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Effects of basalt, concrete fines, and steel slag on maize growth and toxic trace element accumulation in an enhanced weathering experiment

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Fig. S1 Particle size distribution for basalt, concrete fines and steel slag. P80= 80% of the particles having a diameter less than or equal to this size.

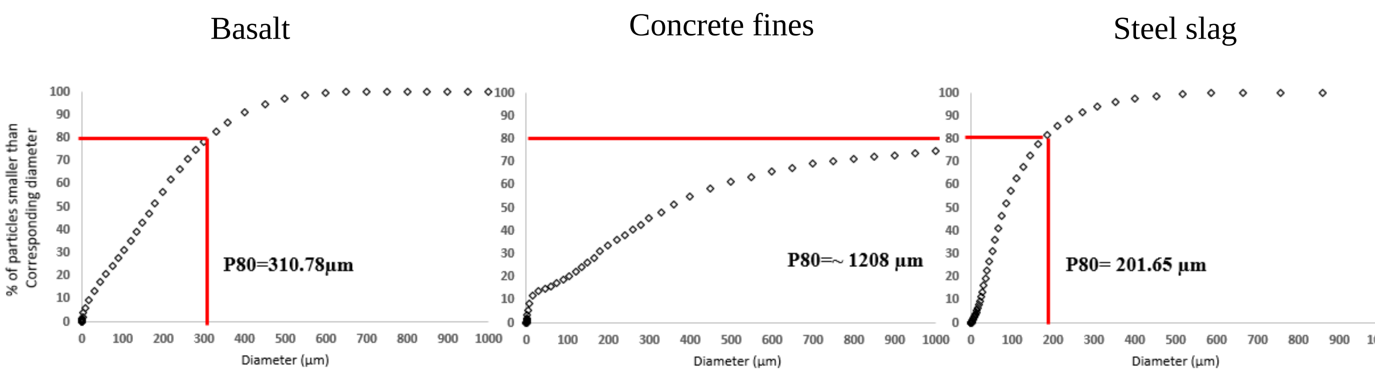


Fig. S2 Soil water content during the experiment of the mesocosms for the different application rates of basalt, concrete fines and steel slag. Data retrieved from Cambell Scientific sensors (CS616).

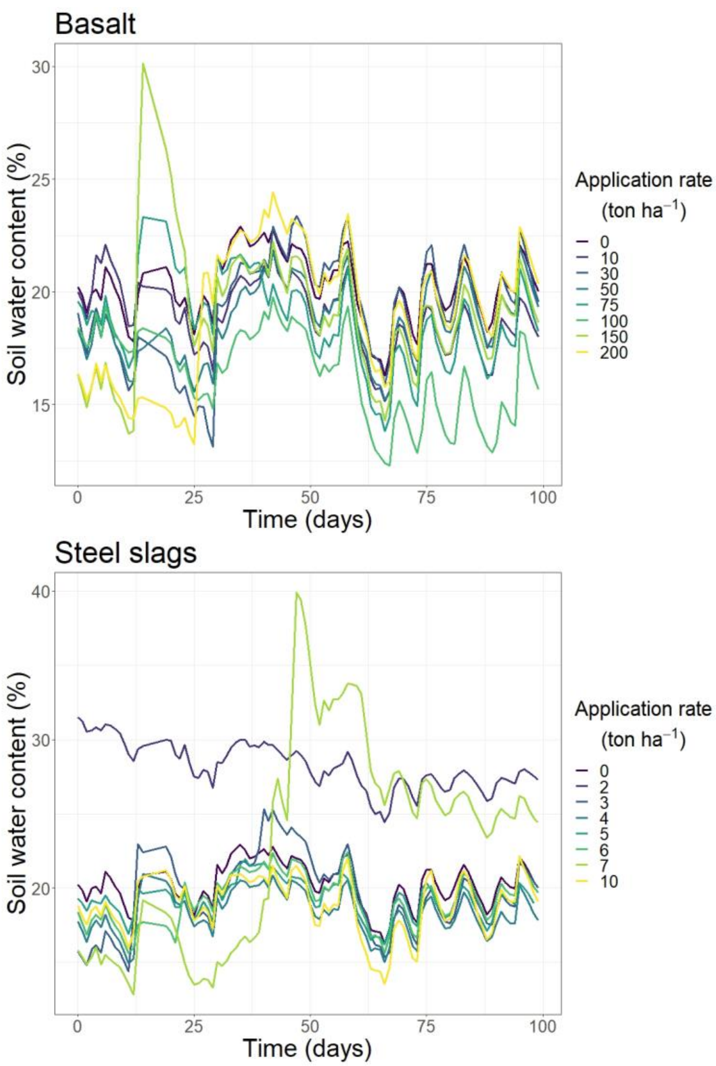
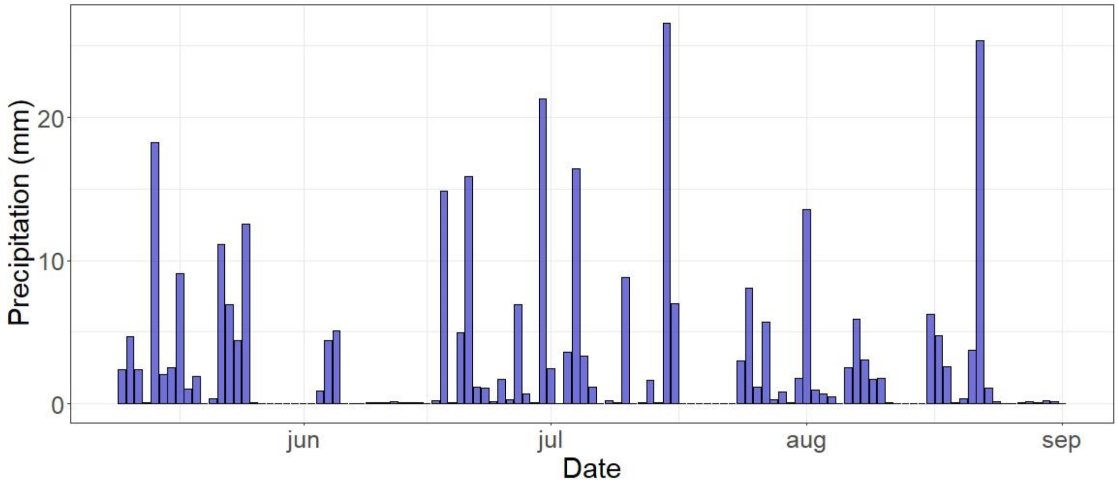


