Wisconsin

Technical Note

United States Department of Agriculture | Natural Resources Conservation Service
Wisconsin Agronomy Technical Note 11 | Amending Soil Properties with Gypsum Products

PURPOSE

Gypsum is used to attempt to change the physical and/or chemical properties of soil to:

- Improve soil health by improving physical/chemical properties and increasing soil infiltration.
- Improve surface water quality by reducing dissolved phosphorus concentrations in surface runoff and subsurface drainage.
- Improve soil health by ameliorating subsoil aluminum toxicity.
- Improve water quality by reducing the potential for pathogens and other contaminants transport from areas of manure and bio-solids application.

NOTE: Gypsum has been used on many soils in Wisconsin with mixed results due to climate factors and soil variables. There is evidence this product has demonstrated some added value to dense mineral soils where drainage may be restricted.

BACKGROUND INFORMATION - GYPSUM AND GYPSUM PRODUCTS

Gypsum is an evaporite mineral most commonly found in layered sedimentary deposits in association with halite, anhydrite, sulfur, calcite and dolomite. Gypsum ($CaSO_4.2H_2O$) is one of the earliest forms of fertilizer used in the US. This soil amendment has been applied to the worlds' agricultural soils for over 250 years. Gypsum is a moderately soluble source of essential plant nutrients, calcium and sulfur. Gypsum is not a liming agent and will not neutralize hydrogen ions or change soil pH, unlike calcium carbonate. Gypsum is most commonly used to mitigate subsoil acidity, aluminum toxicity, sodic soil reclamation, and as a component in

synthetic soils for nursery, greenhouse and landscape use. Sources of gypsum available for agricultural use include:

- Natural gypsum mined from geologic deposits,
- flue gas desulfurization (FGD) or synthetic gypsum produced as a by-product of electricity generation,
- recycled casting gypsum from various manufacturing processes, and
- recycled drywall gypsum.

Flue Gas Desulfurization (FGD) or Synthetic Gypsum

FGD or synthetic gypsum is produced at some coal-fired power plants as a by-product of pollution control measures. The Clean Air Act Amendments of 1990 mandated that electrical utilities install systems for removal ("scrubbing") of sulfur dioxide (SO2) from flue gases that are generated during the burning of coal. The resulting materials are termed flue gas desulfurization (FGD) by-products. Depending on the process, these by-products can have a variety of mineral constituents. Currently, less than half of FGD by-product material produced in the US is used, leaving the excess product for land-filling.

FGD Gypsum is not classified as a hazardous solid waste. It is regulated as an "industrial by-product" per s. NR 538.03(4) Wis. Adm. Code and is regulated for beneficial use under chapter NR 538 Wis. Adm. Code, by the Department of Natural Resources (DNR). In addition, the Department of Agricultural Trade and Consumer Products (DATCP) licensing is required, when the by-product is used for agricultural purposes and is regulated by the Agricultural Trade and Consumer Products (ATCP) 40 - Fertilizer and Related Products. FGD gypsum has been authorized for agricultural applications since 2008 in Wisconsin.

PROPERTIES OF GYPSUM THAT PROVIDE BENEFITS FOR AGRICULTURAL USES BY IMPROVING SOIL HEALTH, IMPROVING PHYSICAL AND CHEMICAL PROPERTIES AND IMPROVING WATER INFILTRATION.

1. Gypsum is a source of calcium and sulfur, and in its pure form, contain 23% Ca and 19% S and include micronutrients utilized by plants.

2. Gypsum is about 200 times more soluble than agricultural lime, or calcium carbonate, allowing it to move readily down the soil profile, providing nutrients to deep plant roots and reducing or alleviating subsoil problems.

3. Gypsum can reduce the aluminum toxicity that often accompanies soil acidity.

4. Research studies, indicate the addition of sulfur, via gypsum to correct sulfur deficiency boosted yields of corn and forages.

