Effects of Cations On Soil Structure

TALK 1-CODY WYOMING

1

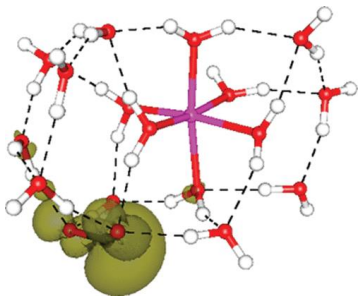
How Does Calcium and Magnesium Exist In the Soil?

Calcium

- As a salt-$CaCl_2$
- With Carbonate-$Ca(COOH)_2$

Magnesium

- Can be as a salt-$MgCl_2$
- Usually it is Hydrated-Epson Salt
  - $Mg\text{-}(H20)_7$



2

The Importance of Calcium in Soil Physical Properties

Too high percent base saturation of Mg will result in the soil being sticky and slick, not aggregated very well- Dispersed not Flocculated

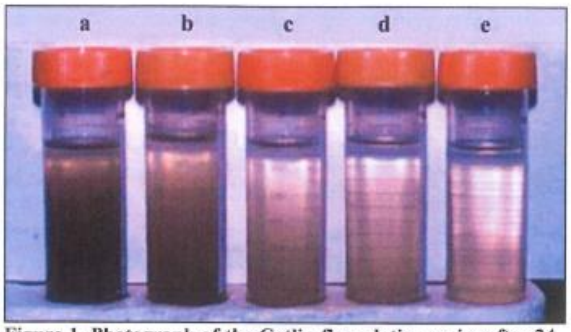


Figure 1. Photograph of the Catlin flocculation series after 24 hours of sedimentation. Treatments are a) 0:100, b) 25:75, c) 50:50, d) 75:25, and e) 100:0 ratios of Ca:Mg in 2.1 mmol L^{-1} solution of calcium:magnesium sulfate.

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Schematic View of Flocculation and Dispersion

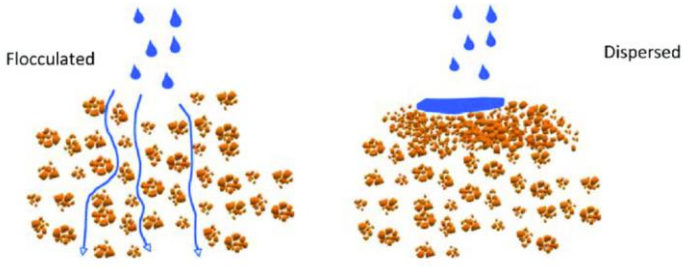
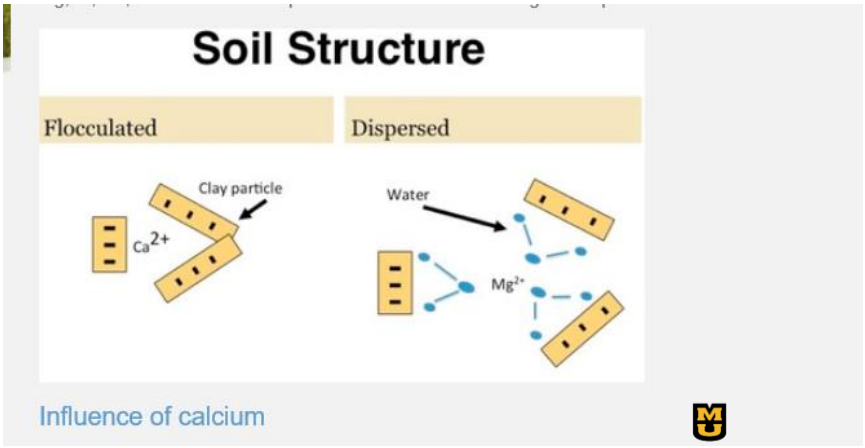


Image: The difference between flocculated (aggregated) and dispersed soil structure. Flocculation (left) is important because water moves through large pores and plant roots grow mainly in pore space. Dispersed clays (right) plug soil pores and impede water movement and soil drainage (Choudhary & Kharche, 2018)

4

What is Happening? Mg Has A Hydration Shell Around it-Shield Negative Charges on The Clay



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Soils That Are High In Mg, Na, or Even K Will Have Erosion Issues

6

Table 1. Chemical characteristics of saline, sodic, saline-sodic, and calcareous soils. In Wyoming, saline, sodic, and saline-sodic soils are usually calcareous as well.