Fig. S3 Daily precipitation and average air temperature during the experiment retrieved from visualcrossing (https://www.visualcrossing.com/). Average air temperature is shown within the range of minimum and maximum air temperature.



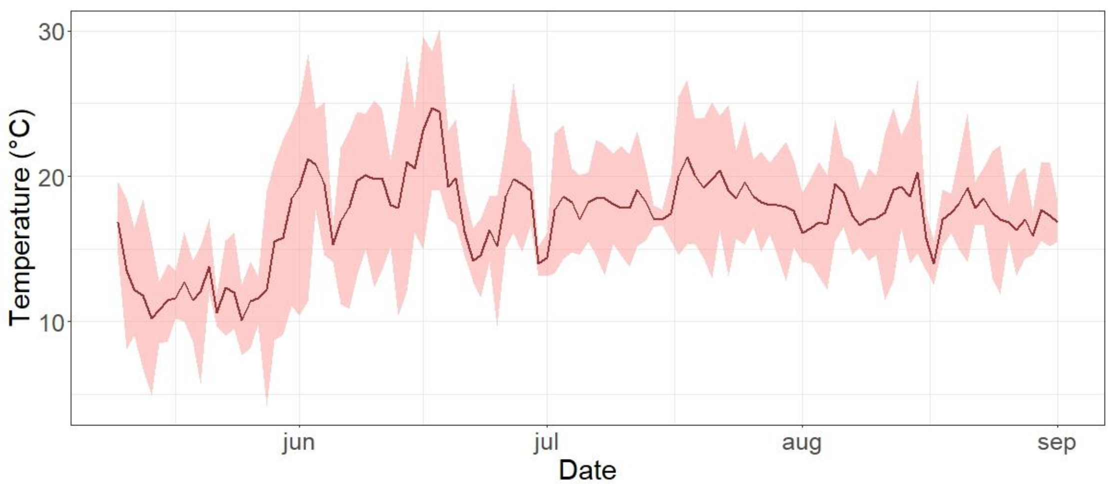
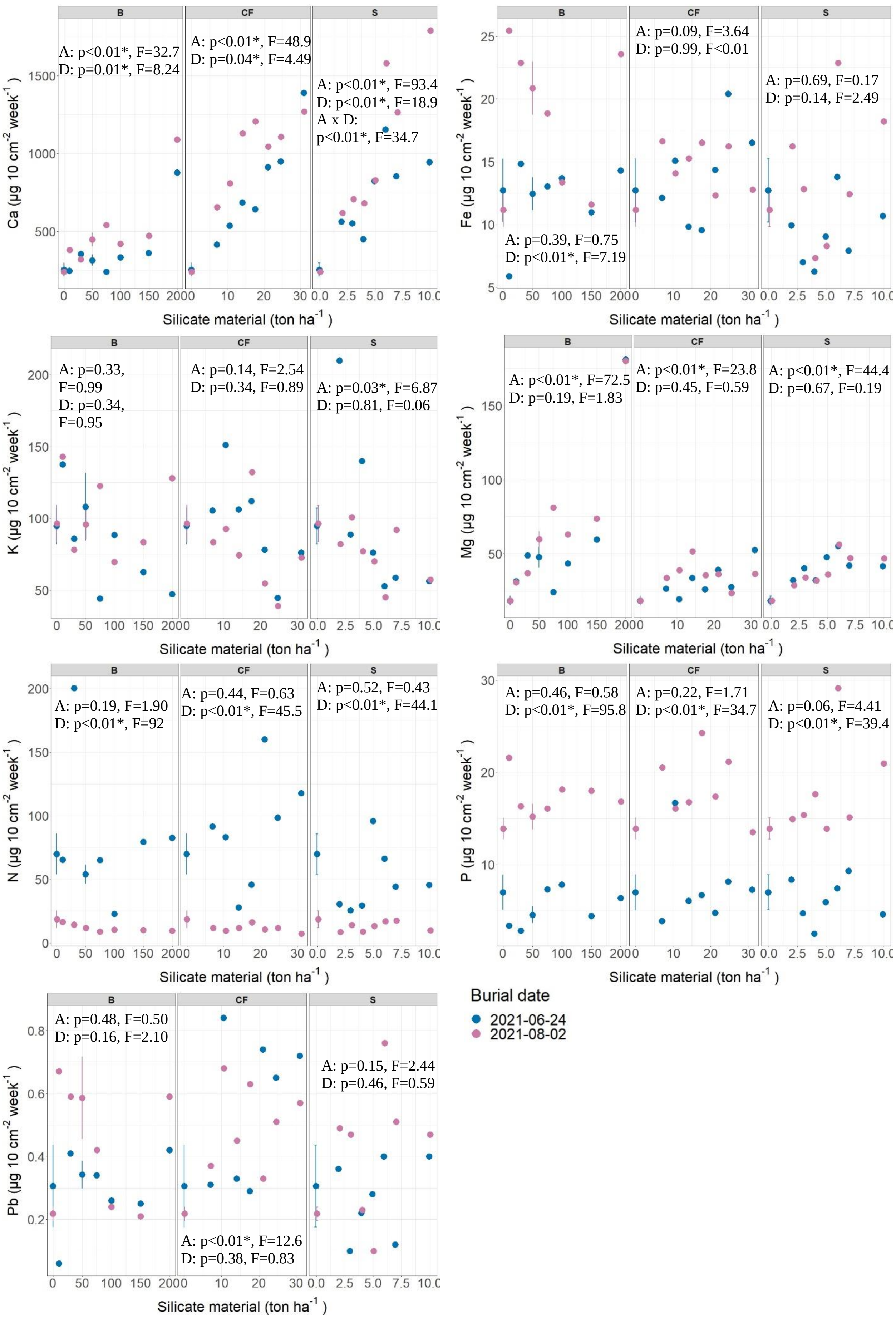