5. Gypsum is a "flocculating" agent that can improve soil structure by:
    - Aggregating or clumping soil particles to prevent dispersion of soil particles,
    - reduce surface crust formation,

- promote seedling emergence,
- increase water infiltration rates through the soil profile,
- reduce erosion losses, and
- the reduction of nutrients and phosphorus concentrations in surface water runoff.

NOTE: Many researchers, plant and soil specialists acquainted with gypsum, concur that this soil amendment can positively effect the soil structure and increased water infiltration when used as outlined.

POTENTIAL NEGATIVE IMPACTS OF GYPSUM ON BOTH AGRICULTURAL PRODUCTION AND THE ENVIRONMENT

- Gypsum applications on soils with pH levels below 6.0, may accelerate leaching of cations, especially in course textured soils. This is why gypsum is not recommended on course textured soil.
- Excess application could result in seedling damage to salt intolerant species, especially if applied near the time of planting. Fall applications are recommended.
- Gypsum from most sources can be applied without restriction for trace metal loading, however, samples from a given source should always be tested prior to application.
- Gypsum may reduce crop yields when pH levels are not aligned with the most acid sensitive crop in the rotation.
- A major concern with FGD gypsum application to soils for agricultural or other uses are the high Mercury (Hg) concentrations. Most analysis indicate that Hg concentrations are very low.
- Other elements of environmental concern in some gypsum products are: a) Arsenic (As), b) Barium (Ba), c) Cadmium (Cd), d) Chromium (Cr), e) Lead (Pb), and f) Selenium (Se). Most analysis of FGD indicate the concentrations of these metals are low.

PLANNING CRITERIA TO ADDRESS THE PURPOSES IDENTIFIED IN STD. 333

When using WI NRCS Practice Standard 333, the soil loss computations for each field must be at or below T. A minimum of 30% surface residue is required at the time of gypsum applications. Cover crops maybe used to provide surface residue as well.

The use of gypsum is recommended when, all planning criteria in this section are met and the Figure 1 flow chart supports the use of gypsum.

