

Effectiveness of Gypsum

in the North-central Region of the U.S.

David Franzen

North Dakota State University

George Rehm

University of Minnesota

James Gerwing

South Dakota State University

Gypsum is the common name for calcium sulfate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$).

It occurs in nature as a crystalline solid (Figure 1). Crystals form in semiarid and arid climates when dissolved calcium sulfate precipitates due to soil water evaporation. Gypsum solubility is roughly 0.35 ounce per gallon (oz/gal) at room temperature. However, the actual solubility depends on the chemistry of the soil water, including dissolved minerals such as carbonates and sulfates. Higher concentrations of carbonates and/or sulfates result in lower solubility of gypsum.

Gypsum has several possible agricultural uses as a soil amendment. It can:

1. Be used to reclaim sodic soils (dispersed soils high in sodium)
2. Improve soil aggregation, which in turn can decrease bulk density and increase water percolation
3. Reduce soil crusting and reduce runoff
4. Decrease soil pH in high-pH soils (greater than pH 8.5)



Figure 1. Gypsum crystals in a glacial till soil in North Dakota.

5. Increase soil pH in aluminum-dominated soils (less than pH 4.5)
6. Decrease iron chlorosis in some soils
7. Be used as a source of fertilizer sulfur and calcium

Although these seven results are possible when gypsum is added to soil, special soil conditions and rates are necessary to achieve them. These conditions do not apply to the very large majority of the soils in the north-central region.

Reclamation of Sodic Soils (soils high in sodium)

Many studies have shown that the addition of a soluble calcium amendment, combined with drainage and tillage, can reclaim sodic soils (Rasmussen et al., 1972; Sharma et al., 1974; Shainberg et al., 1982). Sodium-dominated soils are very poor agricultural soils. Sodium acts to change clay chemistry so clay particles are dispersed and random. This dispersed state results in a more massive soil structure that does not contain fracture planes of low enough

strength to allow water and root penetration. In sodic soils, the revealed structure is in large columns sometimes several inches up to a foot wide. Roots can explore only the area around the structures, but few can penetrate and utilize nutrients and water within the structure. The effective result is the soils are alternately too wet, preventing water penetration, or too dry because of restricted rooting depth.

An Illinois study (Sharma et al., 1974) shows the effectiveness of gypsum in reducing the quantity of sodium in a soil (Table 1). Rates of gypsum were applied, and the soil was tilled to various depths. Tile had been placed at various spacings under the plots before gypsum application and tillage. The result was that the high rate of gypsum (27 tons/acre) was needed and tilled to 3 feet in depth, with tile spacing of 30 feet, to significantly reduce sodium saturation, compared with the check. A gypsum rate of 10 tons/acre, shallower tillage or wider tile spacing all resulted in much less reduction in sodium. All three conditions had to be more intense to result in an improvement.

Table 1. Effectiveness of gypsum, tillage depth and tile spacing in reducing sodium saturation in a southern Illinois soil (Sharma et al., 1974).

Gypsum rate	Tillage depth	Tile spacing	Sodium saturation
t/acre	in.	ft.	meq/100 g
0	6	30	5.13
10	6	30	5.83
10	6	None	5.38
10	24	30	5.75
27	36	30	1.74
Check	—	—	6.09

NDSU
Extension Service

North Dakota State University
Fargo, North Dakota 58105

NOVEMBER 2006

The rate of gypsum needed to aid in remediating a sodic soil can be approximately computed using the following modified formula from Oster et al. (1999), and Oster and Frenkel (1980)

$$\text{Gypsum requirement (tons/a)} = 0.00385 (F) (D_s)(r_b)(10 \times \text{CEC})(\text{SAR}_i - \text{SAR}_f)$$

Where F is the Ca-Na exchange efficiency factor, approximately 1.27; D_s is the soil depth (feet), r_b is the soil bulk density (tons/ft³), CEC is the cation exchange capacity (mmol/100g), and SAR_i and SAR_f are the initial and final exchangeable sodium percentages of the soil.

For example, if the bulk density of the soil was 1.6 g/cm³ (0.05 tons/ft³), the CEC was 20 mmol/100g, the depth to remediate was 2 feet and the goal was to reduce the SAR from 10 to 5, the formula would be –

$$0.00385 \times 1.27 \times 2 \times 0.05 \times 200 \times 5 = 0.49 \text{ tons/acre}$$

The F factor in the above equation and the effective depth that gypsum will be active in a soil at a given concentration can vary. Application of gypsum should be followed the next few years with periodic soil testing to track the remediation process and direct an additional application if needed.