Fig. S4 Plant nutrient availability retrieved from PRS probes on two occasions during the experiment for the application amount of the silicate (B = basalt, CF = concrete fines, S = steel slag). Data of 0 and 50 ton ha^{-1} of basalt are average of five replicates with standard error. Note that in some cases, the error bars are smaller than the symbol. The other treatments each have one measurement. P-and F values are shown of a linear mixed model with nutrient availability from the PRS probes as response variable and application amount of the silicate material (=A), burial date (=D), and the interaction (=A x D) as covariable. Interactions are only shown when statistically significant (p<0.05).



B
CF
S
A: p<0.01*, F=32.7
D: p=0.01*, F=8.24
A: p<0.01*, F=48.9
D: p=0.04*, F=4.49
A: p<0.01*, F=93.4
D: p<0.01*, F=18.9
A x D:
p<0.01*, F=34.7
Ca (µg 10 cm-2 week-1)
A: p=0.09, F=3.64
D: p=0.99, F<0.01
A: p=0.69, F=0.17
D: p=0.14, F=2.49
A: p=0.39, F=0.75
D: p<0.01*, F=7.19
Fe (µg 10 cm-2 week-1)
A: p=0.33,
F=0.99
D: p=0.34,
F=0.95
A: p=0.14, F=2.54
D: p=0.34, F=0.89
A: p=0.03*, F=6.87
D: p=0.81, F=0.06
K (µg 10 cm-2 week-1)
A: p<0.01*, F=72.5
D: p=0.19, F=1.83
A: p<0.01*, F=23.8
D: p=0.45, F=0.59
A: p<0.01*, F=44.4
D: p=0.67, F=0.19
Mg (µg 10 cm-2 week-1)
A: p=0.19, F=1.90
D: p<0.01*, F=92
A: p=0.44, F=0.63
D: p<0.01*, F=45.5
A: p=0.52, F=0.43
D: p<0.01*, F=44.1
N (µg 10 cm-2 week-1)
A: p=0.46, F=0.58
D: p<0.01*, F=95.8
A: p=0.22, F=1.71
D: p<0.01*, F=34.7
A: p=0.06, F=4.41
D: p<0.01*, F=39.4
P (µg 10 cm-2 week-1)
A: p=0.48, F=0.50
D: p=0.16, F=2.10
A: p<0.01*, F=12.6
D: p=0.38, F=0.83
A: p=0.15, F=2.44
D: p=0.46, F=0.59
Pb (µg 10 cm-2 week-1)
Silicate material (ton ha-1)
Burial date
2021-06-24
2021-08-02

Fig. S5 PC3 and PC4 of the principal component analysis with porewater nutrients (Ca, Fe, K, Mg, Si), toxic trace elements (Cr, Ni, Pb, V), porewater pH, soil pH, and soil CEC. Differences in PC3 and PC4 were found among silicate materials (B= Basalt, C= Control, CF= Concrete fines, S= Steel slag) by linear regression analysis with PC3 or PC4 as fixed variable and silicate treatment as covariables. P-and F-values are shown in table S7.