Classification	SAR	EC (dS/m)	Soil pH	ESP %	CaCO3 content	Soil structure and porosity
Saline	<13	>4	<8.5	<15	Varies	Normal
Sodic	>13	<4	>8.5	>15	Varies	Poor
Saline-sodic	>13	>4	<8.5	>15	Varies	Normal or poor
Calcareous	Varies	Varies	>7.2	Varies	>0 (audible or visible effervescence)	Normal

Abbreviations: SAR, sodium adsorption ratio; EC, electrical conductivity of a saturated paste of soil; ESP, exchangeable sodium percentage. "Varies" means that this property is not diagnostic for a given classification. See text box "Identifying Important Properties of Alkaline Soils", below, for explanation.

7

Calcium vs Sodium Between Clay Particles

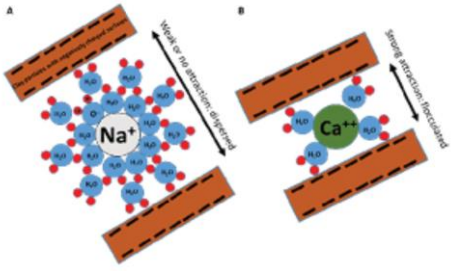

Figure 3. Simplified schematic diagrams of (A) a dispersed soil in which the thick shell of water molecules of strongly hydrated Na ions force negatively charged soil particles apart, destroying soil aggregates and reducing porosity as individual particles plug pores, and (B) a flocculated soil in which less strongly hydrated Ca ions are closer to clay surfaces, forming a strong attraction and binding aggregates together to form inter-aggregate porosity. Larger silt and sand particles

From Alkaline Soils in Wyoming
Jay Norton, 2020

8

Sodic Soil-Poor Structure and Water Infiltration

9

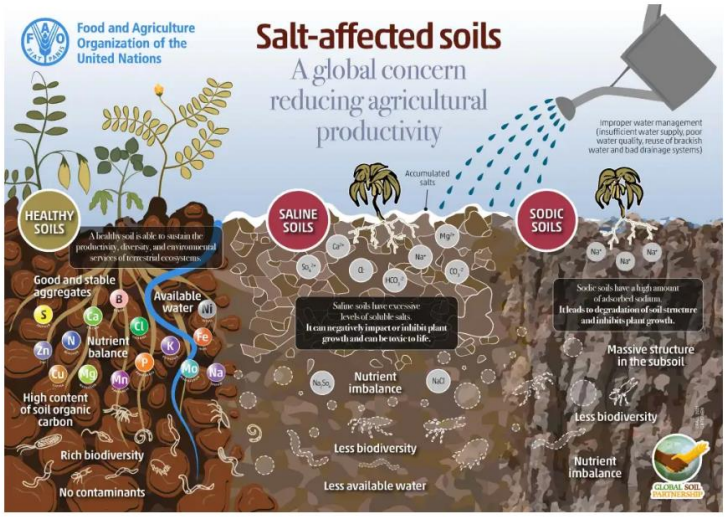

Figure 1: World Soil Day infographic from https://www.fao.org/world-soil-day/en/

10

Effect of Sodium and Gypsum on Water Infiltration

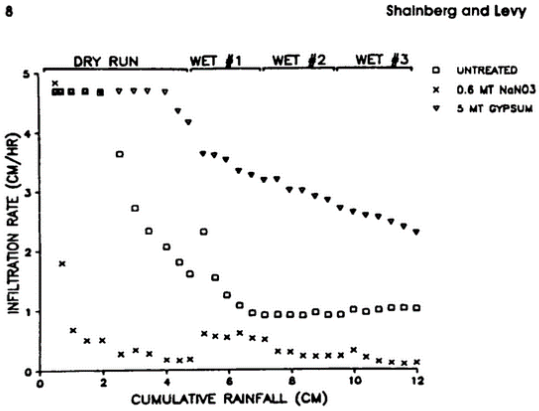

Fig. 3 Infiltration rate of Greenville sandy clay loam soil treated with either 0.6T ha^{-1} $NaNO_3$ or 5 t ha^{-1} $CaSO_4$, compared to untreated control, during 120 mm of simulated rainfall at 45 mm h^{-1}. (From Miller and Scifres, 1988.)

