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BRIDGING ENTERPRISES FOR A HEALTHY AND SUSTAINABLE WORLD

Gypsum for Agricultural Use

September 19, 2012

Abstract

Soil health is a global issue that influences crop productivity and water quality. Farming methods can protect and improve soil health. One effective practice is the use of gypsum as a soil amendment on certain soil types. Gypsum is a sulfate mineral made up of calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$). It has been mined for use as an agricultural amendment for centuries; recently it has been produced as a by-product from emission scrubbers in coal-fired power plants, known as Flue Gas Desulfurization (FGD) Gypsum. FGD gypsum has fewer impurities than mined gypsum. It is a direct source of macronutrients (calcium and sulfur) for plants, and improves soil physical and chemical properties that promote nutrient uptake from soil minerals into plants. By enhancing soil composition and improving water infiltration, gypsum can contribute to enhanced crop growth as well as water conservation, plus reduce the loss of soil and nutrients into area waterways. Research studies and farm management experiences in the U.S. indicate that gypsum is a valuable soil amendment (Chen and Dick, 2011; Chen, Kost, Dick, 2008; Dontsova et. al, 2004; Fisher, 2011; Stout et. al, 1998; Walworth, 2006; Wolkowski et. al, 2000).

Introduction

Demand for increased crop yields to meet global population growth has led to depleted soils. Nearly all U.S. agricultural soil is somewhat degraded and much of the soil in the Midwest is very degraded ("Land Degradation", 2010). Poor soil conditions inhibit plant uptake of important nutrients, like phosphorus and nitrogen, reducing yields and producing less healthy plants. To compensate, farmers often over-apply fertilizers and pesticides, which further stress soils and load nearby waterways with excess nutrients. This causes algal blooms, eutrophication, aquatic life loss, water quality degradation and public health concerns. Additionally, degraded soils retain less water, stressing plants during drought conditions.

Gypsum

Research indicates that certain soil amendments can aid in remediating soils, resulting in higher yields and reduced sediment runoff (Chen and Dick, 2011; Stout et. al, 1998). One promising amendment is gypsum, a sulfate mineral made up of calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$). Gypsum has been used as a fertilizer for centuries (Chen and Dick, 2011). Gypsum is found naturally in sedimentary rocks around the world, including the United States, which has several active gypsum mines. However, mined gypsum is not economically feasible in many locations (Rhoton, 2011) in part due to transportation costs. Gypsum is also produced when sulfur dioxide is scrubbed from coal-fired power plant exhaust stacks. This kind of gypsum, flue gas desulfurization (FGD) gypsum, contains fewer impurities than mined gypsum, with a 90 to 99% purity concentration compared to 66 to 98% concentration for mined gypsum (Chen and Dick, 2011). FGD gypsum has been recognized as a beneficial additive for agricultural application, equivalent to or better than mined gypsum. Compared to mined gypsum, FGD

gypsum has good spreading characteristics, which allow it to be applied easily (Dontsova et. al, 2004). With more coal fired power plants installing pollution scrubbers, FGD gypsum production has increased and will likely double in the next decade and remain economically priced (Wolkowski et. al 2010).

Improved soil composition

Prior to gypsum application, it is important to understand the stability of the soil by looking at soil aggregates. Aggregates are clusters of soil particles; their spacing influences water infiltration. Calcium binds soil particles into aggregates to help with water infiltration (Walworth, 2006). Gypsum especially improves the physical properties of heavy clay and sodic soils (Chen and Dick, 2011). By improving soil composition, gypsum helps prevent soil particulate dispersion, decreases surface crust formation, aids in seedling emergence, increases water infiltration, and decreases the loss of soil and nutrients due to surface runoff and erosion (Chen and Dick, 2011).