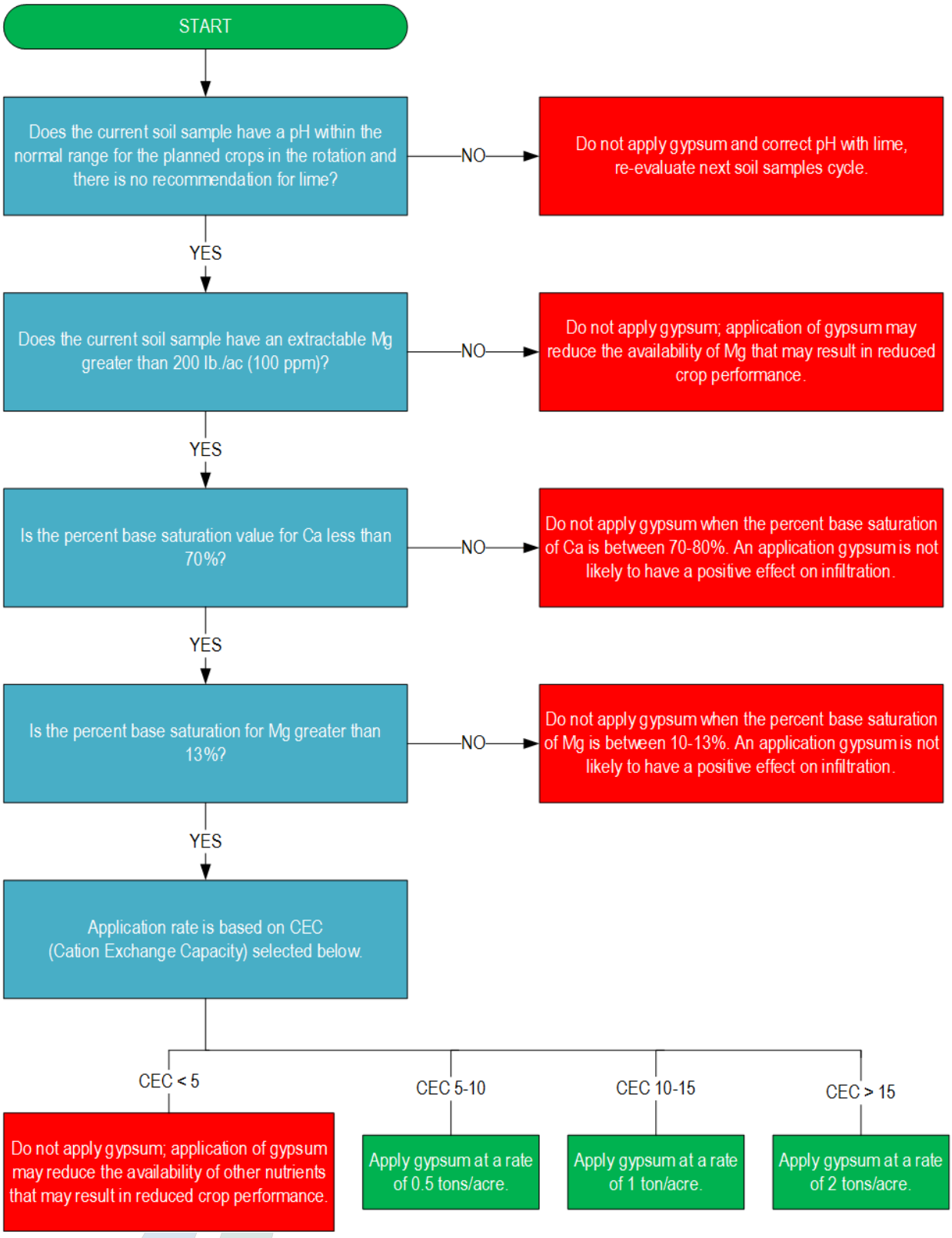
Soil Test Requirements

The following soil test requirements are:

- Current soil test analysis that meet the requirements of A-2809 Nutrient Application Guidelines for Field, Vegetable and Fruit Crops sampling protocol,
- less than one year old at the time of gypsum application,
- soil test results verify a "Cation Exchange Capacity (CEC)" of > 5,
- pH > 5.5, and
- the soil pH is within the range of the most acid sensitive crop in the rotation. Additional, requirements and soil test information outlined below under the heading; "Site and Soil Conditions where Properties of Gypsum can Improve Soil Health, Increase Crop Production and Improve Water Quality" can be used to determine when gypsum applications are most beneficial.

NOTE: Normally, analysis of CEC, extractable Ca, Mg, and sulfate sulfur concentrations will not occur on soil test reports unless requested. An estimation of typical or normal CEC, Ca and Mg concentrations based on soil texture can be used to make a preliminary determination of a potential resource concern for recommending the use of gypsum. An actual soil test analysis must be available prior to ranking applications for funding.

Figure 1. Flow chart is used to determine when gypsum is recommended and the application rates of gypsum on agricultural soils. The flow chart shall be used for future recommendations and application rates based on the next soil sampling cycle analysis.



Site and Soil Conditions where Properties of Gypsum can Improve Soil Health, Increase Crop Production and Improve Water Quality

The criteria to improve soil health by improving physical/chemical properties, and increasing water infiltration through the soil profile is based on the soil test analysis of CEC, extractable Ca, and Mg in the soil.

Gypsum application rates are based on:

- Current CEC values (Table 2),
- Percent base saturation of Ca (Table 1), and
- Subsequent applications of gypsum are determined based on the new soil test report. The goal is to increase the base saturation of Ca to be between 70 and 80% and the base saturation of Mg to be between 10 and 13%.

Note: When the current Soil Test Base Saturation of Ca and Mg is not within the recommended range, consider multiple applications to meet the base saturation range for Ca and Mg. Subsequent applications shall not occur within 1 year of the previous application and no more than 2 years from the previous application. The manipulation of the Ca base saturation shall not exceed 80%.