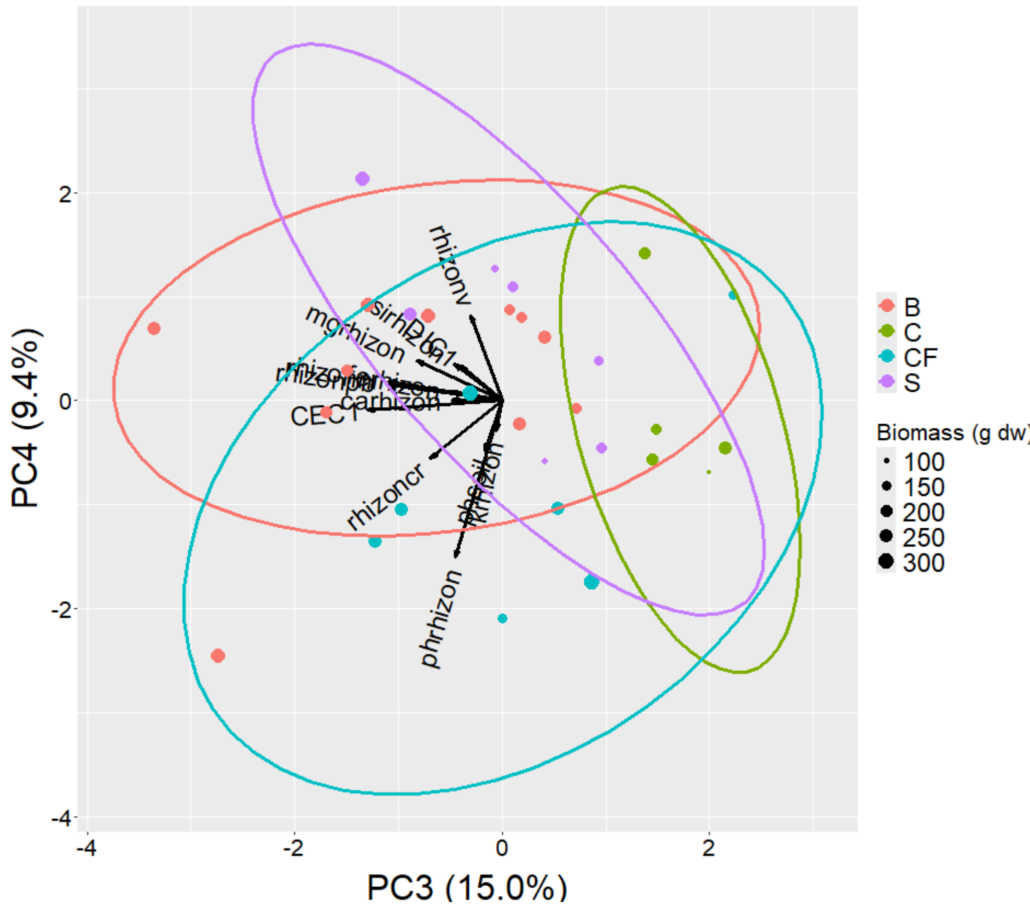


Fig. S6 C and N % in corn, tassel, stem and top leaf of the silicate treatments (basalt, concrete fines, steel slag). Data of 0 and 50 ton ha^{-1} of basalt are average of five replicates with standard error. Note that in some cases, the error bars are smaller than the symbol. The other treatments have one measurement each. P and F-values are shown from a linear model with C and N % in the plant parts as response variable and application amount of the silicate material as covariable. Statistically significant relationships are indicated with an asterisk (*), with equation and regression line.