Improved water quality and quantity

Gypsum also improves chemical properties of soil such as remedying aluminum toxicity caused by subsoil acidity (Chen and Dick, 2011; Dontsova et. al, 2004). Results include better rooting and uptake of water and nutrients, especially during periods of water scarcity (Chen and Dick, 2011). One study in the lower Mississippi River valley (Rhoton, 2011) showed an increase in total water infiltration by 71% (Rhoton, 2011). While gypsum addresses subsoil acidity and aluminum toxicity, it is important to note that gypsum is not a liming agent, and does not alter pH levels in the soil (Fisher, 2011). Gypsum can also amend problems associated with excess phosphorus. High phosphorus levels pose a threat to waterways. The calcium in gypsum lowers the amount of phosphorus released in surface runoff. Additionally, gypsum aggregation of soils also reduces the amount of surface runoff. Water-soluble phosphorus decreased by 50% in one study (Stout et. al 1998). In a lower Mississippi River valley study the total runoff decreased by 30% and soil loss by 77% (Rhoton, 2011). A study on gypsum application on soils where poultry litter was used as fertilizer also significantly reduced soluble phosphorus (Sheng et. al, 2012). In another study in Indiana (Norton, 2008) soluble phosphorus was reduced by more than 50% with the application of gypsum in comparison to a no-till control plot (Norton, 2008). In a south Florida study (Andersen et. al. 1995) dairy manure was the source of phosphorus loading in surface waters, and the application of gypsum resulted in higher retention rates of phosphorus in the soil, thereby reducing soluble phosphorus in waterways. Grass buffers can also reduce soluble phosphorus runoff and are even more effective when gypsum is applied to the buffers. One study (Watts et. al, 2009), showed a reduction in soluble phosphorus by up to 40% when gypsum was applied to the grass buffers in Alabama.

Improved Crops

Improved soil conditions increase crop yields (Chen and Dick, 2011). Gypsum's sulfur and calcium components also contribute to crop yields. Calcium is important for strengthening cell walls and membranes, as well as for developing root tips (Fisher 2011). Sulfur is also a vital element. Corn yields, for example, are often limited by inadequate sulfur needed to balance soil nitrogen in producing protein. Because sulfur aids plants in producing protein, sulfur deficiencies can contribute to lower yields. In fact, sulfur is an often forgotten essential nutrient for plant growth and is rapidly being depleted in soil (Chen and Dick, 2011). A Wooster, Ohio study (Chen, Kost, Dick, 2008) found that in addition to

nitrogen fertilizers, adding sulfur in the form of FGD gypsum boosts corn yields. The gypsum contributed to the increased uptake of these important elements – nitrogen and sulfur. The application of gypsum reduces the amount of nitrogen fertilizer needed for producing higher corn yields, making gypsum economically advantageous while reducing the amount of fertilizer run off (Chen, Kost, Dick, 2008). A Texas study indicated gypsum provided at least three times more available calcium than other tested treatments. A higher level of application was more effective than the lower level (Brauer et. al, 2005). Gypsum applications in Kansas increased wheat yields an average of 10 bushels over a five year period (Lamond, 1992). It should also be noted that Gypsum application in California avocados groves resulted in a decrease in *Phytophthora cinnamomi* infection; however, it is not fully understood how gypsum reduced the incidence of infection, so further research is needed (Messenger et. al, 2000). In California orchards and vineyards, studies have shown gypsum to reduce crop failure associated with the calcium leaching properties of the snow melt (Rouppet, 2008). These cases indicate gypsum is effective in boosting crop yields and acting as a catalyst for nutrient uptake in plants.

Whole systems approach

Gypsum is proven as a successful soil amendment across the United States and the world for various crops (Fisher, 2011; Brauer, 2005; Peacock; Rouppet, 2008; Miller et. al, 1998). While gypsum used alone is a beneficial agricultural application, best results are achieved when used with other sustainable farming methods such as no tillage, cover crops, and crop rotation (Fisher, 2011). Farmers in the Midwest have been using gypsum for decades with beneficial results; including better water infiltration and higher yields (Fisher, 2011).

Application

Several studies indicate gypsum's beneficial properties when used appropriately as a soil amendment (Chen and Dick, 2011; Dontsova et. al, 2004). Some precautions should be considered; the rate and season to apply gypsum will vary by location and soil type (Dontsova et. al, 2004; Peacock). Over-application of gypsum may result in seedling damage and nutrient imbalance. Additionally, when purchasing the FGD gypsum it is important that it has been washed in the manufacturing process to remove potentially high levels of boron that can be toxic to crops, such as corn (Dontsova et. al, 2004). Because low concentrations of trace metals may be found in gypsum, generally at lower concentrations than government regulations, it is best to test samples before applying (Dontsova et. al, 2004). As previously mentioned, gypsum does not remedy all soil problems. Location and soil composition influence gypsum's effectiveness and thus is not suitable for all crops (Franzen, 2008).