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High Sodium Soils In Upper Plains- Example in South Dakota

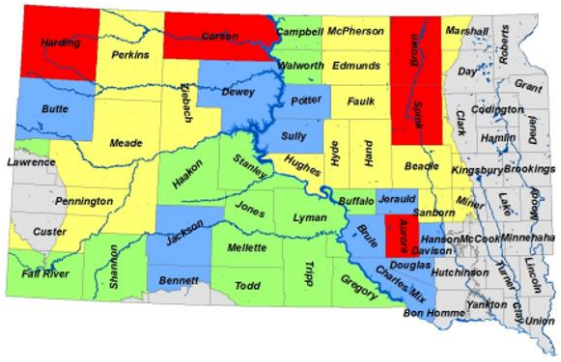

Figure 48.2. The percentage of sodic soils in South Dakota. In this map yellow is 10-20%, blue is 5-10%, green is 1-5%, and red is 20-30% sodium-affected soils. (Modified from Millar, 2003, http://www.sdnotill.com/Newsletters/2003_

12

Application of Gypsum-Calcium Sulfate Can Alleviate Some of the Issues

$$CaSO_4 \rightarrow Ca^{+2} + SO_4^{-2}$$

Ca^{+2} + Na^{+} -(clay mineral) → Ca^{+2} –(clay mineral) + Na^{+} ↓

Swelling Clay | Flocculated Clay | Sodium Leaching

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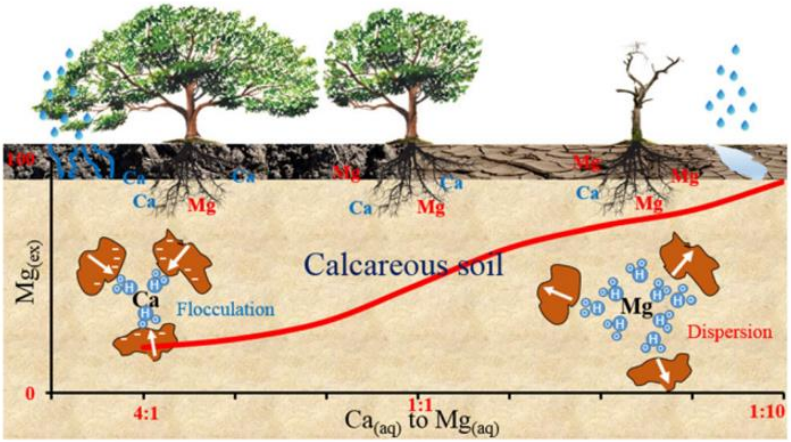
Video of Example of Gypsum on a High Sodium Soil

https://youtu.be/tLaJawbMrT0?si=O3fOUZd7nn2-q-CI

14

Too Much Magnesium Can Result In Poor Structure Just As Sodium. Be Cautious of High Magnesium Irrigation Water



15

Schematic View of Flocculation

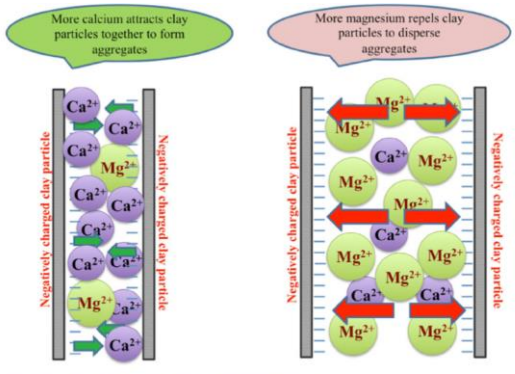


Fig. 3. Possible effects of Ca^{2+} and Mg^{2+} cations on soil aggregation.

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Ocean Bank Erosion With Various Mg/Ca Ratio of Shore

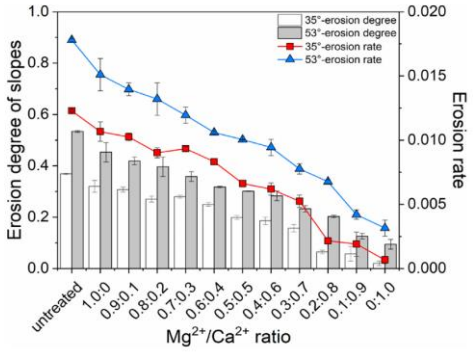
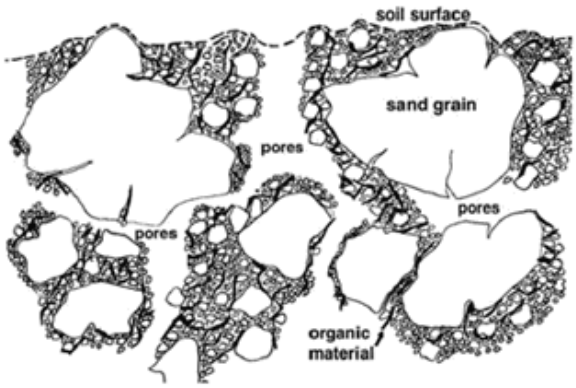


Fig. 4. Calculated erosion degree and erosion rate of untreated slopes and treated slopes.

Sunn, et al, 2023

17

Good Aggregate Formation Results in More Space of Aeration and Water Holding Capacity



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Why?