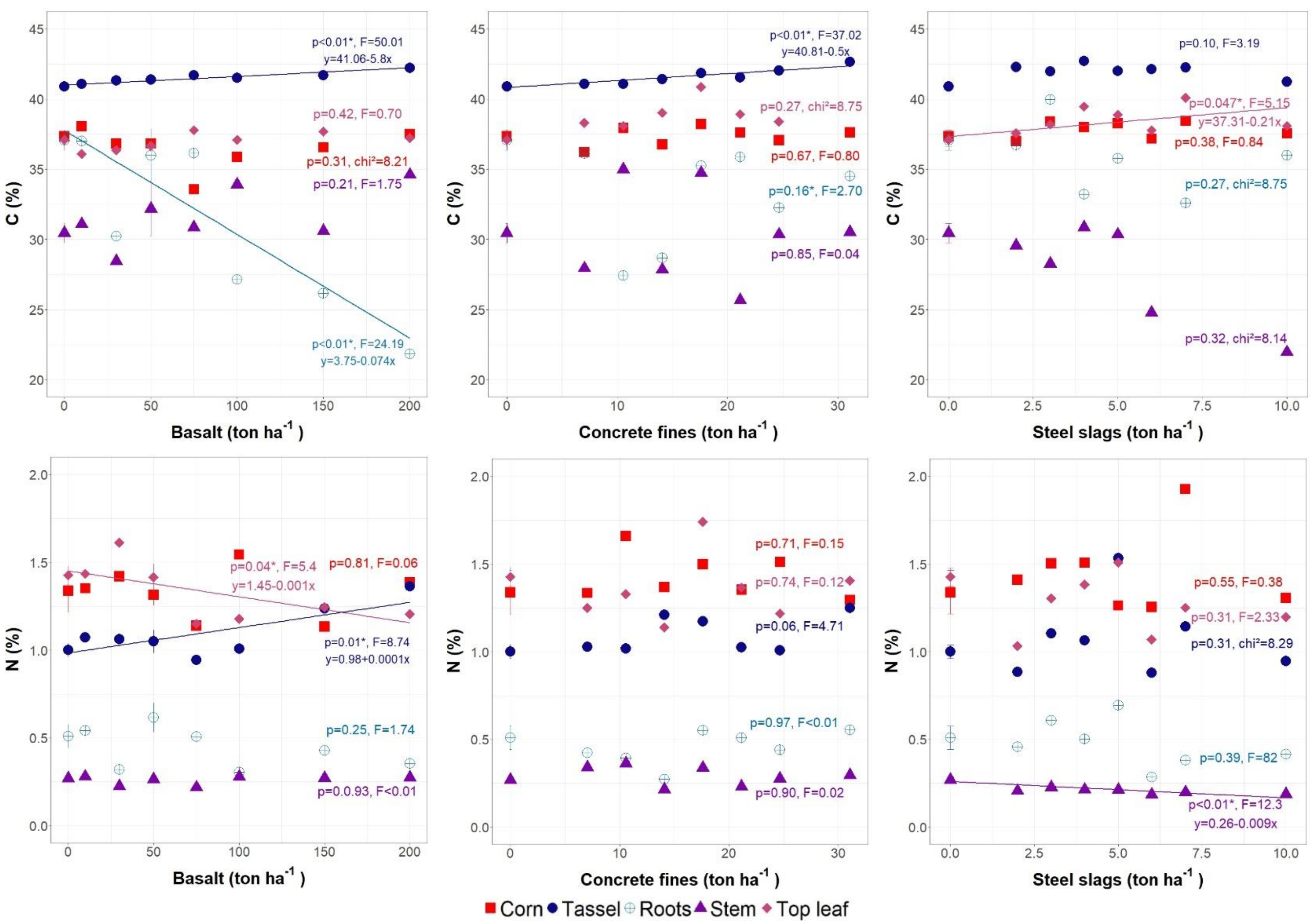


Fig. S7 C and N stocks in maize for the three silicate treatments (basalt, concrete fines, steel slag). Data for the control treatment (0 ton ha^{-1}) and for 50 ton ha^{-1} of basalt are average of five replicates with standard error. Note that in some cases, the error bars are smaller than the symbol. The other treatments each have one replicate. P and F-values are shown of the linear model with C or N stocks as response variable and relative addition (RA) as covariable. P-and F-values for the silicate treatments separately of a linear model with C or N stock as response variable and silicate concentration as covariable are shown as well. Statistically significant relationships are indicated with an asterisk (*), with equation and regression line.

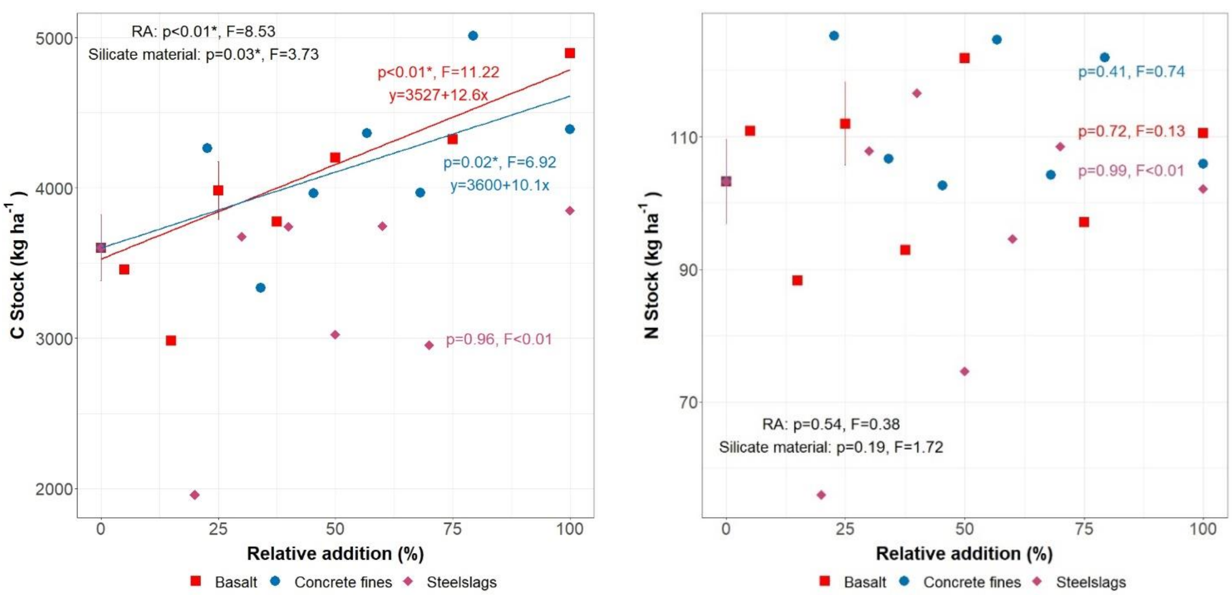


Fig. S8 Ca/Mg ratio in the porewater during the experiment for the silicate treatments (basalt, concrete fines, steel slag). Data of 0 and 50 ton ha^{-1} of basalt are average of five replicates with standard error. Note that in some cases, the error bars are smaller than the symbol. The other treatments have one measurement each. P and F-values are shown of a linear mixed model with Ca/Mg ratio as a response variable and silicate application amount, time and the interaction as covariables. Interactions were not statistically significant (p>0.05) and are therefore not shown.

