SOILS: WHERE FOOD BEGINS

Si bioavailability and fate of the applied phytogenic silica in a soil plant system in acidic, neutral and alkaline soils

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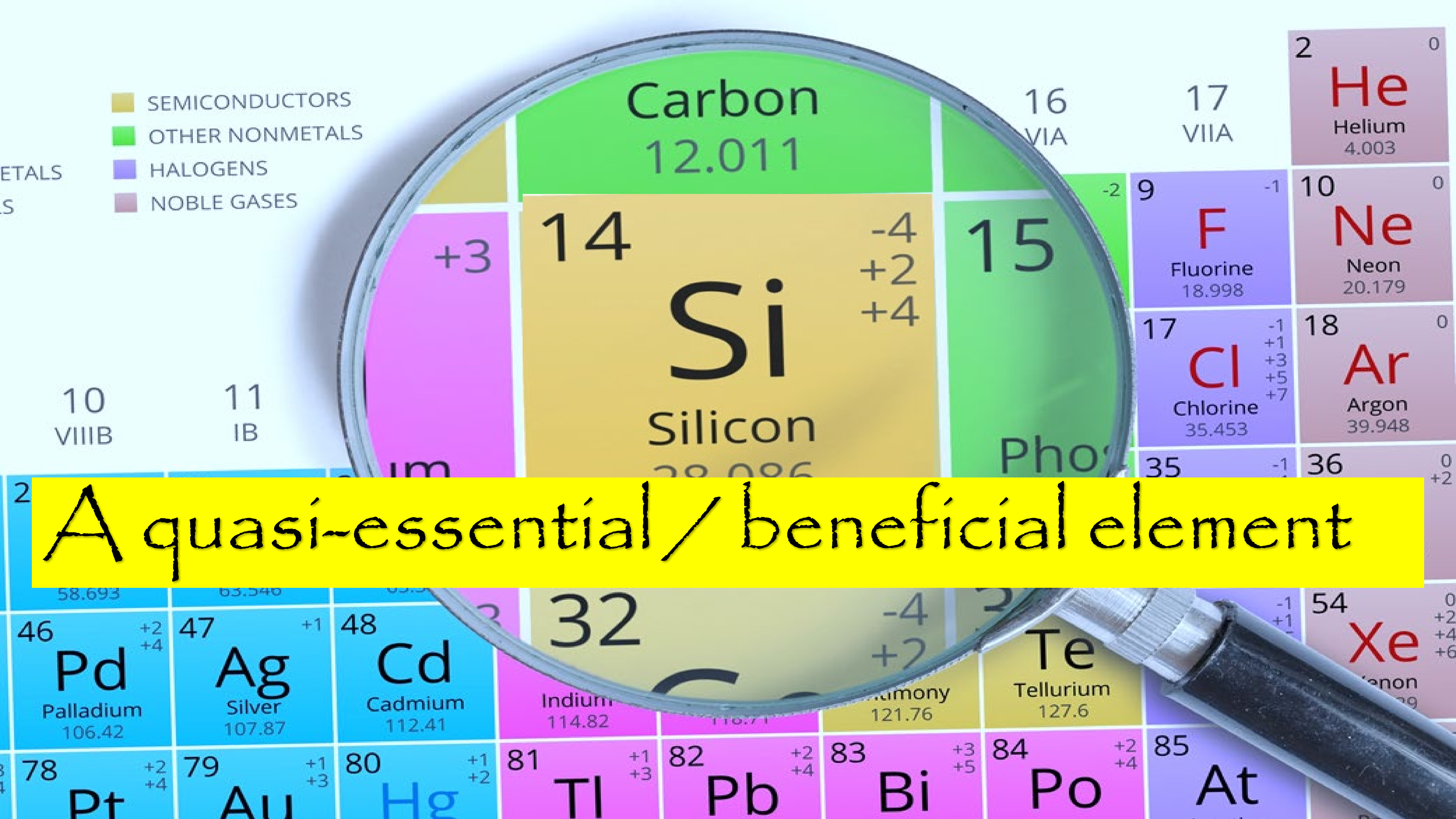
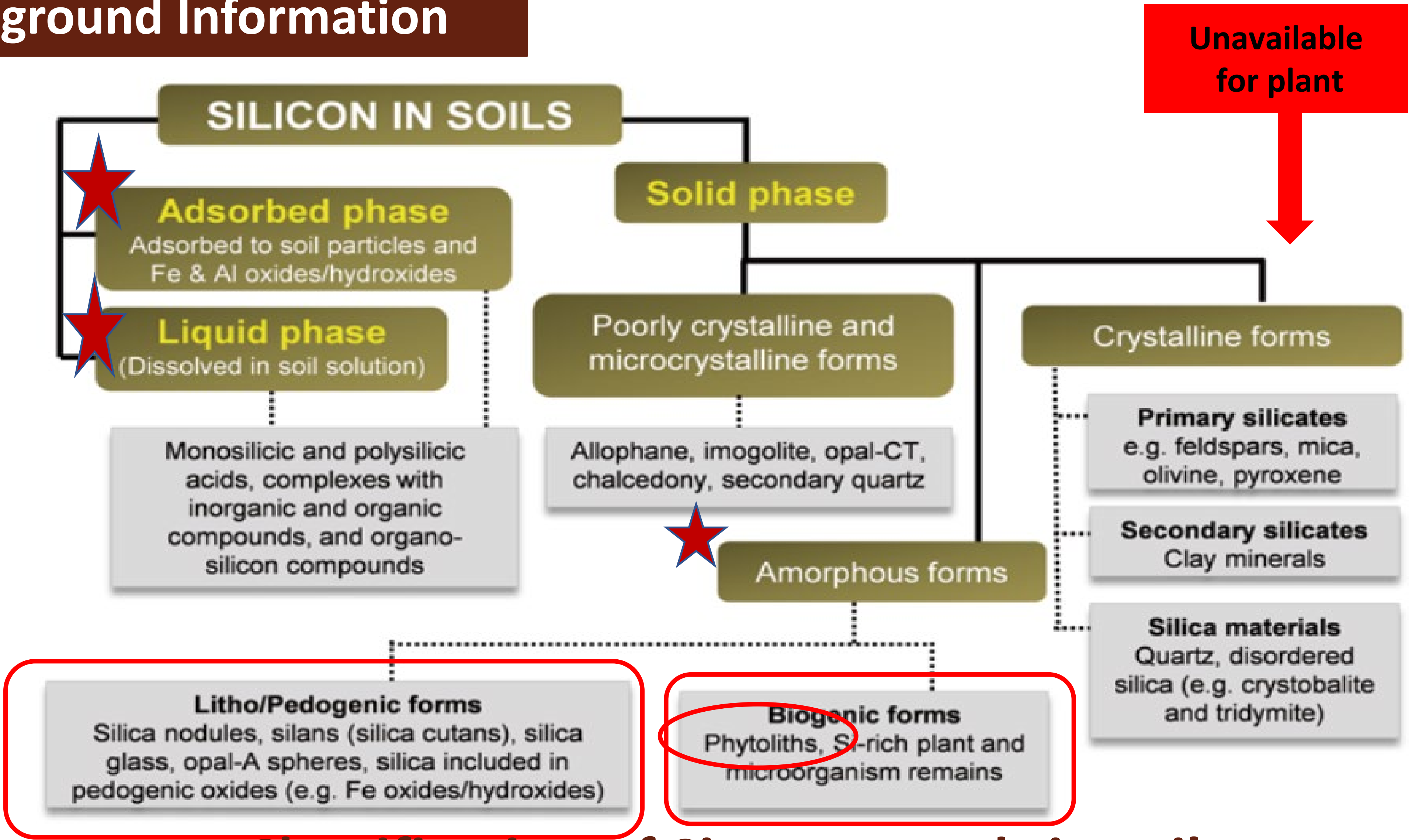