Single Charge Cations Such as K and Na have little Flocculating Power Whereas Divalent Cations Much Greater Flocculating Power

Ion	Chemical Symbol	Relative Flocculating Power
Sodium	Na^{+}	1.0
Potassium	K^{+}	1.7
Magnesium	Mg^{2+}	27.0
Calcium	Ca^{2+}	43.0

Your text here

Al^{+3}> Sr+^{2}> Ca+^{2}>Mg+^{2}, Cs+^{2}, K^{+}=$NH4^{+}$>Na^{+}>Li^{+}

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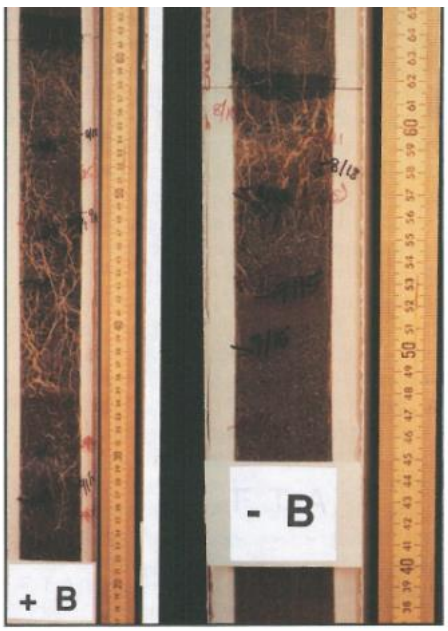
Boron Can Overcome Aluminum Toxicity



20

Why Are Their Differences In Flocculation?: Charge, Hydration Shell and Type of Bonds

Charge: Divalent charges (Ca^{++} and Mg^{++}) are stronger than monovalent such as K^{+} and Na^{+}

Hydration: Na and Mg have large hydration shells that result in weaker bonds and also can mask other negative charges on clay particles

Types of Bonds:

- **Ionic-weak, easily broken by water molecules-Na and K**
- **Covalent-strong-attraction between negative and positive charges-Ca and Mg**

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Calcium Application Can Replace Mg on the Clay Matrix

Reversing magnesium-induced soil degradation by applying calcium

Key elements supporting soil restoration

22

As Calcium Increases In the Soil The Stability of the Soil Increases However, With Greater Mg the Soil Becomes More Instable.

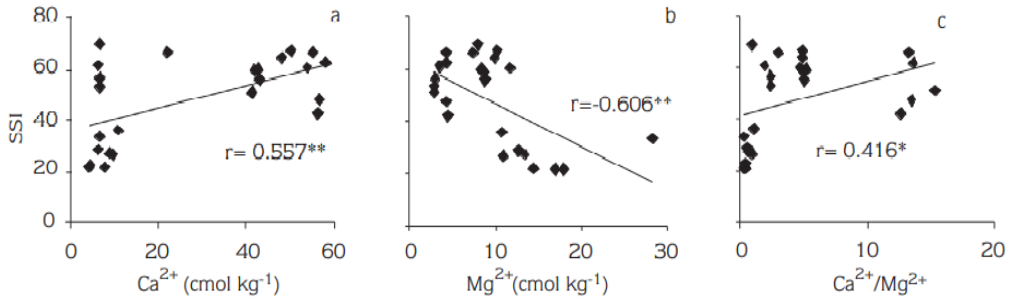

Figure 2. The relationship between exchangeable cations and structural stability index (SSI).

Chan and Henan, 1999

23

Example With Magnets

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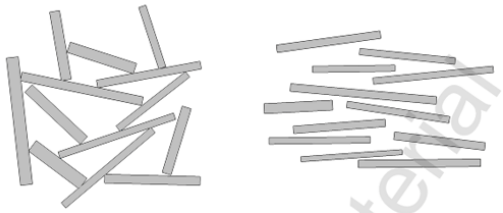
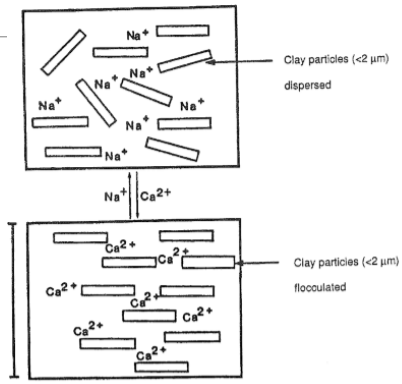
Flocculated Particles-Opposite Charges Line Up: Negative On Clay Particle With Positive On The Divalent Cation-3 Dimensional



(a) Flocculated Structure (b) Dispersed Structure

Figure 3.1 Clay structure.



