000	0.00007	< 2e-16	0.00000	< 2e-16	< 2e-16	< 2e-16	< 2e-16	< 2e-16
Cs	0.09690	0.46700	0.25600	0.00199	0.00029	0.45000	0.00002	0.34400	0.37500
Cu	0.00000	0.04280	0.00011	0.00350	0.00000	0.00178	0.00001	0.00002	0.00032
Fe57	0.00063	0.00715	0.00000	0.00197	0.00001	0.00002	0.00106	0.00179	0.00045
Fe58	0.00360	0.00427	0.00000	0.00377	0.00010	0.25000	0.39000	0.00340	0.01110
K	0.31100	0.71600	0.00299	0.00332	0.02390	0.14500	0.07660	0.00273	0.00647
La	0.07430	0.25100	< 2e-16	0.00040	0.00759	0.12300	0.00000	0.01560	0.00698
Mg	0.08770	0.00394	< 2e-16	0.00012	0.00000	0.36400	0.05510	0.00027	0.00001
Mn	0.00610	0.00001	0.00000	0.00468	0.00001	0.71300	0.21100	0.00625	0.03320
Mo	0.00084	0.00324	< 2e-16	0.00355	0.00000	< 2e-16	0.00078	< 2e-16	< 2e-16
Na	0.39000	0.00963	0.05930	0.65300	0.57200	0.13300	0.15000	0.18600	0.00491
Ni	0.04920	0.09520	0.00002	0.03730	0.00199	0.54500	0.66300	0.03460	0.16100
Pb	0.00099	0.00105	0.00000	0.00000	0.00000	0.00000	0.00000	< 2e-16	0.00000
P	0.86495	0.25509	0.00000	0.22123	0.66051	0.03715	0.47500	0.18000	0.84800
Pr	0.03848	0.28858	< 2e-16	0.00229	0.00825	0.00615	0.00045	0.00367	0.00015
Rb	0.12975	0.19866	0.01150	0.15626	0.02336	0.00669	0.05950	0.00579	0.00387
Sc	0.00000	0.00000	< 2e-16	< 2e-16	< 2e-16	< 2e-16	< 2e-16	< 2e-16	< 2e-16
S	0.30500	0.11500	0.04120	0.13487	0.01193	0.08670	0.01270	0.02870	0.23300
Si	0.15900	0.00000	0.00000	0.01960	0.00000	0.07840	0.00002	0.00329	0.00161
Sr	0.18100	0.01830	0.80700	0.55462	0.25494	0.01185	0.00460	0.28800	0.19900
Th	0.79600	0.01430	< 2e-16	0.00370	0.00000	0.00000	0.00007	0.00000	0.00000
Ti	0.00927	0.20400	< 2e-16	0.00000	< 2e-16	< 2e-16	0.00000	< 2e-16	< 2e-16
U	< 2e-16	< 2e-16	< 2e-16	< 2e-16	< 2e-16	0.00000	< 2e-16	0.00000	0.00000
V	0.00049	0.00813	< 2e-16	< 2e-16	< 2e-16	< 2e-16	< 2e-16	< 2e-16	< 2e-16
W182	0.45300	0.90400	< 2e-16	0.06590	0.00000	< 2e-16	0.71700	< 2e-16	< 2e-16
W184	0.40200	0.69800	< 2e-16	0.14500	0.00000	< 2e-16	0.43600	< 2e-16	< 2e-16
Y	0.03610	0.27000	< 2e-16	0.00175	0.00034	0.01200	0.32100	0.00073	0.00001
Zn	0.91800	0.15000	0.30200	0.00165	0.06810	0.74600	0.11600	0.48400	0.95700
Zr90	0.49300	0.41200	< 2e-16	0.11900	0.00000	< 2e-16	0.01140	0.00000	0.00000
Zr91	0.05120	0.32200	< 2e-16	0.00831	0.00000	< 2e-16	0.00042	0.00000	0.00000

Supplementary Table S3. p-values which describe the y-intercepts of each acid compared to sulfuric acid for each acid-cation pair for Model 2 for Research Question 3.