A quasi-essential / beneficial element

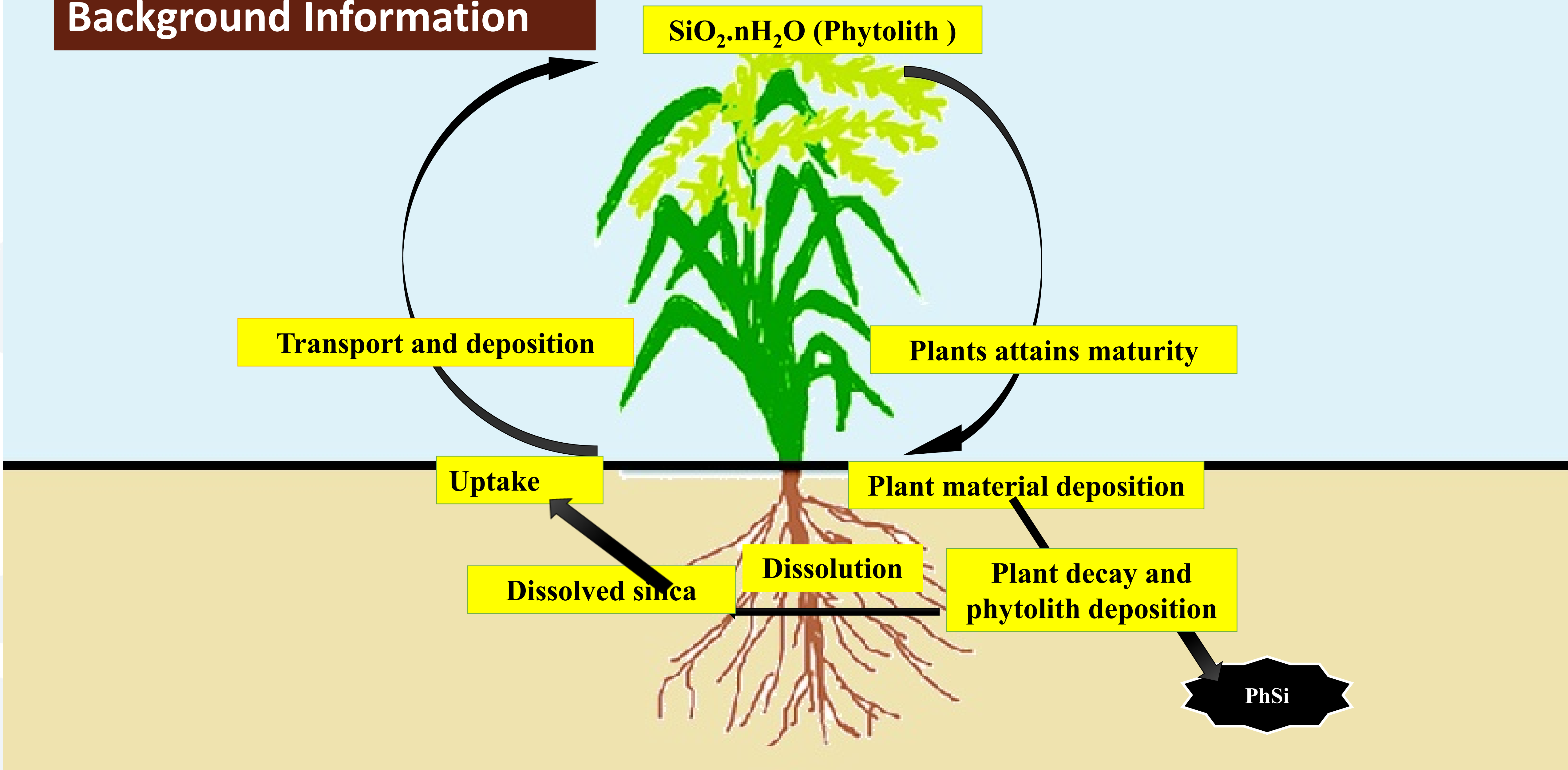
Background Information



Classification of Si compounds in soil

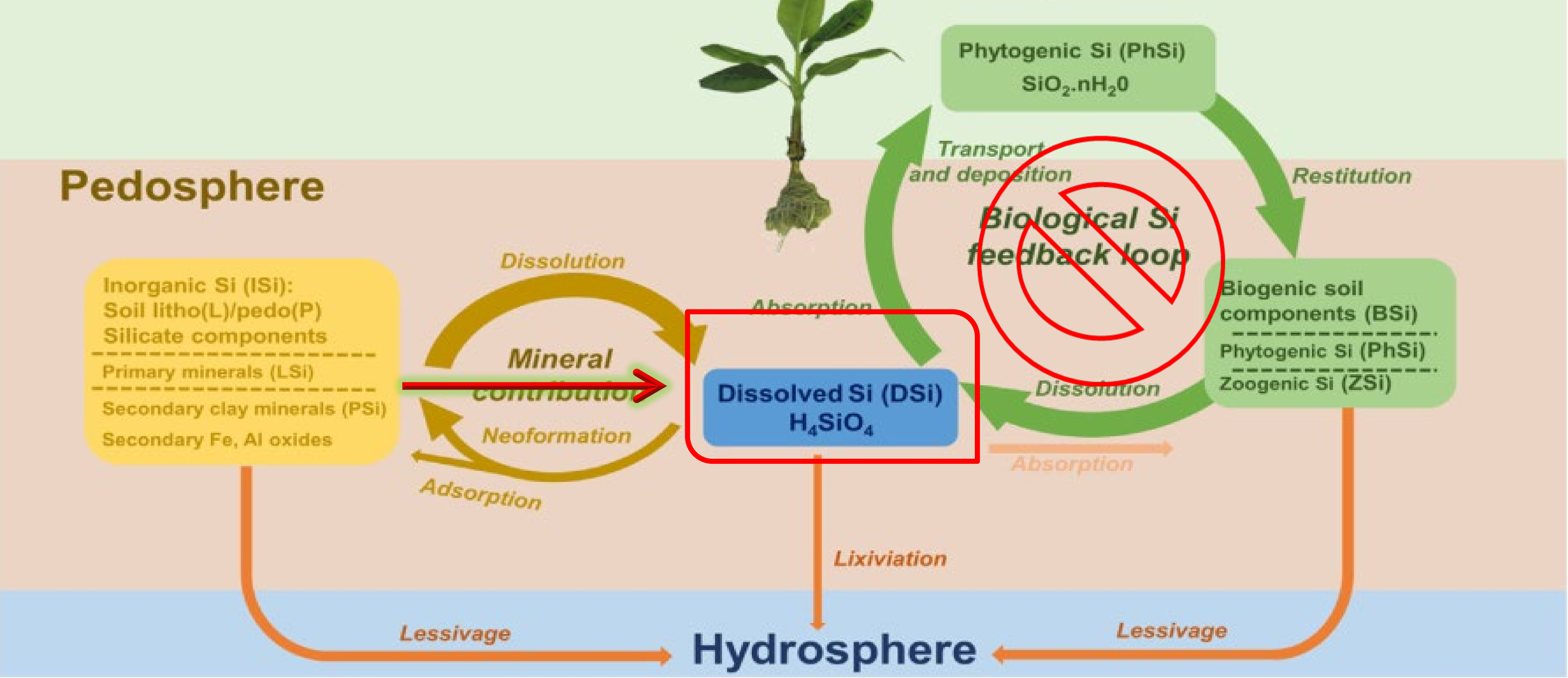
Modified from Matichencov and Bocharnikova (2001) and Sauer *et al.* (2006)