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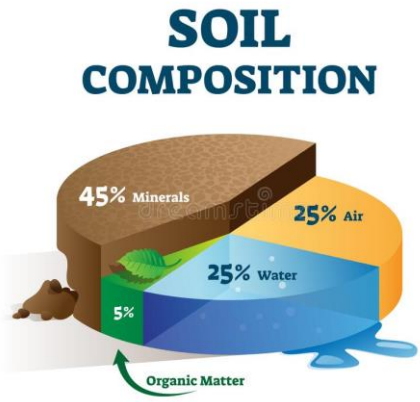
When You Have Good Soil Structure You Have Good Water and Air Space



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A Demonstration That Compare Different Ca/Mg Base Saturations on Soil Physcial Properties

27

Treated a Soil With Base Saturation of Ca 68% and Mg 16% With Different Levels of Mg and Ca

Control

50 lbs Mg as MgSO4

100 lbs Mg as MgSO4

250 lbs Mg as MgSO4

500 lbs Mg as MgSO4

750 lbs Mg as MgSO4

1000 lbs Mg as MgSO4

1000 lbs Gypsum

2000 lbs Gypsum

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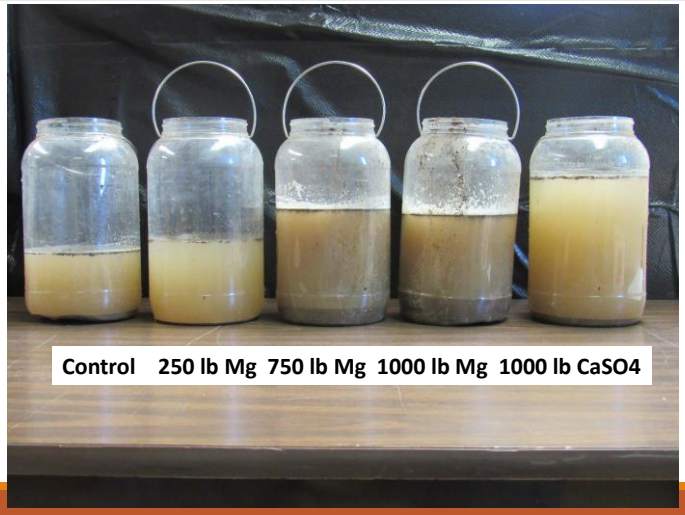
Rainfall Table With Different Mg and Gypsum Treatments

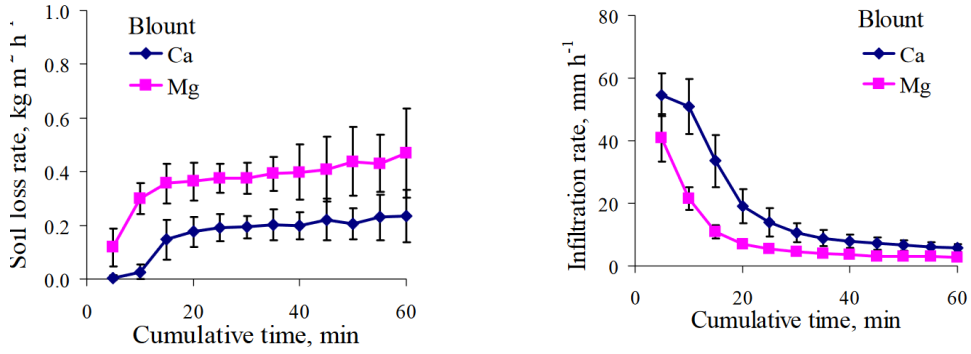
29

What Happened? Runoff



30

Erosion and Water Infiltration When Calcium or Magnesium is Added



Dontsova and Norton, 2001

31

Soils That Are High In Mg, Na, or Even K Will Have Erosion Issues

32

Magnesium and Sodium Effects on Soil Erosion

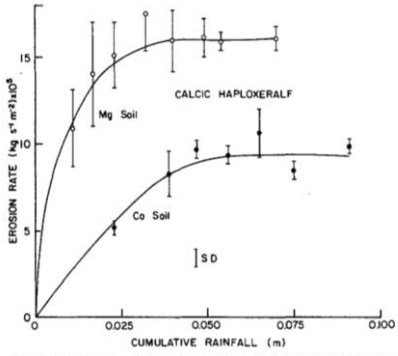


Fig. 2. Erosion rate of a Calcic Haploxeralf soil saturated with Mg and Ca ions, as a function of cumulative rainfall at a water-drop kinetic energy of 12.5 kJ m⁻².