Element	Malic	MSA	Nonanoic	Oxalic	Sulfuric	Valeric
Al	< 2e-16	0.00000	0.29700	< 2e-16	0.00543	0.15800
Ba	0.00011	0.00000	0.07190	0.31800	< 2e-16	0.03190
Ca	0.04080	0.01710	0.03950	0.01970	0.01960	0.12100
Cd	0.00045	0.76800	0.00123	0.51800	0.03840	0.00985
Ce	0.00000	0.56800	0.02500	0.00000	0.19300	0.53000
Co	0.00000	0.58100	0.48600	0.00000	0.00717	0.00462
Cr	< 2e-16	0.11600	0.00011	< 2e-16	0.00000	0.00048
Cs	0.00057	0.00008	0.82200	0.04610	0.67300	0.00199
Cu	0.00012	0.04240	0.52300	0.08600	0.62100	0.01140
Fe57	0.00000	0.62500	0.40500	0.10100	0.21100	0.01670
Fe58	0.00007	0.00184	0.17200	0.00274	0.10600	0.01400
K	0.07580	0.53100	0.01330	0.03290	0.00013	0.03040
La	0.00000	0.05980	0.05490	0.00000	0.22900	0.60300
Mg	< 2e-16	0.09790	0.13900	< 2e-16	0.00000	0.09650
Mn	0.00046	0.01130	0.16200	0.30300	0.05680	0.00691
Mo	< 2e-16	0.23200	0.00057	< 2e-16	0.00000	0.05650
Na	0.67000	0.16900	0.01500	0.19800	0.07230	0.01010
Ni	0.00194	0.04950	0.41700	0.00021	0.05900	0.18300
Pb	0.00000	0.00066	0.00004	0.00000	0.00362	0.00163
P	0.00027	0.61000	0.02330	0.00002	0.04370	0.49257
Pr	0.00000	0.81700	0.02069	0.00000	0.19500	0.52894
Rb	0.00085	0.77500	0.11952	0.27200	0.00005	0.11955
Sc	< 2e-16	0.19300	0.33300	< 2e-16	< 2e-16	0.00000
S	0.16300	< 2e-16	0.03161	0.00000	< 2e-16	0.32700
Si	0.00000	0.02370	0.19500	0.00000	0.00000	0.51300
Sr	0.37000	0.00191	0.18280	0.11400	0.03800	0.45800
Th	< 2e-16	0.00727	0.04887	< 2e-16	0.00013	0.82800
Ti	< 2e-16	0.00000	0.14947	< 2e-16	0.00000	0.67200
U	< 2e-16	< 2e-16	0.00716	< 2e-16	< 2e-16	0.00009
V	< 2e-16	< 2e-16	0.07980	< 2e-16	0.00000	0.89200
W182	< 2e-16	0.49900	0.00000	< 2e-16	0.00478	0.35200
W184	< 2e-16	0.29400	0.00000	< 2e-16	0.00109	0.55700
Y	< 2e-16	0.83000	0.01740	< 2e-16	0.01110	0.56800
Zn	0.12700	0.72300	0.00112	0.26200	0.48800	0.02840
Zr90	< 2e-16	0.03630	0.01310	< 2e-16	0.00000	0.01520
Zr91	< 2e-16	0.16600	0.01830	< 2e-16	0.00003	0.00082