The effectiveness of the formula-derived gypsum requirement rate assumes sufficient drainage will be available to leach out the sodium replaced by the soluble calcium in gypsum. Gypsum is not the only salt that can replace sodium, but it often is the cheapest source and the amendment most commercially available in the large quantities required to perform the task. Calcium chloride, for example would substitute for gypsum at a rate of about 85 percent of gypsum. However, calcium chloride would be much more effective in soils dominated by a saturation of sulfate salts, as is found often in North Dakota (Skarie et al., 1987).

Producers often make a mistake when they assume soluble salts and sodium saturation are the same thing. Part of the confusion is terminology. The word

“alkali” is used properly as an archaic term to define sodium saturation. However, the word has worked its way into the colloquial terminology of the Midwest to mean other conditions. In the central Corn Belt, alkali often is used to identify areas with pH greater than 7, containing free lime. The condition of high free lime often has nothing to do with sodium. High sodium soils can be found with low pH as well as high pH. Conversely, high pH soils with free lime rarely contain sodium in Iowa, Illinois and other central Corn Belt states.

The most confusing condition is found in the western areas of the region, where growers often refer to soils with high soluble salts as “alkali” spots (Figure 2). Again, high soluble salt soils may or may not contain sodium. However, most already contain very high levels of gypsum. Addition of gypsum to soils already high in gypsum does not reduce levels of gypsum. Addition of any salt to areas of high salt will not reduce soil salt levels.

Therefore, sufficient soil testing must be conducted to reveal the true nature of the condition before recommending gypsum to take care of an “alkali” problem. Soil pH, soluble salts and the ratio of sodium to calcium and magnesium (ESP, exchangeable sodium percentage, or SAR, sodium absorption ratio), as well as residual sulfate, should be analyzed in soil samples within the rooting depth. If soluble salt levels are low and sufficient drainage



Figure 2. An area of excessive salts, often misnamed “alkali spot.” The area is high in salts and may or may not contain high levels of sodium. Gypsum is often, but not always, a component of the salts present in these areas.

occurs for sodium to be leached from the effective rooting zone, then gypsum may serve to reclaim these soils. If sulfate levels are high, then perhaps a more soluble source, such as calcium chloride, might be a more suitable amendment.

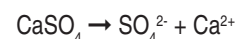
Reducing Soil Bulk Density

Some studies have shown gypsum application at high rates can decrease bulk density through increased soil aggregation. An Alberta study (Webster and Nyborg, 1986) compared the effects of an 8 tons/acre lime and 8 tons/acre gypsum treatment on clod size and stable aggregate formation in a sodic soil. The gypsum treatment was superior to the lime treatment and the check in enhancing these characteristics, but only when tillage deeper than 6 inches was used. Tilling deeper than 18 inches improved soil physical characteristics where natural gypsum deposits underneath the sodic layer were mixed with the soil above. Sandoval and Jacober (1977) also saw this improvement with tillage where naturally occurring gypsum is found in subsoil near Mandan, N.D.

However, investigations in Georgia (Radcliffe et al., 1986) found the effect of gypsum on a compacted soil in an alfalfa-row crop rotation was not a direct effect of the gypsum, but an enhancement of growth of the alfalfa. The deep-rooting effect of the alfalfa helped improve subsoil bulk density.

Soil pH Effects

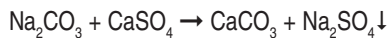
The role of gypsum in adjusting soil pH may be confusing. In corn and soybean growing areas, soil pH in the range of 6 to 7 is preferred for optimal growth and yield. Soil pH encountered in most areas of the north-central region of the U.S. range from 5 to 8. Within the pH range of 4.5 to 8.4, the addition of gypsum will have no effect on soil pH. The reaction will be as follows:



Dissolving gypsum in water does not result in net change in soil water charge.

At pH levels below 4.5, aluminum becomes soluble and dominates as the controller of lower soil pH. Under these conditions, which are seen often in the tropics and in some areas of the southeastern U.S., addition of gypsum can replace aluminum on clay and organic matter surfaces, allowing aluminum to leach away and raising pH to the lowest level at which hydrogen ions again dominate soil pH regulation (Oates and Caldwell, 1985; Sumner et al., 1986).

Soils with free lime are limited in pH to an upper threshold of about 8.4. When soil pH is 8.5 or higher, a significant amount of sodium carbonate (Na_2CO_3) likely is present. Addition of gypsum under these conditions results in precipitation of sodium as less soluble sodium sulfate (Na_2SO_4), resulting in a corresponding decrease in soil pH.



Although both reducing and increasing soil pH with gypsum is possible, each effect is appropriate for soil conditions that are seen only rarely in the north-central region. Use of gypsum to increase soil pH from 5 to 6 will not be effective, nor will its use to try to lower pH from 8 to 7. For these reasons, gypsum is not considered to be a liming material or an additive to reduce pH in this region.