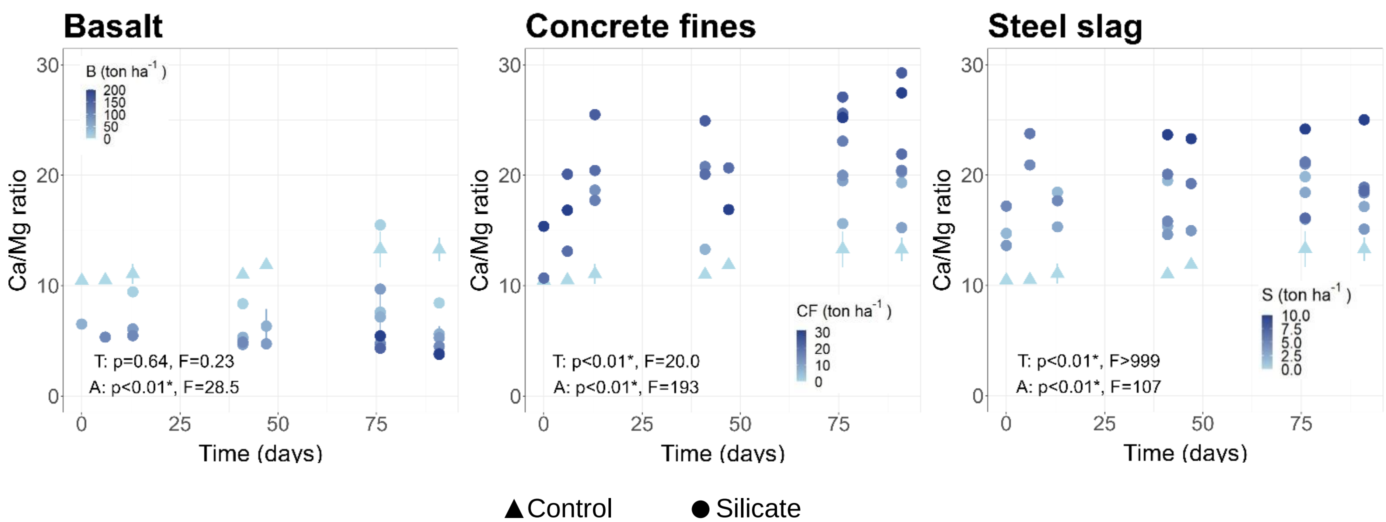


Table S1 XRD of basalt, steel slag and concrete fines used in this study.

Basalt		Seel slag		Concrete fines	
Mineral phase	**Mass %**	**Mineral phase**	**Mass %**	**Mineral phase**	**Mass %**
Clinopyroxene	21.22	Srebrodolskite	8.36	Quartz (SiO2)	73.42
Enstatite	0.66	Magnetite	1.81	Calcite (CaCO3)	17.89
Pigeonite	2.36	beta-C2S	7.06	Corundum (Al2O3)	2.57
Forsterite	14.45	Bredigite	4.41	Aluminium Iron Oxide (Al2O3 with 10% of the Al substituted by Fe)	6.16
Hedenbergite	6.98	Wuestite	3.93		
Ankerite	0.18	Portlandite	2.38		
Grossmanite	1.29	Calcite	8.66		
Albite	1.29	Hematite	0.27		
Labradorite	5.7	Quartz	1.11		
Analcime	0.93	Periclase	1.92		
Quartz	0.07	Lime	0.00006		
Magnetite	2.73	Iron	0.62		
Amorphous phase	42.14	Amorphous phase	59.46		

Table S2 The amount of water that was added manually during the experiment. For the control treatment and 50 ton ha^{-1} of basalt, the experiment had five replicates. It is indicated how many of these replicates got the amount of water in the column 'Water added (L)'. From the 31 of May onwards, each mesocosm received the same amount of water.

Date	Water added (L)	treatments	application rates (ton ha^{-1})
17/May	4	Control	5x0
		Basalt	10, 30, 4x50, 75, 100, 150, 200
		Concrete fines	7.04, 10.57, 14.09, 17.62, 21.15, 24.67, 31.07
		Steel slag	2, 3, 4, 6, 7, 10
	5	Basalt	1x50
		Steel sla	5
25/May	4	Control	3x0
		Basalt	10, 3x50, 150, 200
		Concrete fines	31.07
		Steel slag	4, 7
	4.5	Basalt	30
		Concrete fines	10.57, 14.09
		Steel slag	2, 10
	5	Control	2x0
		Basalt	1x50, 75, 100
		Concrete fines	7.04, 17.62, 21.15, 24.67
		Steel sla	3, 6
	5.5	Basalt	1x50
	6	Steel slag	5
31/May	6.5	All	All
7/Jun	1.5	All	All
10/Jun	2	All	All
14/Jun	2	All	All
23/Jun	1	All	All
28/Jun	1	All	All
6/Jul	1	All	All
13/Jul	1	All	All
22/Jul	2	All	All
26/Jul	2	All	All
2/Aug	2	All	All
9/Aug	2	All	All

Table S3 The p and F-values from a linear mixed model with nutrient concentration in the porewater as response variable and application amount of the silicate material (basalt, concrete fines, steel slag), time (days after sowing) and the interaction as covariable (Fig 3). ns=not statistically significant, statistically significant relationships are indicated with an asterisk (*)

	Basalt		**Concrete fines**		**Steel slag**	
Ca	**p-value**	**F-value**	**p-value**	**F-value**	**p-value**	**F-value**
Application amount	<0.01*	12.1	<0.01*	974	<0.01*	165
time	<0.01*	9.27	<0.01*	56.3	<0.01*	28.7
application amount :time	0.04*	4.45	ns	ns	ns	ns
Mg						
Application rate	<0.01*	8.22	<0.01*	287	<0.01*	65.3
time	<0.01*	22.7	<0.01*	133	<0.01*	20.6
application amount :time	<0.01*	3.16	0.04*	4.62	<0.01*	11.7
Si						
Application rate	0.09	3.06	<0.01*	15.0	<0.01*	10.2
time	<0.01*	961	<0.01*	106	<0.01*	69.3
application amount :time	<0.01*	15.3	<0.01*	16.0	0.03*	5.45
Fe						
Application rate	0.76	0.10	0.03*	6.46	0.87	0.03
time	0.20	1.30	<0.01*	26.2	<0.01*	10.1
application amount :time	ns	ns	ns	ns	ns	ns
K						
Application rate	0.57	0.34	<0.01*	26.7	0.11	3.09
time	0.05	4.25	0.30	1.13	0.57	0.33
application amount :time	ns	ns	0.20*	5.86	ns	ns