Element	AIB	Acetic	Citric	Formic	Fumaric	Gluconic	Glutamic	Glycolic	Lactic
Al	0.44983	0.14468	0.00000	0.00506	0.00000	0.03750	0.00130	0.05816	0.00370
Ba	< 2e-16	0.00808	0.00000	0.00004	0.00010	0.00000	0.00016	0.00000	0.00000
Ca	0.20161	0.05738	0.01270	0.10994	0.11688	0.00030	0.00469	0.22941	0.10748
Cd	0.09960	0.67010	0.24440	0.93570	0.84610	0.19870	0.02780	0.53990	0.83730
Ce	0.44906	0.10042	< 2e-16	0.01969	0.12782	0.24665	0.00040	0.13585	0.02273
Co	0.98083	0.86270	0.00000	0.01148	0.00145	0.15336	0.81554	0.65537	0.41483
Cr	0.19667	0.27387	< 2e-16	0.04294	0.00000	0.00000	0.00001	0.00000	0.00000
Cs	0.03759	0.75987	0.11959	0.00745	0.00133	0.23901	0.00012	0.17134	0.19077
Cu	0.00002	0.12518	0.00073	0.01503	0.00000	0.00833	0.00006	0.00015	0.00186
Fe57	0.02883	0.14732	0.00000	0.06325	0.00113	0.00191	0.04129	0.05919	0.02275
Fe58	0.19144	0.21054	0.00027	0.19625	0.02130	0.64051	0.44892	0.18526	0.35275
K	0.00455	0.00003	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
La	0.55880	0.95670	< 2e-16	0.01840	0.14010	0.73190	0.00002	0.22170	0.13260
Mg	0.00025	0.01257	0.00000	0.12644	0.23057	0.00001	0.00055	0.08397	0.35158
Mn	0.39767	0.00720	0.00034	0.35099	0.00796	0.12402	0.51204	0.40223	0.82066
Mo	0.00000	0.00000	0.00000	0.00000	0.38508	0.00367	0.00000	0.00006	0.00983
Na	0.34680	0.42465	0.92905	0.17733	0.01838	0.76579	0.71973	0.63274	0.30547
Ni	0.93737	0.82472	0.01483	0.84503	0.22397	0.01282	0.02029	0.82097	0.62581
Pb	0.69636	0.70775	0.00015	0.00000	0.00003	0.02489	0.00036	0.00000	0.00635
P	0.02881	0.37726	0.00070	0.00125	0.11395	0.94635	0.00644	0.49593	0.06773
Pr	0.43680	0.81410	< 2e-16	0.07720	0.17560	0.14620	0.02570	0.10510	0.01180
Rb	0.01010	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Sc	0.00000	0.00002	< 2e-16	0.35116	0.00000	0.00077	0.16275	0.00000	0.00000
S	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Si	0.00002	0.35449	0.12080	0.00063	0.95197	0.00007	0.15216	0.00488	0.00936
Sr	0.00069	0.77448	0.06691	0.13699	0.34709	0.65553	0.44288	0.30985	0.42714
Th	0.00004	0.15942	< 2e-16	0.34293	0.36777	0.00022	0.88752	0.00221	0.08107
Ti	0.00279	0.00002	< 2e-16	0.08275	0.00008	< 2e-16	0.02146	0.00001	< 2e-16
U	0.00341	0.78055	0.31615	0.00435	0.00424	0.00008	0.00008	0.00687	0.00394
V	0.01148	0.00076	< 2e-16	0.00003	0.00000	0.00000	0.00000	0.00023	0.00002
W182	0.03763	0.00687	< 2e-16	0.00000	0.00092	0.00000	0.01376	0.00000	0.00000
W184	0.01471	0.00392	< 2e-16	0.00000	0.00121	0.00000	0.01251	0.00000	0.00000
Y	0.65401	0.14902	< 2e-16	0.54893	0.28799	0.97879	0.12033	0.39477	0.05863
Zn	0.42535	0.45571	0.08475	0.01379	0.25716	0.30866	0.37813	0.99485	0.45456
Zr90	0.00004	0.00008	< 2e-16	0.00121	0.00050	0.00000	0.02322	0.09618	0.04651
Zr91	0.02507	0.00142	< 2e-16	0.12139	0.00004	0.00000	0.51697	0.03589	0.01288

Element	Malic	MSA	Nonanoic	Oxalic	Sulfuric	Valeric
Al	0.00000	0.00649	0.00543	0.08090	0.00000	0.16805
Ba	0.00000	0.00014	< 2e-16	0.00000	< 2e-16	0.00000
Ca	0.77075	0.00000	0.01955	0.78052	0.99813	0.42896
Cd	0.14440	0.01810	0.03840	0.23950	0.15340	0.60630
Ce	0.00000	0.46411	0.19270	0.34509	0.00000	0.49900
Co	0.00345	0.03220	0.00717	0.00074	0.00055	0.88410
Cr	< 2e-16	0.00045	0.00000	0.22486	< 2e-16	0.11181
Cs	0.00244	0.00040	0.67298	0.51748	0.01584	0.00744
Cu	0.00075	0.01176	0.62091	0.88561	0.22092	0.04120
Fe57	0.00017	0.08254	0.21143	0.03766	0.69501	0.25026
Fe58	0.01745	0.00000	0.10614	0.00299	0.16400	0.39713
K	0.00000	0.00129	0.00013	0.16771	0.00000	0.00000
La	0.00000	0.49520	0.22910	0.47130	0.00000	0.49400
Mg	0.00031	0.00000	0.00000	0.00010	0.00000	0.00021
Mn	0.10537	0.00001	0.05683	0.00101	0.00344	0.42127
Mo	0.00024	0.00000	0.00000	0.00000	0.47369	0.00000
Na	0.16976	0.67190	0.07229	0.52271	0.60918	0.43425
Ni	0.22085	0.00015	0.05895	0.00710	0.06466	0.57586
Pb	0.00001	0.61314	0.00362	0.21109	0.03501	0.80602
P	0.10001	0.13105	0.04366	0.80005	0.02001	0.18205
Pr	0.00000	0.12690	0.19500	0.30610	0.00000	0.50470
Rb	0.00000	0.00001	0.00005	0.01130	0.00000	0.00000
Sc	< 2e-16	< 2e-16	< 2e-16	< 2e-16	< 2e-16	0.00018
S	0.00000	0.06745	0.00000	0.00000	0.00000	0.00000
Si	0.67169	0.00060	0.00000	0.00001	0.57592	0.00000
Sr	0.23690	0.29740	0.03802	0.45556	0.00028	0.00497
Th	< 2e-16	0.24201	0.00013	0.05897	< 2e-16	0.00005
Ti	< 2e-16	0.90102	0.00000	0.00004	< 2e-16	0.00000
U	0.91468	0.87330	< 2e-16	0.00000	0.24958	0.00000
V	0.00000	0.00496	0.00000	0.00002	< 2e-16	0.00000
W182	< 2e-16	0.03138	0.00478	0.00963	0.00000	0.05737
W184	< 2e-16	0.02576	0.00109	0.02768	0.00000	0.00721
Y	0.00000	0.00593	0.01110	0.87057	0.00000	0.04839
Zn	0.02664	0.73364	0.48768	0.01003	0.66783	0.13318
Zr90	< 2e-16	0.00680	0.00000	0.02039	< 2e-16	0.01763
Zr91	< 2e-16	0.00507	0.00003	0.06708	< 2e-16	0.40442