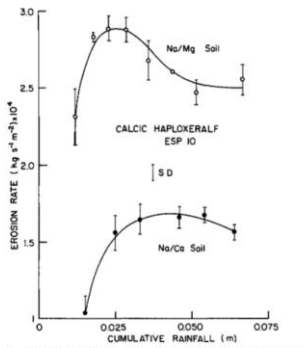


Fig. 5. Erosion rate of a Calcic Haploxeralf soil adsorbed with Na-Mg and Na–Ca ions at exchangeable sodium percentage (ESP) 10, as a function of cumulative rainfall at a water-drop kinetic energy of 12.5 kJ m⁻².

Keren, 1991

33

Effect of Sodium and Gypsum on Water Infiltration

8 Shainberg and Levy

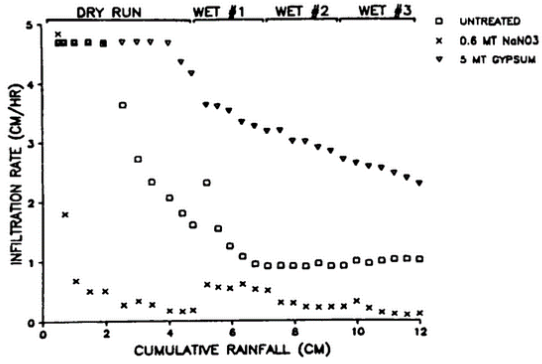


Fig. 3 Infiltration rate of Greenville sandy clay loam soil treated with either 0.6T ha^{-1} $NaNO_3$ or 5 t ha^{-1} $CaSO_4$, compared to untreated control, during 120 mm of simulated rainfall at 45 mm h^{-1}. (From Miller and Scifres, 1988.)

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With High Mg a Platy Structure

35

Control, A More Balance Soil- No Platy Structure

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Which are The High Mg?

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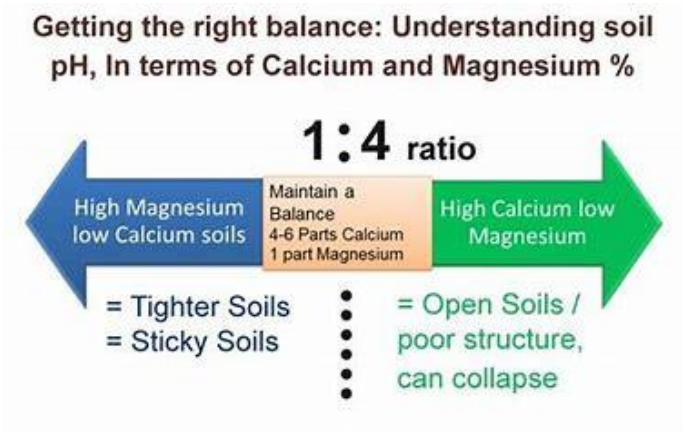
Calcium and Magnesium Balance



38

Too Much Sodium Can Lead to Similar Issues

39

Sodium and Salinity Level and Infiltration

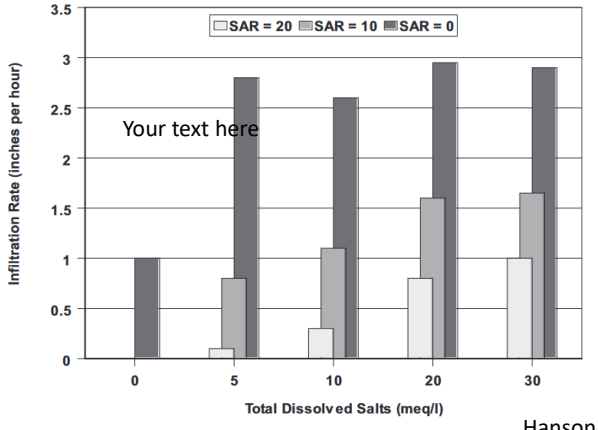


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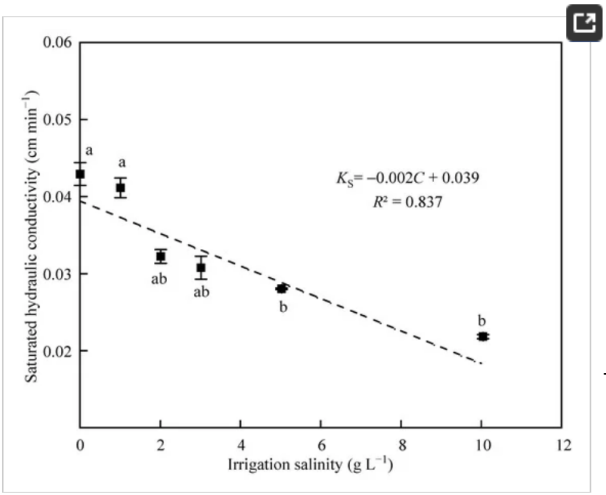
Figure 3. Effect of salinity and sodium adsorption ratio on infiltration rate of a sandy loam soil.