Influence on Iron Chlorosis

Soils with low soluble salt content and significant free lime have shown in increase in iron uptake and alleviation in iron chlorosis with application of gypsum (Olsen and Watanabe, 1979). Although some studies have shown this effect, the consistency of results was less than in experiments with banded iron sources, such as ferrous sulfate. The nature of the improvement was attributed sometimes to alleviation of sulfur deficiency, decrease in soluble bicarbonate due to calcium addition and perhaps an imbalance of anions in these wet, calcareous soils (R. Wiese, personal communication, 2005).

Many soils with serious iron chlorosis problems in the northern Great Plains have high soluble salts in addition to

free lime and free gypsum. The higher soluble salts are an additional stress on the plants, which aggravates iron chlorosis symptoms (Franzen and Richardson, 2000). Addition of gypsum to these soils would be expected to only aggravate chlorosis, not alleviate it.

Gypsum as a Source of Plant Nutrients

Gypsum can be used as a source of sulfur. Hoefft, et al. (1985), used gypsum in a total of 82 sites during three years and found five responding sites. In North Dakota, its use has not been widely recommended for canola due to its relative low solubility, compared with the more widely used and tested ammonium sulfate. However, its role as a possible sulfate-sulfur source should not be ignored.

Gypsum also is used as a calcium amendment, especially for peanuts in the southeastern U.S., to improve peanut set. Calcium deficiencies are not common in the north-central states when soils are properly limed. The few documented cases of calcium deficiencies in this region have been related to soil and environmental conditions that result in poor plant xylem flow and transpiration, such as extremely damp conditions, continuously high humidity and saturated soils (Moraghan, 1977). When conditions improve, the symptoms go away.

Increases in Water Infiltration

Under conditions of significant soil sodium content, application of gypsum to the soil surface at rates of about 2 tons/acre have increased water infiltration and reduced surface runoff and erosion (Keren et al., 1983; Morin and Van Winkel, 1996). Generally, if soils are not dispersive, gypsum applications do not help water infiltration (Ben-Hur et al., 1992).

Decreased Soil Crusting

Gypsum has been found effective in reducing soil crusting in laboratory experiments using both sodic and nonsodic soil (Amezketta et al., 2005).

However, these effects have not been demonstrated in a practical manner in this region.

The positive response of gypsum as a fertilizer or soil amendment in the region when sulfur is not deficient has not been demonstrated. Several studies in South Dakota on sites where a sulfur response was unlikely have not shown positive yield responses in corn, wheat or soybeans (Table 2, 3 and 4). An Iowa study (Sawyer and Barker, 2002) compared the response of corn to applications of gypsum and elemental sulfur at six sites. Neither gypsum nor elemental sulfur resulted in yield increases at any site. This study showed that gypsum responses did not differ from the sulfur effect. These results suggest that unless a sulfur response occurs or producers need sodic soil remediation, use of gypsum would not be expected to produce economic benefits in the north-central region.

Table 2. Gypsum influence on spring wheat and corn yield, Brown County, S.D. (Gelderman, et al., 2003).

Gypsum rate	Wheat yield	– Corn yields –	
		Site 1	Site 2
lb/a			
0	67	204	181
300	65	189	184
Sig. 5%	NS	NS	NS

Table 3. Gypsum influence on corn and soybean yield, Beresford, S.D. (Gelderman, et al., 2003).

Gypsum rate	Corn yield	Soybean yield
lb/a	bu/a	bu/a
0	108	39a
600	101	34b
1500	98	35ab
Sig 5%	NS	4.6

Table 4. Gypsum influence on spring wheat yield, Aurora, S.D. (Gelderman, et al., 2003).

Gypsum rate	Wheat yield
lb/a	bu/a
0	74
140	67
Sig. 5%	NS

Summary

Although in different soils under different conditions around the world, gypsum is used correctly to correct soil pH, improve soil condition and increase yield, only special directed uses are appropriate for the north-central region.

Gypsum is not an effective liming product in the region. Gypsum can improve soil condition if the soil is dispersive due to excessive sodium. Sodic soils can be improved with gypsum if the appropriate rate is applied, the gypsum is worked into the soil to a deep depth, tile is present and rainfall or irrigation moves the sodium out of the system. Gypsum has decreased iron chlorosis on some soils in Nebraska, but the effects are inconsistent and generally are not recommended in place of iron amendments.

Gypsum may be used as a source of sulfur, although its relatively low solubility, compared with other sulfur sources, may be a concern in more arid parts of the region.