Table 1. Target ranges for base saturation of cations to improve soil chemical and physical properties

Base Saturation	Balanced
Calcium	70-80%
Magnesium	10-13%
Potassium	2-5%
Hydrogen	1-10%

Table 2. Gypsum application rates to improve the soil chemical and physical properties

CEC	Annual Application Rate (ton gypsum/acre)
<5	0.0
5-10	.5
10-15	1
>15	2

Criteria to Improve Surface Water Quality by Reducing Dissolved Phosphorus Concentrations in Surface Runoff and Subsurface Drainage

General use is to mitigate high phosphorus soils-apply no less than 1 ton/acre broadcast on the soil surface when soil test phosphorus (STP) is High or greater.

General use is for manure application-broadcast no less than 1 ton/acre of gypsum within 5 days after manure application or prior to the next runoff event, whichever occurs first.

Criteria to Reduce the Potential for Pathogen Transport

Apply no less than 2 tons/acre of gypsum within 5 days after manure or bio-solid application, or prior to the next runoff event after manure application, whichever occurs first.

Criteria to Improve Soil Health by Ameliorating Subsoil Al Toxicity

Conditions where exchangeable aluminum below a 12-inch soil depth is greater than 1.0 milli-equivalent/100 mg soil, apply gypsum at a rate recommended by the land grant university (LGU) or the Agricultural Research Service (ARS). The soil analysis for aluminum shall be no older than 1 year from the time of gypsum application.

NOTE: Refer to the technical support section for additional information regarding suggested application methods, timing, and rates specific the purposes in practice standard 333.

REFERENCES

Cation Exchange Capacity and Base Saturation-University of Georgia Ext.Leticia S. Sonon, David E. Kissel, and Uttam Saha

Effects of Exchangeable Ca:Mg ratio on Soil Clay Flocculation, Infiltration and Erosion, Katerina Dontsova and Darrell Norton

Gypsum Amendment and Exchangeable Calcium and Magnesium Affecting Phosphorus and Nitrogen in Runoff; Favaretto,* L. D. Norton, B. C. Joern, and S. M. Brouder

Management of Wisconsin Soils, UW Extension

National Soil Erosion Research Laboratory, gypsum fact sheet: www.ars.usda.gov/Services/docs.htm?docid=18103

Sustainable Uses of FGD Gypsum in Agricultural Systems: Introduction Dexter B. Watts* and Warren A. Dick

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TECHNICAL SUPPORT AND RESEARCH DATA

What is the nutrient content of FDG gypsum and mined gypsum?

Table 3. Comparison of the Chemical Properties of FGD Gypsum and Mined Gypsum

Material	Ca	S	Mg	As	Cd	Cr	Co	Cu	Pb	Hg	Mo	Ni	Se	Zn
	%			ppm										
FGD	23.0	18.6	0.03	0.56	<0.5	1.30	<0.5	1.16	0.80	<0.3	0.51	0.73	5.51	3.88
Mined	19.1	15.2	1.35	<0.5	<0.5	1.38	0.53	1.33	2.92	<0.3	1.28	1.42	<1.5	0.91

When should gypsum be applied?

Apply Gypsum only after a soil test has been completed within one year of the scheduled application and,

- the pH is at least 5.5 or greater, CEC is at least 5, % base saturation for Ca is less than 70%, and Mg is above 13%,
- soil test phosphorus is High or greater,
- soil test results indicate sulfur deficiency,
- crops requiring a low pH and liming is not recommended and or soils are low in Mg.

Should gypsum be applied to organic soils?

No. A typical CEC for these soils ranges between 50-100.

Does the Ca:Mg ratio provide actual nutrient concentrations?

No. The Ca:Mg ratios is the relative proportions of available Ca and Mg in the soil and does not give the actual levels of these elements.

What are the optimal soil test levels for exchangeable magnesium in the soil?

For sandy soils-51-250 ppm and 101-500 ppm for fine-textured soils. Neutral soils or those with a high pH usually contain more than 500 ppm of exchangeable Mg.

What are the optimal soil test levels for exchangeable calcium in the soil?

For sandy soils-400-600 ppm and 601-1000 ppm for fine-textured soils.

Gypsum can impact infiltration which in turn can reduce erosion and nutrient concentration in run off.