Hanson et al 1999

40

As Na in the Irrigation Water Increases the Water Infiltration Decreases



Tan et al. 2023

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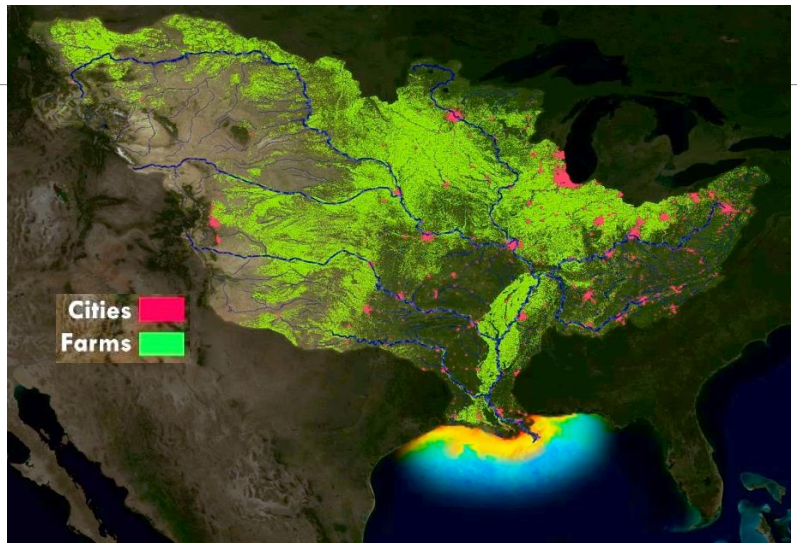
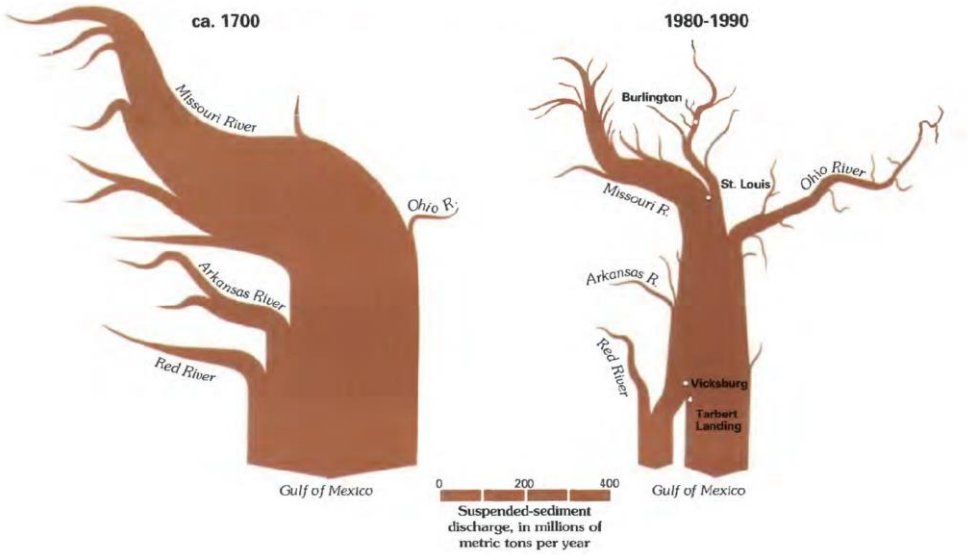
Mississippi/Missouri River Drainage Basin



42

Impacts of on Ecosystem Services…
Suspended Sediment Delivery to the Gulf Coast

Over 300 years of development…



Source: Contaminants in the Mississippi River, USGS Circular 1133 (1995)

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Confluence of the Mississippi (left) and Ohio (right) near Cairo Illinois. The Mississippi Gets Much of Its Water and Mud From the Missouri

What Happens If We Have An Excess of Calcium?

45

Is More Ca Better? High Calcium Soil

46

What Happened?

Mg shields negative charges on clay and as result more easily broken apart resulting in more erosion.

Higher Calcium?