Supplementary Table S4. Adjusted R^2 values for Model 2.

ELEMENT	<i>RQ2</i>	<i>RQ3</i>
	Adjusted R^2 Values	Adjusted R^2 Values
Mg	0.82	0.872
Si	0.67	0.6713
Al	0.95	0.9536
Ba	0.5	0.5023
Ca	0.67	0.6656
Cd	0.53	0.5283
Ce	0.56	0.5579
Co	0.76	0.7648
Cr	0.63	0.6275
Cs	0.65	0.6459
Cu	0.51	0.5142
Fe57*	0.36	0.3645
Fe58	0.85	0.8478
K	0.3	0.3021
La	0.53	0.5285
Mn	0.89	0.8872
Mo	0.65	0.647
Na	0.16	0.1586
Ni	0.88	0.8757
Pb	0.26	0.2589
P	0.26	0.2637
Pr	0.57	0.5701
Rb	0.51	0.5106
Sc	0.76	0.7602
S	0.91	0.912
Sr	0.77	0.7686
Th	0.74	0.7447
Ti	0.77	0.7706
U	0.5	0.502
V	0.7	0.6972
W182	0.67	0.6707
W184	0.67	0.6727
Y	0.63	0.6293
Zn	0.14	0.1374
Zr90	0.67	0.6688
Zr91	0.66	0.6644

Supplementary Table S5. All experimental data, stability constants, and conditions for stability constant analysis.

Experiment number	Acid Name	Metal	$M (M)$	R	Log k	Temp (°C)	Ionic Strength
162	Acetic	Ca	5.08×10^{-5}	0.93	1.18	25	0.0
216	Citric	Ca	1.45×10^{-4}	2.65	4.85	25	0.0
198	Formic	Ca	4.74×10^{-5}	0.86	1.43	25	0.0
180	Fumaric	Ca	5.72×10^{-5}	1.04	2	25	0.0
207	Gluconic	Ca	4.50×10^{-5}	0.82	1.21	25	0.1
189	Glutamic	Ca	4.73×10^{-5}	0.86	2.06	25	0.0
252	Glycolic	Ca	6.00×10^{-5}	1.09	1.62	25	0.0
225	Lactic	Ca	5.77×10^{-5}	1.05	1.48	25	0.0
234	Malic	Ca	1.03×10^{-4}	1.88	2.72	25	0.0
279	Nitric	Ca	5.48×10^{-5}	1.00	0.5	25	0.0
261	Oxalic	Ca	8.68×10^{-5}	1.58	3.19	25	0.0
171	Sulfuric	Ca	1.06×10^{-4}	1.93	2.36	25	0.0
270	AIB	Cu	4.64×10^{-6}	3.39	8.26	25	0.1
162	Acetic	Cu	1.88×10^{-6}	1.38	1.79	25	0.1
216	Citric	Cu	5.55×10^{-6}	4.05	3.9	25	0.1
198	Formic	Cu	1.56×10^{-6}	1.14	1.61	25	0.1
180	Fumaric	Cu	5.99×10^{-6}	4.37	2.51	25	0.0
207	Gluconic	Cu	5.47×10^{-6}	3.99	2.51	25	0.1
189	Glutamic	Cu	3.90×10^{-6}	2.85	8.32	25	0.1
252	Glycolic	Cu	6.93×10^{-6}	5.06	2.4	25	0.1
225	Lactic	Cu	4.63×10^{-6}	3.38	3.02	25	0.0
234	Malic	Cu	5.13×10^{-6}	3.75	3.63	25	0.1
279	Nitric	Cu	1.37×10^{-6}	1.00	0.5	25	0.0
261	Oxalic	Cu	1.94×10^{-6}	1.42	4.85	25	0.1
171	Sulfuric	Cu	8.08×10^{-7}	0.59	1.26	25	0.1
288	Valeric	Cu	3.17×10^{-6}	2.31	2.12	25	0.0
162	Acetic	K	2.32×10^{-4}	0.09	-0.27	25	0.0
216	Citric	K	4.77×10^{-5}	0.02	1.17	25	0.0
234	Malic	K	7.54×10^{-5}	0.03	0.43	25	0.0
279	Nitric	K	2.48×10^{-3}	1.00	-0.19	25	0.0
261	Oxalic	K	1.15×10^{-4}	0.05	0.8	25	0.0
171	Sulfuric	K	1.38×10^{-2}	5.59	0.85	25	0.0
162	Acetic	Mg	5.83×10^{-4}	1.03	1.26	25	0.0
216	Citric	Mg	5.35×10^{-3}	9.45	4.86	25	0.0
198	Formic	Mg	5.23×10^{-4}	0.93	1.43	25	0.0
207	Gluconic	Mg	7.67×10^{-4}	1.36	0.70	25	0.1