Background Information



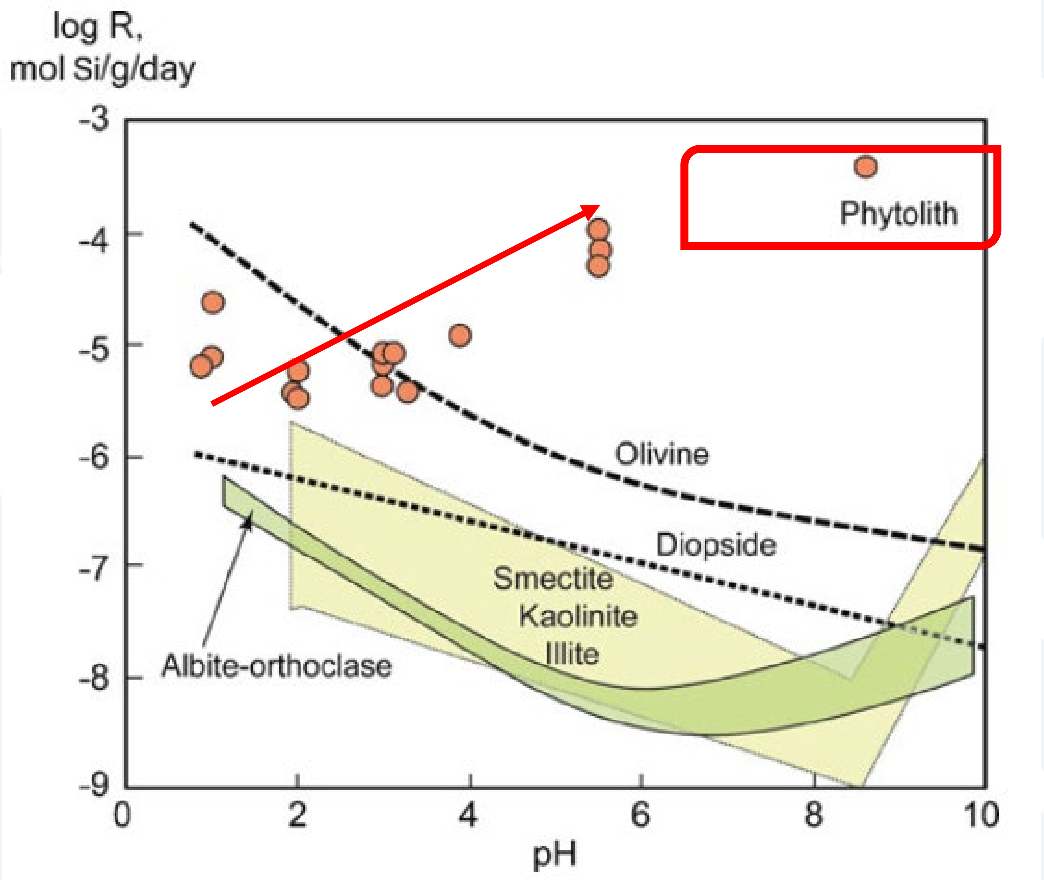
Mechanism of phytolith formation

Background Information

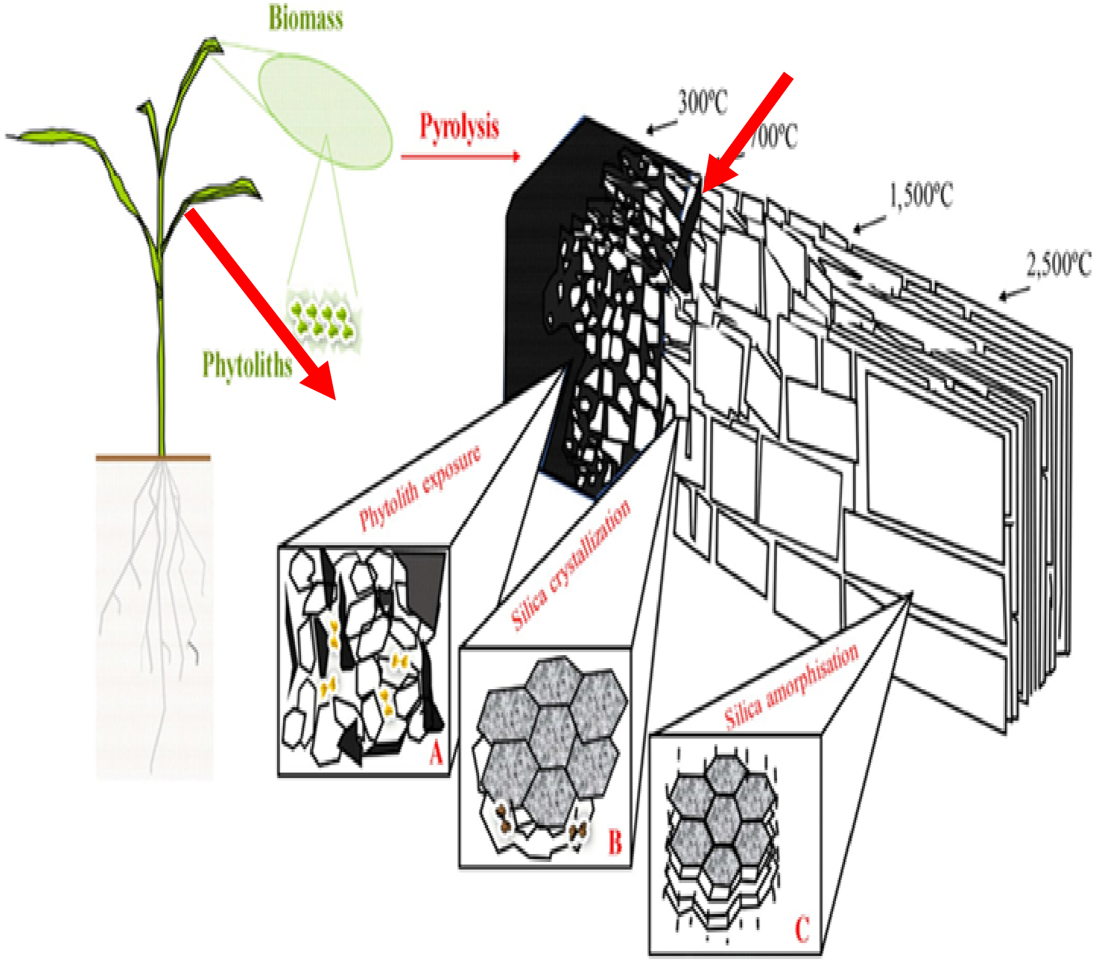


Fate of Dissolved Si (DSi) originates from the inorganic Si and PhSi pools (Linden and Delvaux, 2019)

Previous studies

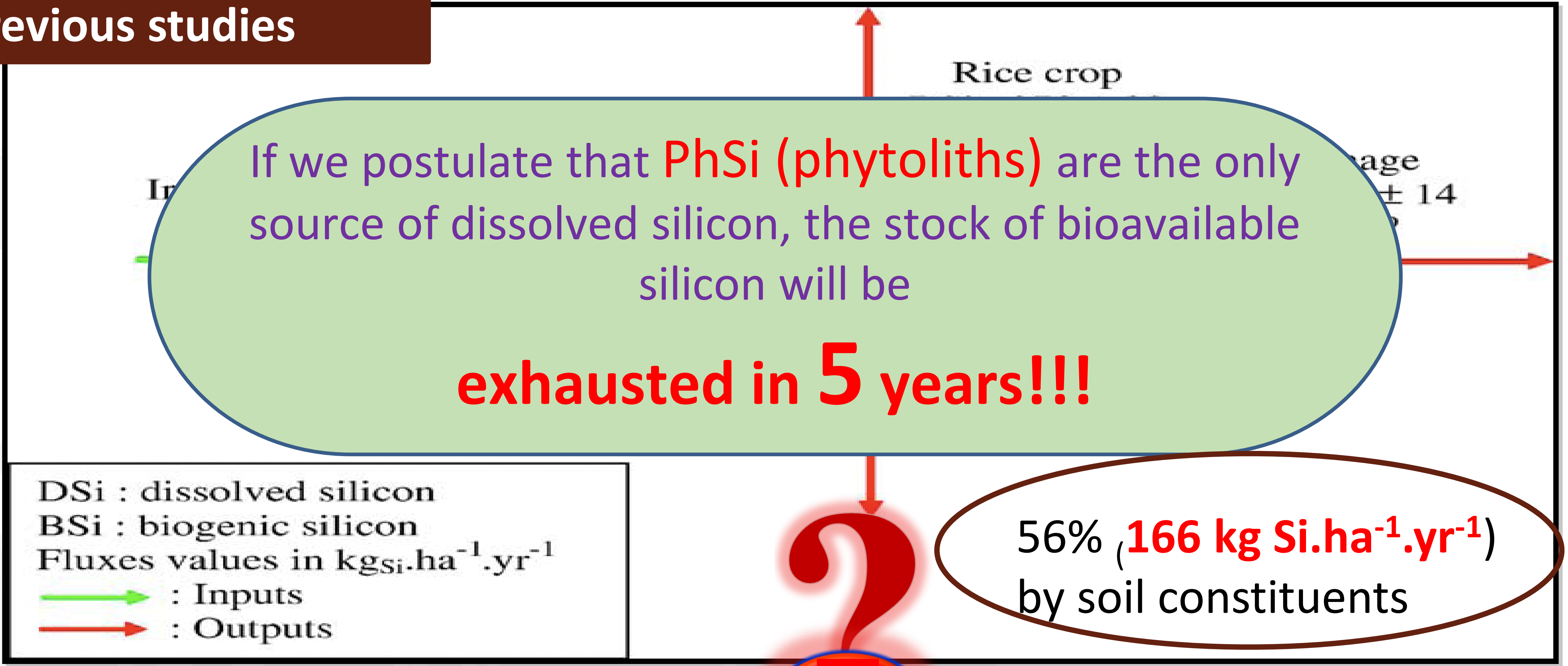


Solubility of phytoliths (Fraysse *et al.*, 2009)



Phytogenic Si (PhSi) structural interaction relative to pyrolysis process (Li et al., 2018)

Previous studies



If we postulate that PhSi (phytoliths) are the only source of dissolved silicon, the stock of bioavailable silicon will be

exhausted in 5 years!!!