Table S4 The p-and F-values of a linear mixed effect with dissolved inorganic carbon (DIC), porewater pH, soil pH and porewater nutrients or toxic trace element concentration as response variable and silicate material, relative addition (RA) and the interaction as covariable. For DIC, porewater pH and soil pH, the interaction with time (day) is also incorporated in the model. RA is used to allow for comparison among the silicate types (Fig 2, 3, 4). ns=not significant, statistically significant relationships are indicated with an asterisk (*)

	DIC		**pH**		**Soil pH**		**K**	
	p-value	*F*	*p-value*	*F*	*p-value*	*F*	*p-value*	*F*
Silicate	<0.01*	8.02	0.06	2.84	0.01*	18.7	0.54	0.59
RA	<0.01*	169	<0.01*	165	<0.01*	77.4	0.12	2.59
RA *silicate	0.01*	4.91	0.04*	3.79	0.04*	3.50	ns	ns
Silicate*day	ns	ns	ns	ns	0.06	2.91		
RA*silicate*day	ns	ns	ns	ns	0.01*	4.61		
	Ca		**Fe**		**Mg**		**Si**	
	p-value	*F*	*p-value*	*F*	*p-value*	*F*	*p-value*	*F*
Silicate	0.01*	4.97	0.82	0.20	0.81	0.21	0.80	0.23
RA	<0.01*	13.3	0.02*	5.99	0.70	0.16	0.19	1.76
RA *silicate	<0.01*	7.82	ns	ns	ns	ns	ns	ns
	Cr		**Ni**		**Pb**		**V**	
	p-value	*F*	*p-value*	*F*	*p-value*	*F*	*p-value*	*F*
Silicate	0.01*	4.88	<0.01*	38.1	<0.01*	8.44	<0.01*	31.8
RA	0.15	2.18	0.01*	7.09	<0.01*	25.8	<0.01*	58.1
RA *silicate	<0.01*	9.14	<0.01*	12.2	<0.01*	8.29	<0.01*	23.9

Table S5 The p-and F values from a linear mixed model with plant availability of Ca, Fe, K, Mg, total N, P and Pb retrieved from PRS probes as response variable and the relative addition (RA) of the different silicate materials (basalt, concrete fines and steel slag), burial date and the interaction between RA and silicate treatment as covariable. Statistically significant relationships are indicated with an asterisk (*)

PRS probes	**Ca**		**Fe**		**K**		**Mg**		**Total N**		**P**		**Pb**	
	p-value	F	p-value	F	p-value	F	p-value	F	p-value	F	p-value	F	p-value	F
RA	<0.01*	133	0.20	1.74	0.01*	7.36	<0.01*	38.9	0.37	0.83	0.13	2.42	0.048*	4.30
Treatment	0.01*	4.63	0.10	2.41	0.96	0.04	<0.01*	6.42	0.59	0.54	0.47	0.78	0.46	0.80
Burial date	<0.01*	15.5	<0.01*	7.49	0.50	0.46	0.06	3.80	<0.01*	204	<0.01*	173	0.27	1.23
RA*T	<0.01*	6.64	ns	ns	ns	ns	<0.01*	10.2	ns	ns	ns	ns	ns	ns

Table S6 Concentrations of Cd in the porewater and Pb in the plant stems that were above the limit of quantification (LOQ, for Cd = 0.0015 mg L^{-1}, for Pb = 0.1 mg kg^{-1}). For the other treatments, Cd and Pb concentrations were below the LOQ.

Treatment	Application amount (ton ha^{-1})	Cd	Medium
Control	0	0.00032	Porewater (mg L^{-1})
Control	0	0.00023	
Basalt	30	0.00023	
Basalt	50	0.00022	
Basalt	150	0.00076	
Control	0	0.03	Corn (mg kg^{-1})
Basalt	50	0.03	
Concrete fines	21.14	0.03	
		Pb	
Basalt	10	0.21	Stem (mg kg^{-1})
Basalt	30	0.20	
Basalt	50	0.22	
Steel slag	2	0.21	

Table S7 The P-and F-values obtained from a linear model with principal component (PC) 1, 2, 3, 4 or 5 as response variable and treatment as a covariable. When a significant effect was found (p>0.05, indicated with an asterisk (*)), a Tukey post-hoc test was used to investigate differences among treatments (B= Basalt, C= Control, CF= concrete fines, S= Steel slag).

	PC1	PC2	PC3	PC4	PC5
p-value	<0.01*	0.50	<0.01*	0.04*	<0.01*
F-value	32.9	0.48	6.32	3.13	8.18
Treatment	**PC1**		**PC3**	**PC4**	**PC5**
B-C	0.24		<0.01*	0.94	0.39
B-CF	<0.01*		0.23	0.13	0.16
B-S	<0.01*		0.35	0.75	0.03*
CF-C	<0.01*		0.11	0.55	0.02*
CF-S	0.99		0.99	0.03*	<0.01*
S-C	<0.01*		0.07	0.53	0.74

Table S8 The P-and F-values obtained from a linear model with leaf area index (LAI) or aboveground/belowground ratio (A/B ratio) as response variable and silicate application amount as a covariable. LAI was measured on two occasions during the experiment.

Day	**LAI day 43**		**LAI day 70**		**A/B ratio**	
Silicate	*p-value*	*F*	*p-value*	*F*	*p-value*	*F*
Basalt	0.13	2.54	0.98	<0.01	0.18	2.02
Concrete fines	0.35	0.98	0.16	2.36	0.28	1.34
Steel slag	0.43	0.67	0.17	2.28	0.19	2.06

Table S9 The P-and F-values of a linear model with total biomass, biomass of the different plant parts or aboveground/belowground ratio (A/B ratio) as response variable and type of silicate material (basalt, concrete fines or steel slag) and relative addition (RA) as covariables. Statistically significant differences are indicated by an asterisk (*). The interaction between silicate type and RA was also incorporated in the model, but were all not significant and are therefore not shown.