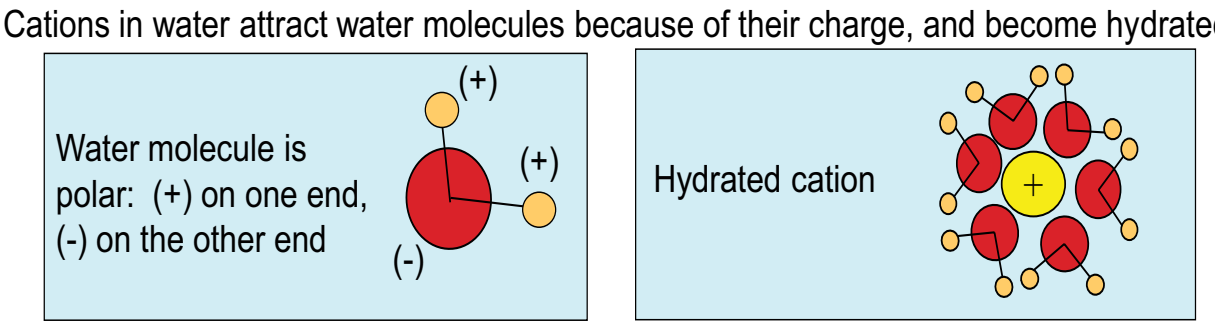
Silty and clayey soils have a tendency to disperse and form a stable suspension of particles in water. As a result, they develop a more compacted structure, particularly at or near the soil surface. Dispersion is caused by the mutual repulsion between the soil particles which results from the presence of extensive negative electric fields surrounding them. Flocculation of soil is the opposite process of soil dispersion, where the electric layer is sufficiently compressed so that attractive forces allow coagulation of the individual clay particles into micro-aggregates. Flocculation is a necessary condition for the formation and stabilization of soil structure. Application of gypsum may reduce dispersion, promote flocculation of soils and reduced dissolved P in runoff by:

1. Ca from gypsum application bonding to available P in the soil solution forming insoluble calcium phosphates (Ca-P) compounds that are not detected as soluble P in water. The Ca-P compounds are normally formed at a pH > than 7; Ca-P precipitates are more soluble at lower pH ratings,

2. Ca from the gypsum application modifying the topsoil chemistry such that it stabilizes the soil and reduces the potential for sediment runoff. The Ca increasing or promoting soil aggregation, the soil particle detachment and transport in runoff is less, and loss of P that is sorbed to soil particles is lessened as a result of increased water infiltration and percolation. The precipitated Ca-P compound would require more energy to move with surface runoff and,

3. Soil aggregation and the Ca-P precipitate should promote increased infiltration and drainage which means greater volumes of water moving to tile drains, but less dissolved P and less particle detachment should result in a net decrease in P loss to tile drains.

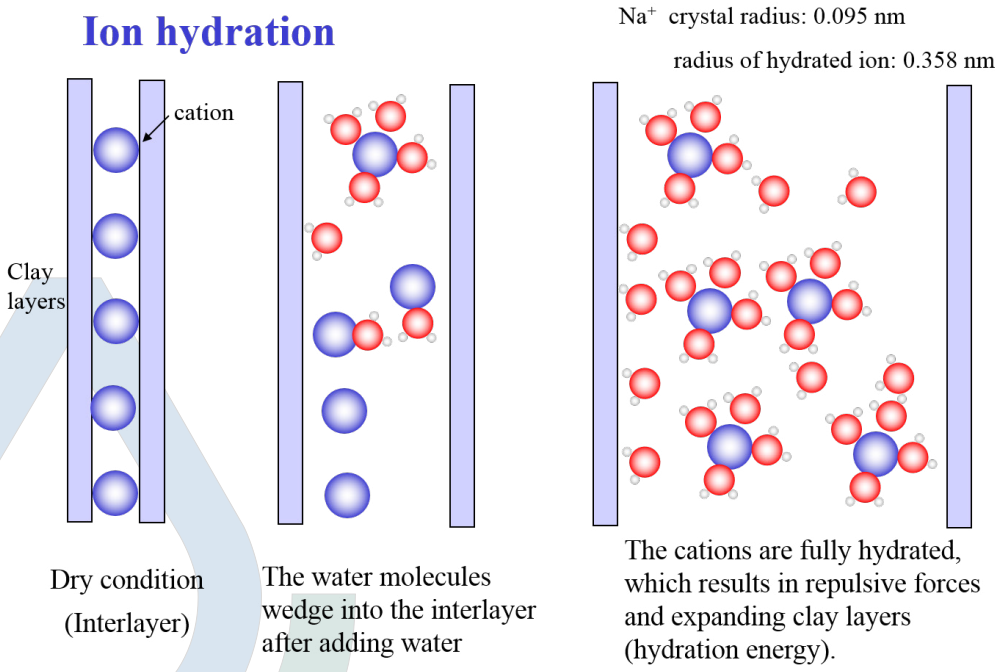
Figure 2. Comparison of the Relative Flocculating Power of the main Cations