56% (**166 kg $Si.ha^{-1}.yr^{-1}$**) by soil constituents

Si

Silicon balance in paddy field (Desplanques *et al.,* 2006)

Purpose

- To study the release pattern of the different PhSi source in contrasting pH soils to understand the bioavailability to the plant
- Si Budgeting in acidic, neutral and alkaline soils to understand the net change in different Si pools in contrasting pH soils

Overview of pot experiment in greenhouse

Soil

a) Acidic - Hassan

b) Neutral - Mandya

c) Alkaline -Chamarajanagara

Bulk soil (0-30cm)

Dried, Processed through 2 mm sieve

Thoroughly mixed with different PhSi sources and filled the pots

5 kg Soil

Treatment details

Silicon sources

a) **Rice straw (RS)– 6% Si**

b) **Rice Husk (RH)– 8% Si**

c) **Rice straw biochar (RSB)– 16% Si**

d) **Rice husk biochar (RHB)- 30 % Si**

T_1	C_k – RP
T_2	C_k – RP
T_3	RS @ 20 t ha^{-1}
T_4	RSB @ 20 t ha^{-1}
T_5	RH @ 20 t ha^{-1}
T_6	RHB @ 20 t ha^{-1}

Physico-chemical parameters of soil

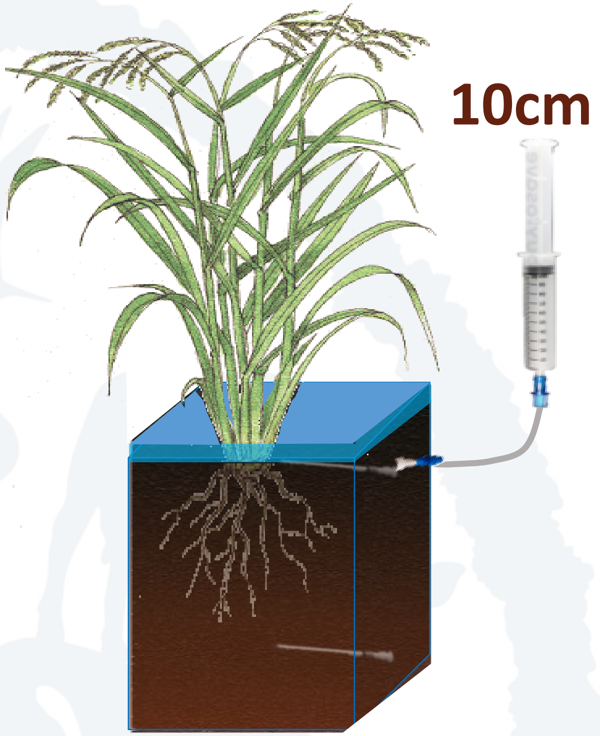
Parameters		Acidic Soil	Neutral soil	Alkaline soil
pH (1:2.5 water)		4.73	7.40	8.89
EC (dS m^{-1}) (1:2.5 water)		0.27	0.60	3.01
Organic carbon (g kg^{-1})		7.20	11.10	8.70
CEC [cmol (p^+) kg^{-1}]		7.83	15.70	31.34
Particle size distribution (%)	Sand	65.42	53.83	47.34
	Silt	8.79	16.92	6.48
	Clay	25.79	29.25	46.17
Textural class		Sandy clay loam	Sandy clay loam	Sandy clay
Distilled water –Si (mg kg^{-1})		2.41	8.43	10.87
0.01 M $CaCl_2$ – Si (mg kg^{-1})		29.72	51.62	47.14
0.5 M Acetic acid – Si (mg kg^{-1})		14.69	80.50	98.06
Phytogenic Si (g kg^{-1})		10.48	24.53	20.58

C_k - control; RP - rice plant; RS - rice straw; RSB - rice straw biochar; RH - rice husk; RHB - rice husk biochar)

Measurement of Dissolved Silicon (DSi)

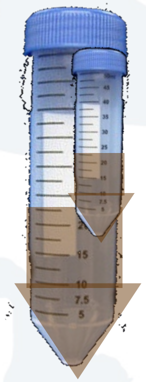
Rhizon sampler

- 5cm long porous part
- outside diameter of 2.5 mmpore size of 0.15 microne
- 1 mm internal diameter (*Eijkelkamp* Agrisearch equipment)

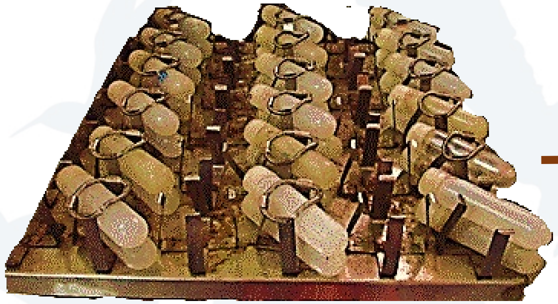


- ➢Submerged moisture regime
- ➢Rec. NPK was applied
- ➢Soil solution sampled at 0, 7, 15, 30, 45, 60, 90 and 120 DAT

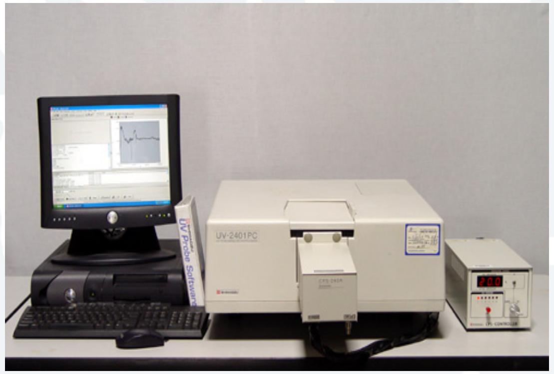
Extraction of 0.01 M $CaCl_2$ extractable Si (CCSi) from soil



2g soil + 20 mL 0.01 M $CaCl_2$

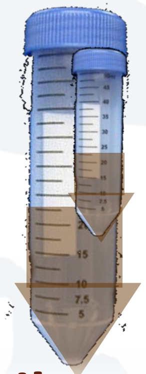


16 hours

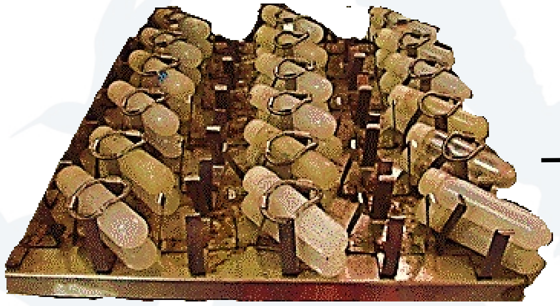


UV-VIS Spectrophotometer

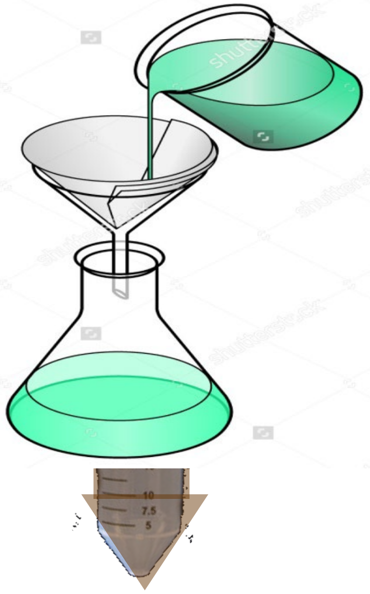
Extraction of 0.5 M acetic acid extractable Si (AASi) from soil