	Total biomass		**Corn**		**Stem**		**Leaves**		**Tassel**		**Roots**		**A/B ratio**	
	p	F	p	F	p	F	p	F	p	F	p	F	p	F
Silicate type	0.03*	3.92	0.09	2.56	0.21	1.62	0.17	1.86	0.49	0.73	0.95	0.05	0.81	0.22
RA	<0.01*	7.94	0.67	0.18	<0.01*	7.78	0.07	3.46	<0.01*	34.2	<0.01*	12.7	0.01*	6.69

Table S10 The p-and F values of a linear model with nutrient (Ca, Mg, Si, K, P) concentrations or the C/N ratio in the plant parts as response variable and relative addition (RA), type of silicate material (basalt, concrete fines, steel slag) and the interaction as covariables. Statistically significant relationships are indicated with an asterisk (*). Non-significant interactions are shown as ns and are removed from the model. For leaves and tassel, no statistically significant interactions were found.

	Ca		**Mg**		**Si**		**K**		**P**		**Fe**		**C/N ratio**	
	p-value	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**	**F**
Stem														
Silicate	<0.01*	19.2	<0.01*	12.8	0.78	0.37	0.26	1.43	0.94	013	0.11	2.36	0.08	2.51
RA	0.26	1.33	0.14	2.27	0.02	6.35	0.19	1.82	0.46	0.55	0.31	1.08	0.60	0.28
Corn														
Silicate	0.83	0.30	0.60	0.64	<0.01*	15.9	0.13	2.08	0.59	0.34	0.74	0.3	0.48	0.84
RA	0.32	1.04	0.14	2.36	<0.01*	79.0	0.46	0.56	0.51	0.29	0.03*	4.62	0.67	0.13
Leaves														
Silicate	0.06	2.75	<0.01*	4.07	<0.01*	14.9	0.05	2.94	0.68	0.51	0.88	0.13	0.41	0.99
RA	0.93	<0.01	<0.01*	9.04	<0.01*	17.2	0.28	1.23	0.02*	5.79	0.02*	6.16	<0.01*	10.2
Tassel														
Silicate	0.32	1.22	0.48	0.90	0.08	2.50	0.69	0.49	0.73	0.44	0.35	1.09	0.82	0.31
RA	0.04*	4.89	<0.01*	26.5	0.04*	4.63	0.71	0.14	0.03*	5.55	0.16	2.10	0.13	2.43
Roots														
Silicate	0.03*	3.52	<0.01*	6.94	0.14	2.09	0.92	0.16	0.28	1.36	/	/	0.74	0.42
RC	<0.01*	13.2	0.12	2.66	0.34	0.97	0.67	0.19	0.26	1.35	/	/	0.60	0.28
Silicate*RA	ns	ns	<0.01*	7.87	ns	ns	ns	ns	ns	ns	/	/	ns	ns

Table S11 The p-and F values of a linear model with toxic trace element (Cd, Cr, Fe, Ni, Pb, V) concentrations in the plant parts as response variable and relative addition (RA), type of silicate material (basalt, concrete fines, steel slag) and the interaction as covariables. Statistically significant relationships are indicated with an asterisk (*). Non-significant interactions are shown as ns and are removed from the model. For corn, leaves and tassel, no significant interactions were found.

	Cd		**Cr**		**Ni**		**Pb**		**V**	
	p-value	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**	**F**
Stem										
Silicate	0.01*	5.27	0.29	1.27	0.49	0.73	<LOQ	<LOQ	0.64	0.45
RA	<0.01*	8.53	0.14	2.26	0.02*	6.22	<LOQ	<LOQ	0.49	0.49
Silicate x RC	0.04*	3.54	ns	ns	ns	ns	<LOQ	<LOQ	ns	ns
Corn										
Silicate	<LOQ	<LOQ	0.99	41.4	0.01	5.22	<LOQ	<LOQ	0.85	0.17
RA	<LOQ	<LOQ	<0.01*	<0.01	<0.01*	17.12	<LOQ	<LOQ	0.06	3.82
Leaves										
Silicate	0.97	0.03	0.78	0.25	0.61	0.26	0.50	0.70	0.90	0.11
RA	<0.01*	7.47	0.85	0.04	0.61	0.5	0.23	1.47	<0.01*	9.45
Tassel										
Silicate	0.70	0.37	0.13	2.14	0.16	1.95	0.44	0.84	0.64	0.89
RA	<0.01*	27.2	0.11	2.68	0.47	0.54	0.19	1.77	0.56	16.6

Methods S1 Statistical analysis to investigate differences in influence among the three types of silicate materials on soil and plant variables.

Due to the differences in application amounts of the three silicate materials, direct comparison among the types of silicate material was not possible. Nonetheless, in an attempt to standardize across silicate materials, the application amounts were expressed as a percentage of the highest added amount, hereafter referred to as relative additions. A two-way ANOVA was employed to analyse the influence of silicate material type, relative addition, and their interaction on plant biomass, plant nutrient and metal concentrations, metal concentrations of the soil porewater, and CEC of the soil. The 'area under curve' method was utilized to assess the overall effect of silicate material type, relative addition, and their interaction on soil pH and soil porewater pH, DIC, and nutrient concentrations in the soil porewater over the growing season.