Cations with a single charge and large hydrated radii are the poorest flocculators.

Cation	Charges per molecule	Hydrated radius (nm)	Relative flocculating power
Sodium	1	0.79	1.0
Potassium	1	0.53	1.7
Magnesium	2	1.08	27.0
Calcium	2	0.96	43.0

Figure 3. Demonstrating Soil Dispersion

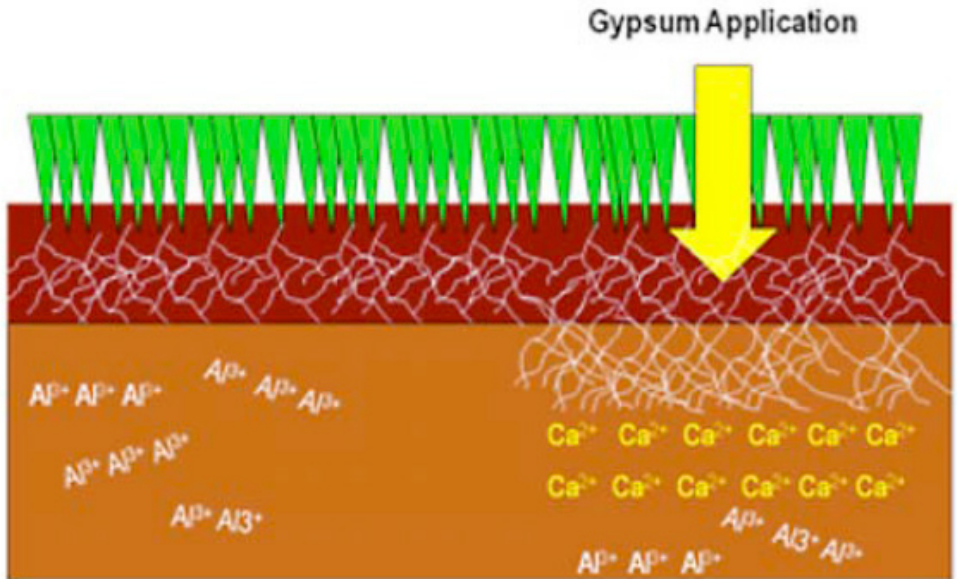


How does gypsum properties improve soil health by interacting with chemical properties of soils, thus improving crop production?

1. As stated earlier gypsum is about 200 times more soluble than calcitic or dolomite lime. Gypsum will mitigate the acidic hydrogen ion (H+), ionize from soil carbonic acid and the calcium ions (Ca++) will force (H+) ions held by soil particles into the soil solution. (5)

2. Gypsum can reduce the aluminum toxicity that often accompanies soil acidity; forming soluble complexes with Al3+ therefore reducing its toxic effects on plant roots. The detached Al3+ ion from the clay particle present in the soil-water solution would now be available to leach through the profile. The same interaction occurs with the sodium (Na+) ion, under sodic conditions, where (Ca++) has selectivity over (Na+) and Magnesium (Mg++) ions.