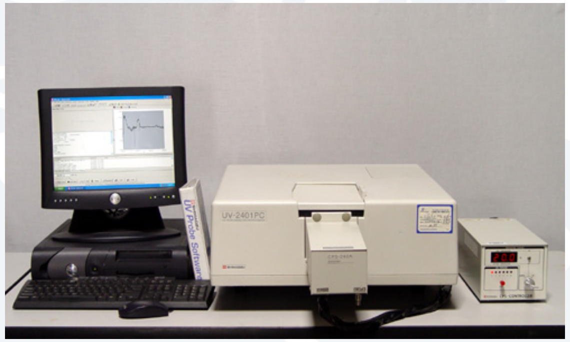


5g soil + 12.5 mL 0.5 N Acetic Acid



60 minute





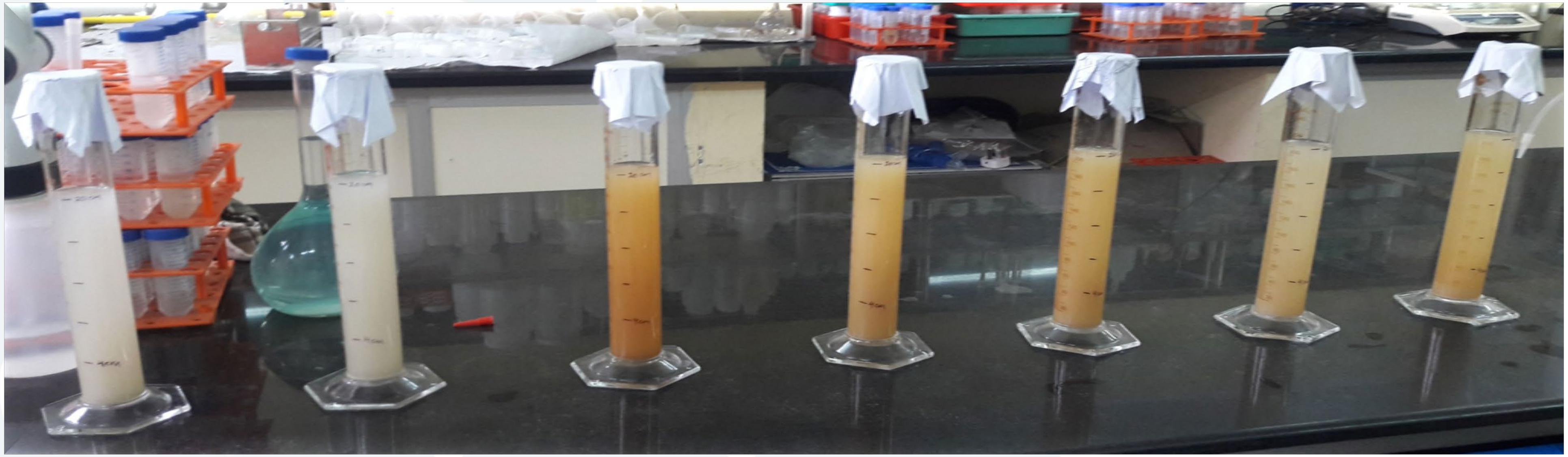
UV-VIS Spectrophotometer

Physical extraction of phytolith from soils

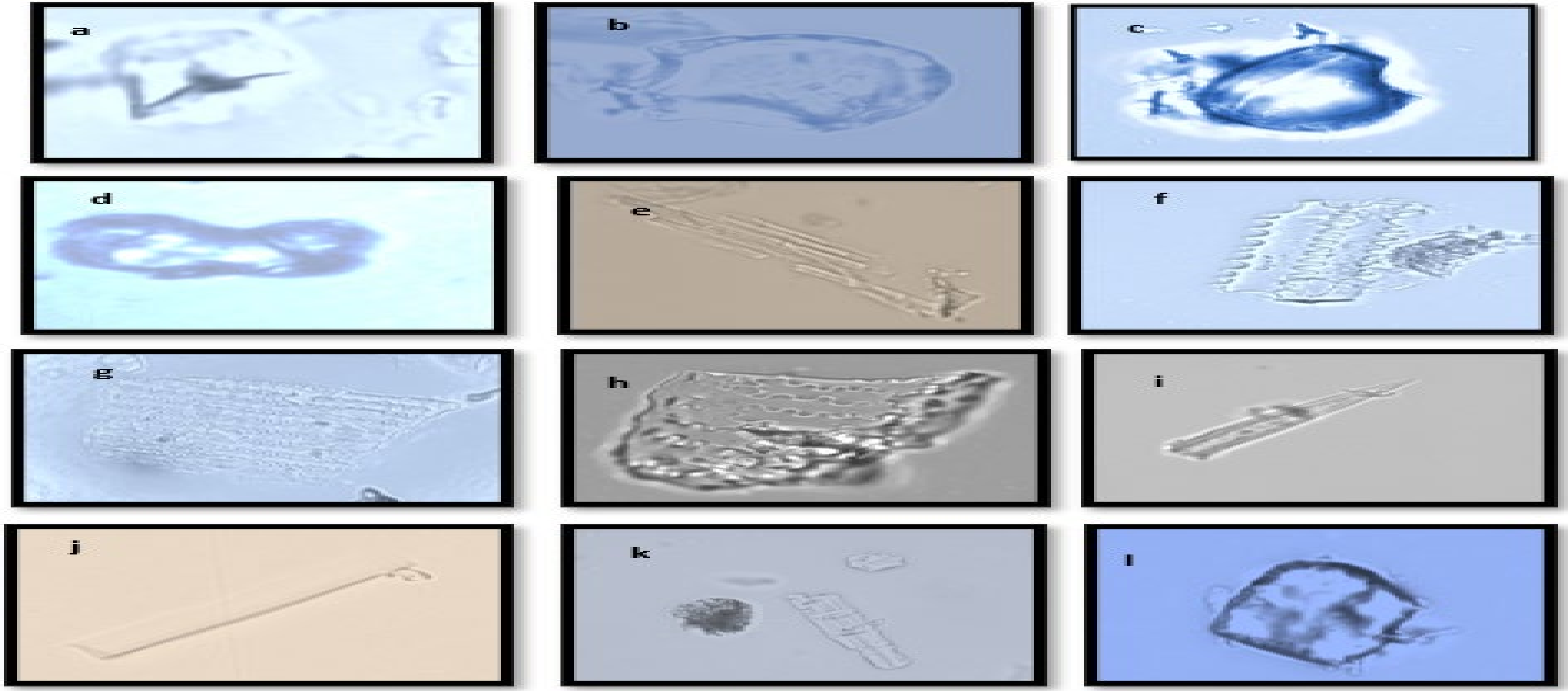
- ❖ Destruction of calcium carbonate – Conc. HCl
- ❖ Removal of organic matter - H_2O_2
- ❖ Dispersion of colloidal material – Calgon
- ❖ Removal of Clay – Sedimentation technique (≅for > 1 month)
- ❖ Extraction of phytolith – Sodium polytungstate (Heavy liquid)
- ❖ Filtration of phytolith – 5 µ filter paper
- ❖ Drying of phytolith – 50° C
- ❖ Slide preparation (medium) – Benzyl benzoate
- ❖ Observation under microscope
- ❖ Identification and quantification