Experiment number	Acid Name	Metal	$M (M)$	R	Log k	Temp (°C)	Ionic Strength
189	Glutamic	Mg	4.37×10^{-4}	0.77	1.9	25	0.1
252	Glycolic	Mg	7.87×10^{-4}	1.39	1.33	25	0.0
225	Lactic	Mg	8.54×10^{-4}	1.51	1.37	25	0.0
234	Malic	Mg	2.73×10^{-3}	4.82	1.71	25	0.1
279	Nitric	Mg	5.48×10^{-5}	1.00	NA	NA	NA
261	Oxalic	Mg	3.00×10^{-3}	5.30	2.76	20	0.1
171	Sulfuric	Mg	1.35×10^{-3}	2.39	2.26	25	0.0
162	Acetic	Mn	1.69×10^{-5}	1.13	1.4	25	0.0
216	Citric	Mn	2.17×10^{-5}	1.45	4.15	25	0.1
180	Fumaric	Mn	1.78×10^{-5}	1.19	0.99	25	0.1
252	Glycolic	Mn	1.40×10^{-5}	0.94	1.58	25	0.0
225	Lactic	Mn	1.30×10^{-5}	0.87	1.73	25	0.0
234	Malic	Mn	1.83×10^{-5}	1.22	2.24	25	0.1
279	Nitric	Mn	1.50×10^{-5}	1.00	0.2	25	0.0
261	Oxalic	Mn	1.39×10^{-5}	0.93	3.95	25	0.0
171	Sulfuric	Mn	2.59×10^{-5}	1.73	2.25	25	0.0
270	AIB	Ni	7.31×10^{-5}	1.24	2.12	25	0.5
162	Acetic	Ni	6.22×10^{-5}	1.06	0.88	25	0.1
216	Citric	Ni	2.01×10^{-5}	0.34	5.32	25	0.1
207	Gluconic	Ni	6.39×10^{-5}	1.08	1.82	25	0.1
189	Glutamic	Ni	6.62×10^{-5}	1.12	5.61	25	0.1
252	Glycolic	Ni	7.31×10^{-5}	1.24	2.26	25	0.0
225	Lactic	Ni	6.30×10^{-5}	1.07	2.2	25	0.0
234	Malic	Ni	6.52×10^{-5}	1.11	3.17	20	0.1
279	Nitric	Ni	5.89×10^{-5}	1.00	0.4	25	0.0
261	Oxalic	Ni	4.55×10^{-5}	0.77	4.16	25	0.1
171	Sulfuric	Ni	7.20×10^{-5}	1.22	1	25	0.1

Supplementary Table S6. Parameter estimates and R^2 values for individual regressions.

Element	Parameter estimate	R2
Ca	$y = 0.4872x + 0.2181$	$R^2 = 0.8898$
Mg	$y = 2.3242x - 1.6777$	$R^2 = 0.8358$
Ni	$y = -0.0916x + 1.2654$	$R^2 = 0.2942$
Mn	$y = 0.0491x + 0.9919$	$R^2 = 0.0897$
Cu	$y = 0.0288x + 2.9826$	$R^2 = 0.0027$
K	$y = -0.0475x + 0.0727$	$R^2 = 0.7887$