References

- Amezketta, E., R. Aragues and R. Bazol. 2005. Efficiency of sulfuric acid, mined gypsum and two gypsum byproducts in soil crusting prevention and sodic soil reclamation. *Agronomy Journal* 97:983-989.
- Ben-Hur, M., R. Stern, A.J. van der Merwe and I. Shainberg. 1992. Slope and gypsum effects on infiltration and erodibility of dispersive and nondispersive soils. *Soil Science Society of America Journal* 56:1571-1576.
- Franzen, D.W., and J.R. Richardson. 2000. Soil factors affecting iron chlorosis of soybean in the Red River Valley of North Dakota and Minnesota. *Journal of Plant Nutrition* 23:67-78.
- Gelderman, R., A. Bly, J. Gerwing, H. Woodard and R. Berg. 2003. Influence of gypsum on crop yields. South Dakota State University Soil/Water Research, 2003 Progress Report PR03-12, pp. 1-4.
- Hoef, R.G., J.E. Sawyer, R.M. Vanden Heuvel, M.A. Schmitt and G.S. Brinkman. 1985. Corn response to sulfur on Illinois soils. *Journal of Fertilizer Issues*. 2:95-104.
- Keren, R., I. Shainberg, H. Frenkel and Y. Kalo. 1983. The effect of exchangeable sodium and gypsum on surface runoff from loess soil. *Soil Science Society of America Journal* 47:1001-1004.
- Moraghan, J. 1977. Soil fertility investigations. 1976 Sugarbeet Research and Extension Reports 7:169-170.
- Morin, J., and J. Van Winkel. 1996. The effect of raindrop impact and sheet erosion on infiltration rate and crust formation. *Soil Science Society of America Journal* 60:1223-1227.
- Oates, K.M., and A.G. Caldwell. 1985. Use of by-product gypsum to alleviate soil acidity. *Soil Science Society of America Journal* 49:915-918.
- Olsen, S.R., and F.S. Watanabe. 1979. Interaction of added gypsum in alkaline soils with uptake of iron, molybdenum, manganese and zinc by sorghum. *Soil Science Society of America Journal* 43:125-130.
- Oster, J.D., and H. Frenkel. 1980. The chemistry of the reclamation of sodic soils with gypsum and lime. *Soil Science Society of America Journal* 44:41-45.
- Oster, J. D., I. Shainberg and I.P. Abrol. 1999. Reclamation of salt-affected soils. p. 659-691. In *Agricultural Drainage*. Agronomy Monograph No. 38. R.W. Skaggs and J. van Schilfhaar ed. ASA-CSSA-SSSA, Madison, Wis.
- Radcliffe, D.E., R.L. Clark and M.E. Sumner. 1986. Effect of gypsum and deep-rooting perennials on subsoil mechanical impedance. *Soil Science Society of America Journal* 50: 1566-1570.
- Rasmussen, W.W., D.P. Moore and L.A. Alban. 1972. Improvement of a solonchic (slick spot) soil by deep plowing, subsoiling and amendments. *Soil Science Society of America Proceedings* 36:137-142.
- Sandoval, F.M., and F.C. Jacober. 1977. Deep plowing: Cure for sodic claypan. *Crops and Soils* 1977:9-10.
- Sawyer, J.E., and D.W. Barker. 2002. Corn and soybean response to sulfur application on Iowa soils. p. 157-161. In 2002 North Central Extension - Industry Soil Fertility Conference, November 20-21, 2002, Des Moines, Iowa. Potash & Phosphate Institute, Brookings, S.D.
- Sharma, A.K., J. B. Fehrenbacher and B.A. Jones Jr. 1974. Effect of gypsum, soil disturbance and tile spacing on the amelioration of Huey silt loam, a nitric soil in Illinois. *Soil Science Society of America Proceedings* 38:628-632.
- Shainberg, I., R. Keren and H. Frenkel. 1982. Response of sodic soils to gypsum and calcium chloride application. *Soil Science Society of America Proceedings* 46:113-117.
- Skarie, R.L., J.L. Richardson, G.J. McCarthy and A. Maianu. 1987. Evaporite mineralogy and groundwater chemistry associated with saline soils in eastern North Dakota. 51:1372-1377.
- Sumner, M.E., H. Shahandeh, J. Bouton and J. Hammel. 1986. Amelioration of an acid soil profile through deep liming and surface application of gypsum. *Soil Science Society of America Journal* 50:1254-1258
- Webster, G.R., and M. Nyborg. 1986. Effects of tillage and amendments on yields and selected soil properties of two solonchic soils. *Canadian Journal of Soil Science* 66:455-470.

This publication may be copied for noncommercial, educational purposes in its entirety with no changes.

Requests to use any portion of the document (including text, graphics or photos) should be sent to permission@ndsuxt.nodak.edu.

Include exactly what is requested for use and how it will be used.

For more information on this and other topics, see: www.ag.ndsu.edu