- **Phytolith content was converted to Si content as per Meunier *et al*. (2014) by assuming a phytolith mean water content of 10 % (equivalent to 0.37 mol of H_2O per 2 mol of SiO_2).**
- **Hence, 42 % of the measured weight of phytoliths would be Si. This content of Si is referred further as phytogenic Si (PhSi).**

Initially-after Hydrogen peroxide treatment

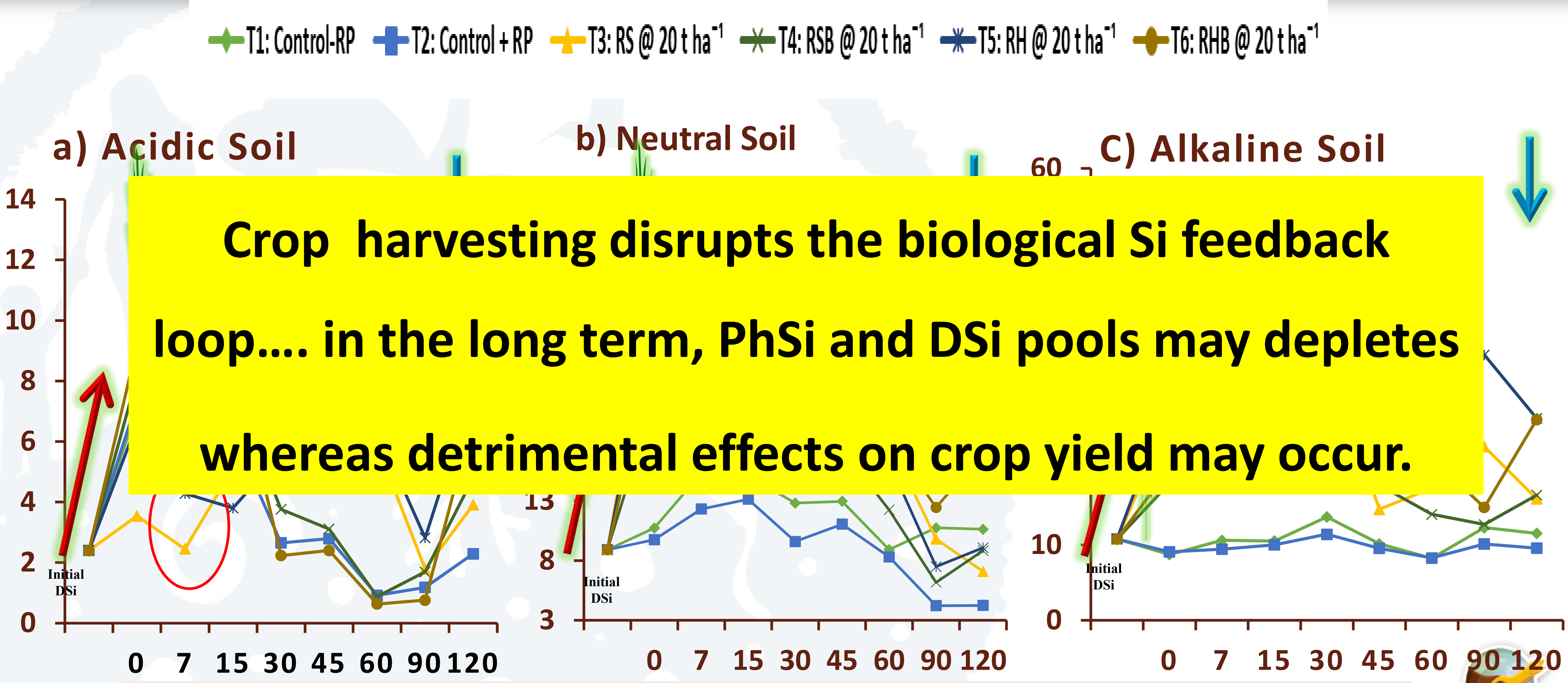


After – 32 days with treatment with Calgon solution



Dominant phytolith morphotypes in soil observed under optical microscope (EVOS M700) (400 x or 75µm) (a-c) bulliform (d) bilobate (e-f) elongated sinusoid (g-h)reticulate (i) acicular (j) elongated smooth (k) globular (l) cubic

Effect of different phytogenic Si sources on DSi (mg L^{-1}) at different interval in a) acidic, b) neutral and c) alkaline soil



Crop harvesting disrupts the biological Si feedback loop…. in the long term, PhSi and DSi pools may depletes whereas detrimental effects on crop yield may occur.

(C_k - control; RP - rice plant; RS - rice straw; RSB - rice straw biochar; RH - rice husk; RHB - rice husk biochar)

Effect of different phytogenic Si sources on yield and Si uptake of rice crop in different soils