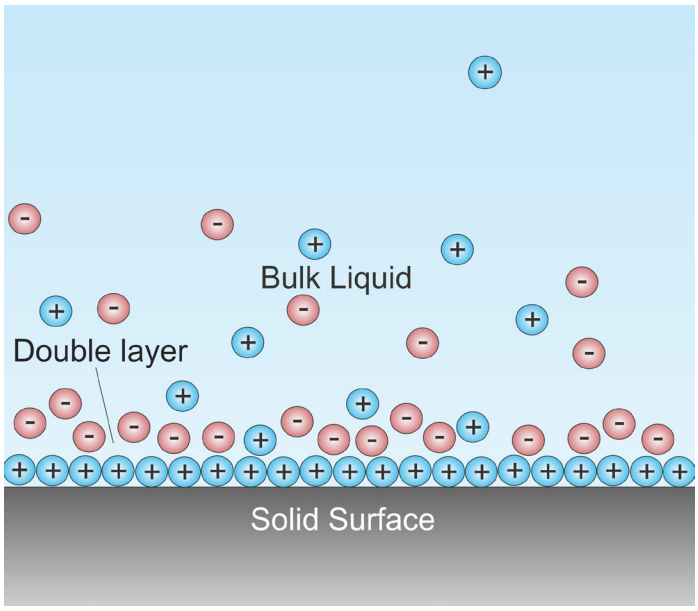
Figure 5. Gypsum as a soil amendment to remediate subsoil acidity



Why does mixing or incorporating gypsum into the soil diminish its effect of reducing P transport in surface water runoff?

According to most scientific data, gypsum can improve the physical and chemical properties of soils, thus reducing erosion losses of soils and nutrient concentrations (especially phosphorus) in surface water runoff when surface applied. Mixing gypsum into the soil diminishes its effect at the surface where most of the P transport occurs. (4,7) Gypsum applied at the soil surface increases the electrolyte concentration of the infiltrating rainwater, compresses the electric double layer, and provides Ca to the exchange complex where it has selectivity over Mg and Na in most soils.

Figure 6. Electrical double layer (DL) Illustration



Schematic of double layer in a liquid at contact with a negatively-charged solid. Depending on the nature of the solids, there may be another double layer (unmarked on the drawing) inside the solid.

Soil texture groups and typical CEC values in meg/100 grams of soil

- Sands-3-5 CEC (do not apply)
- Loams and silt loams-10-20 CEC
- Silty clay loams and silty clays-15-25 CEC
- Organic soils-50-200 CEC (do not apply)

Additional Guidance for Determining Appropriate Application Rates

The rate of gypsum application depends on the specific purposes when using gypsum for crop production and the producer's perception of return on investment. For many land-application uses of gypsum, it is important that the recommended rates are based on well-defined principles of soil and agronomic science. The specific purpose for applying gypsum to the soil and the appropriate rates can vary greatly, from less than 100 lbs. to several tons per acre each year.

Table 4. Rate, Time, and Method of Application of Gypsum Products for Various Functions

Function	Application Rates lbs./acre			Time of Application	Application Method
	Low	Normal	High		
Sulfur fertilizer to reduce deficiency and increase crop production	100	300	500	Prior to planting	Soil surface or incorporate
Calcium fertilizer to enhance crop production	1000	2000	4000	Prior to planting	Soil surface
Soil amendment to remediate sub-soil acidity	3000	6000	10000	Fall and 1-180 days prior to planting	Soil surface or incorporate
Soil amendment to remediate sodic or effects of sodium soils	2000	10000	20000	Fall and 90-180 days prior to planting	Soil surface or incorporate
Soil amendment to improve water quality	1000	6000	9000	Fall and 1-180 days prior to planting	Soil surface
Soil amendment to improve physical properties to increase water infiltration	1000	3000	9000	Fall and 1-180 days prior to planting	Soil surface
A component of synthetic soils used in horticulture by nurseries	5%	10%	20%	At the time of preparing synthetic soils	Mixed with other synthetic soil components