- Calcium takes up too many of exchange sites
- Too Much Free Ca?
  - CaCO3 can shield clay charges

Soil Structure Collapses

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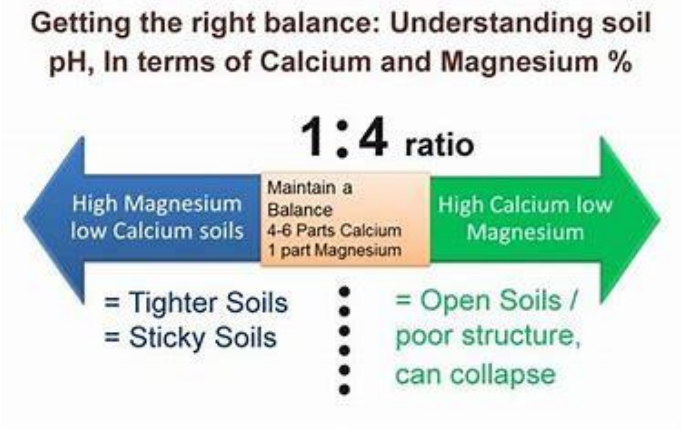
Calcium and Magnesium Balance



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February 2022 Issue

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Look At Some Field Studies

50

Soils High Ca (over 80% Base saturation) Low Sulfur (1 lb/acre) Corn and Soybean

Treatment	Corn	Soybean
	bu/acre	bu/acre
Control	111 b	62 b
Recommendations	142 a	69 a
Recommendations w/o S	118 b	63 b
Recommendations w/Mg	145 a	68 a
Micros Only	124 ab	63 b

Different Letters Indicate Significant Differences at the 0.05 level

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Which Would You Want? Too Much Ca or Too Much Mg?

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Increasing the Mg Base Saturation Can Decrease Corn Yield

Soil Mg Level	Yield
Percent Base Saturation	bu/acre
10	104
20	119
25	98
30	95

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How Does Soil Calcium and Magnesium Affect Water Infiltration?

Chatterjee and Clay, 2017

	Infiltration Rate in/h	Total Infiltration in	Runoff Rate in/h	Total Runoff in
High Ca Soil	2.2	7.4	22.7	17.0
High Mg Soil	0.9	1.6	23.8	23.2

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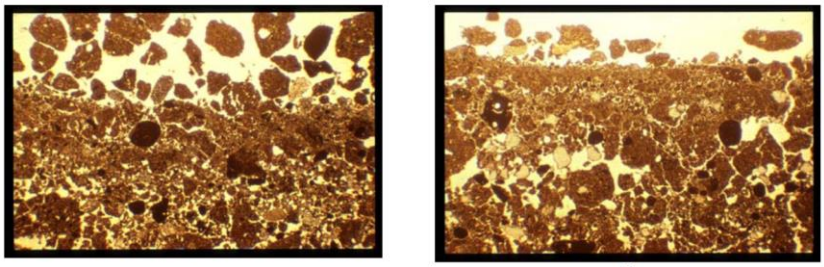
High Mg Can Seal the Soil



a b

Figure 5. Photomicrographs of the Catlin soil treated with a) Ca and b) Mg. Frame width equals 11.5 mm. Pores are seen as yellow and aggregates as brown.

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Overall Conclusions

Calcium Is Superior to Building Soil Structure Than Mg. Too Much Mg or Na Will Result In Greater Soil Erosion and Less Water Infiltration

A High Level of Ca-80% Base Saturation-Can Result In Greater Soil and Water Runoff

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Conclusion Video-About Soil Structure As Related to Ca and Mg

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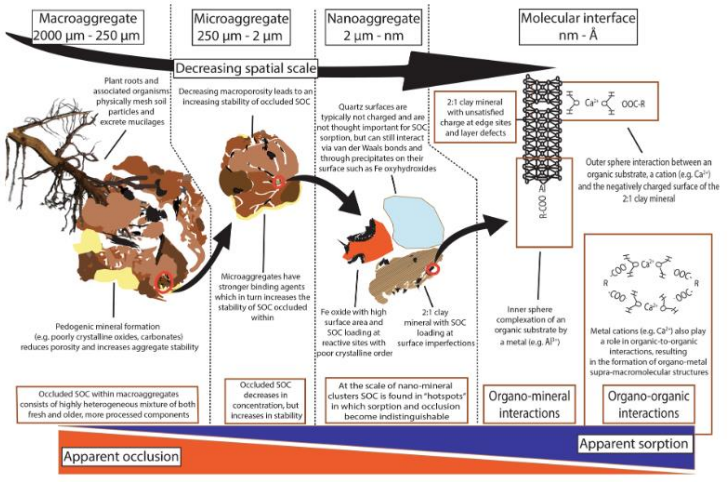

Fig. 1 Occlusion and sorption co-stabilise soil organic carbon at all spatial scales, but this co-occurrence becomes more apparent at the nano-scale where they become operationally indistinguishable

Rowley, et al, 2018

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