		Dry weight Pot^{-1} (g)			Si uptake (mg pot^{-1})			
		Straw	Grain	Root	Straw	Grain	Root	Total
Treatment (T)	T_1: C_k+ RP	17.78	13.70	3.60	575.61	56.63	23.13	655.37
	T_3: RS @ 20 t ha^{-1}	15.46	10.45	3.02	588.11	60.80	27.69	676.91
	T_4: RSB@ 20 t ha^{-1}	22.04	18.15	4.25	910.70	110.09	43.39	1065.18
	T_5: RH@ 20 t ha^{-1}	24.60	20.40	4.50	1100.07	135.67	39.47	1275.21
	T_6: RHB@ 20 t ha^{-1}	26.44	21.23	4.95	1264.00	148.20	56.87	1469.08
	S.Em±	**0.37**	**0.37**	**0.15**	**40.68**	**6.23**	**3.95**	**41.91**
	C. D. @ 5%	**1.08**	**1.07**	**0.43**	**118.07**	**18.08**	**11.48**	**121.65**
Soil (S)	S_1: Acidic	28.90	22.47	6.48	976.29	102.16	58.51	1136.96
	S_2: Neutral	26.40	21.01	4.32	1273.55	147.70	37.83	1459.28
	S_3: Alkaline	8.49	6.88	1.38	413.84	56.98	17.99	488.81
	S.Em±	**0.29**	**0.29**	**0.11**	**31.51**	**4.82**	**3.06**	**32.46**
	C. D. @ 5%	**0.83**	**0.83**	**0.33**	**91.46**	**14.01**	**8.89**	**94.22**
Interaction effect (T x S)								
Acidic Soil (S_1)	T_1: C_k+ RP	23.00	17.78	5.42	528.62	45.77	34.88	609.26
	T_2: RS @ 20 t ha^{-1}	20.00	11.94	4.56	541.00	59.38	40.33	640.71
	T_3: RSB@ 20 t ha^{-1}	30.40	25.20	6.60	1023.34	122.63	66.25	1212.23
	T_4: RH@ 20 t ha^{-1}	36.13	30.43	7.55	1386.36	154.91	66.46	1607.73
	T_5: RHB@ 20 t ha^{-1}	35.00	27.00	8.30	1402.13	128.10	84.65	1614.88
Neutral Soil (S_2)	T_1: C_k+ RP	23.00	18.01	4.16	913.26	92.15	27.37	1032.78
	T_2: RS @ 20 t ha^{-1}	20.33	15.54	3.27	932.47	93.61	28.30	1054.38
	T_3: RSB@ 20 t ha^{-1}	26.67	19.95	4.54	1259.32	130.94	45.71	1435.96
	T_4: RH@ 20 t ha^{-1}	29.00	24.27	4.70	1464.04	194.36	38.85	1697.25
	T_5: RHB@ 20 t ha^{-1}	33.00	27.28	4.95	1798.71	227.42	49.88	2076.00
Alkaline Soil (S_3)	T_1: C_k+ RP	7.33	5.33	1.21	284.95	31.97	7.15	324.07
	T_2: RS @ 20 t ha^{-1}	6.06	3.85	1.24	290.86	29.40	15.38	332.56
	T_3: RSB@ 20 t ha^{-1}	8.99	9.30	1.60	452.45	76.70	18.22	545.10
	T_4: RH@ 20 t ha^{-1}	8.67	6.50	1.25	449.82	57.73	13.11	520.66
	T_5: RHB@ 20 t ha^{-1}	11.33	9.40	1.60	591.18	89.08	36.08	716.34
	S.Em±	**0.64**	**0.64**	**0.26**	**70.47**	**10.79**	**6.85**	**72.60**
	C. D. @ 5%	**1.86**	**1.85**	**0.74**	**204.50**	**31.32**	**NS**	**210.69**

C_k - control; RP - rice plant; RS - rice straw; RSB - rice straw biochar; RH - rice husk; RHB - rice husk biochar

Effect of different phytogenic Si sources on soil pH and plant available Si pools in different soils

		pH (1:2.5 water)	CCSi (mg kg^{-1})	AASi (mg kg^{-1})	PhSi (g kg^{-1})
Treatments (T)	T_1: C_k-RP	7.59	47.77	84.13	4.28
	T_2: C_k + RP	7.67	43.48	69.95	3.86
	T_3: RS @ 20 t	7.58	62.85	80.88	6.05
	T_4: RSB@ 20 t	7.64	72.91	87.71	9.69
	T_5: RH@ 20 t	7.56	72.44	79.82	7.95
	T_6: RHB@ [illegible]	7.54	81.65	94.30	12.48
	S.Em±	0.03	1.51	2.10	0.17
	C. D. @ [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]SB@ 20 t	[illegible]	[illegible]	[illegible]	12.78
	[illegible]RH@ 20 t	[illegible]	[illegible]	[illegible]	11.67
	[illegible] RHB@ 20 t	[illegible]	[illegible]	[illegible]	13.24
	[illegible]Em±	0.05	[illegible]	3.64	0.30
	C. D. @ 5%	0.15	7.52	10.48	0.87

The Lowest Plant available Si pools was reported in the control with plant (C_k+ RP) treatment because readily soluble Si pools is controlled by clay minerals, but **in** Si amended soil by ASi (phytolith) .

Change in DSi (mg L^{-1}) during crop growth and total Si uptake (mg pot^{-1}) by the plant and contribution of the Applied PhSi to the total Si uptake (%) in acid neutral and alkaline soil

Treatments	±ΔDSi change in soil solution (mg L^{-1})			Total Si uptake by plant (mg pot^{-1})			Contribution of the applied PhSi to the total Si uptake (%)		
	…cidic	Ne…	…kaline	…	N…	…lkali…	A…	…tral	…line
T_5: R…	[illegible]	10	2…	[illegible]	[illegible]	[illegible]	[illegible]	…15	…76
T_6: RHB @ 20 t ha…	[illegible]	11	15	16…	20…	716	62.27	50.25	54.76

Increased Si uptake of rice plants in the treatments receiving different PhSi sources (RS, RSB, RH and RHB @ 2o t ha^{-1}) over control clearly shows that the Si released during the decomposition of these materials are plant available

(control without plant = C_k-RP)

C_k = control; RP = rice plant; RS = rice straw; RSB = rice straw biochar; RH = rice husk; RHB = rice husk biochar

±ΔDSi difference between DSi in soil solution during crop growth period with respect to c_k-RP

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Plant available Si stock in acid, neutral and alkaline soil

Treatments	±ΔCCSi (mg pot^{-1})			±ΔAASi (mg pot^{-1})			±ΔPhSi (mg pot^{-1})		
	Acidic	Neutral	Alkaline	Acidic	Neutral	Alkaline	Acidic	Neutral	Alkaline
Initial									8
T_1:									
T_2									
T_3:									27
T									43
T									38
T_6: RHB @ 20 t ha		154	366			20		67	46

Application of PhSi materials (RS, RSB, RH and RHB) boost the biological Si feedback loop in soil-plant systems by increasing Si bioavailability, which may further depend on soil properties and processes, hence soil type

C_k = control; RP = rice plant; RS = rice straw; RSB = rice straw biochar; RH = rice husk; RHB = rice husk biochar; CCSi – 0.01M Calcium chloride extractable Si; AASi - 0.5M Acetic acid extractable Si; hlPhSi – heavy liquid extractable phytogenic Si

± Δ Difference between Si content in soil estimated after and before the experiment

Summary

- Application of the biochar prepared at lower pyrolytic temperature (<700℃) increases PASi increasing solubility of phytoliths enhances their ability to release plant-available Si over their feedstocks

- **The negative or lower value of DSi in and readily soluble Si pools in control with plant for all the soils emphasizes the need for Si fertilization.**

- The solubility of different PhSi sources depends on soil types

- **Among three soils, the extent of dissolved Si and plant available Si stock was recorded lower in the acid soil compared to neutral and alkaline soils. But, the contribution of applied PhSi to total Si uptake was recorded higher in the acid soil. At identical phytolith supply, Si bioavailability largely depended on the soil weathering stage and pH.**

Acknowledgement

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AND

MY BELOVED FAMILY

Thank you for patient hearing !