Other environmental benefits

In addition to water quality and agronomic benefits, use of FGD gypsum as a soil amendment contributes to the environment through avoiding land filling impacts of FGD gypsum disposal and avoiding the mining and associated impacts of extracting virgin gypsum deposits (Chen and Dick, 2011). Additionally, gypsum can reduce nitrous oxide (N_2O), a potent greenhouse gas. In 2010, agricultural soil management practices made up 68% of N_2O emissions in the U.S. (EPA, 2012). Several farming practices contribute to direct N_2O emissions, including the application of synthetic fertilizer, which alone accounts for 18% of N_2O contributed by agricultural soil management practices. Indirect contributions also include surface leaching and runoff, making up 12% of N_2O due to agricultural soil

management practices. Synthetic fertilizer and surface leaching and runoff together make up 20% of total U.S. N_2O emissions (EPA, 2012). Gypsum reduces the amount of fertilizer needed and reduces agricultural runoff, thereby reducing N_2O emissions.

Conclusions

Overall, gypsum is an effective soil amendment which improves soil conditions and their effective nutrient processing capabilities in certain soil types. It helps to restore degraded soils and produce more nutritious plants. Gypsum enhances water infiltration and improves soil composition, which contributes to lower erosion rates and less nutrient loading to area waterways. Gypsum is most effective as one component of a whole systems approach to managing agricultural lands that takes into consideration soil type, crop, and hydrology. Healthy functioning soils contribute to healthy crops and healthy waterways, and gypsum can be an important component of this result.

Gypsum Literature

Use of soil amendments to reduce soluble phosphorus in dairy soils
D.L. Anderson, O.H. Tuovinen, A. Faber, I. Ostrokowski; 1995
http://www.stormwater.ucf.edu/chemicaltreatment/documents/Anderson%20et%20al.,%201995.pdf
This is a Florida study on dairy animal manure as a source of phosphorus, which contaminates surface waters in south Florida. The study indicates that soil amendments, including gypsum, reduce soluble phosphorus.

Amendment Effects on Soil Test Phosphorus
D. Brauer, G.E. Aiken, D.H. Pote, S.J. Livingston, L.D. Norton, T.R. Way, and J.H. Edwards; 1998
http://naldc.nal.usda.gov/download/7250/PDF
A two year study of the use of a waste paper product and gypsum as an agricultural application suggests that gypsum effectively lowers phosphorus levels, resulting in a decrease of water pollution – did the data published support remark on pollution?.

Flue Gas Desulfurization Products as Sulfur Sources for Corn
Liming Chen, David Kost, Warren A. Dick; 2008
http://www.gypsoil.com/research-library?id=74&filterCrop=&filterFocus=Yield&filterState=&filterKeyword=
This peer-reviewed article discusses how FGD gypsum can remedy sulfur deficiency in crops, including corn. Tests were conducted in Wooster, Ohio. Other gypsum literature can be found on Gypsoil's Research Library site – www.gypsoil.com/research-library

Gypsoil Brochures
www.gypsoil.com
Gypsoil has three brochures on gypsum for the Midwest, the Southeast, and the Delta region. These are available to download at the bottom of the home page.

Gypsum as an Agricultural Amendment
Liming Chen and Warren Dick; 2011
http://ohioline.osu.edu/b945/b945.pdf
This is a comprehensive report on gypsum that reviews the sources of gypsum, the benefits of gypsum for agricultural uses and discusses how it can be used economically. Benefits of gypsum applications include better plant nutrition and improved soil properties, as well as reduction in soil and nutrient losses, particularly phosphorus.

FGD as a Soil Amendment for Mine Reclamation
Warren Dick 2006
https://kb.osu.edu/dspace/bitstream/handle/1811/24473/FGD%20as%20?sequence=1
This is a Powerpoint presentation on the benefits of gypsum in Ohio. This presentation includes a history of the use of gypsum to improve soil quality.

Use of FGD Gypsum Soil Amendments for Improved Forage and Corn Production
Warren A. Dick, Liming Chen and David Kost

http://library.acaa-usa.org/1-Use_of_FGD_Gypsum_Soil_Amendments_for_Improved_Forage_and_Corn_Production.pdf
This is a PowerPoint presentation comparing control fields and fields with gypsum in several locations. The crops studied include corn, millet, wheat and alfalfa.

Gypsum for Agricultural Use in Ohio Sources and Quality of Available Products
Katerina Dontsova, Post-doctoral Researcher, Yong Bok Lee Post-doctoral Researcher, Brian K. Slater, State Extension Specialist, Jerry M. Bigham, Professor; 2004
http://ohioline.osu.edu/anr-fact/0020.html
This article explains different kinds of gypsum and its uses. The article mentions the precautions that should be taken with using unwashed FGD in relation to boron uptake and notes that it should be washed. It is recommended that gypsum is applied in the fall and that an appropriate amount is applied to avoid seedling damage.

FGD Workshop, Indianapolis, November 17 - 19, 2009
FGD Gypsum Power Point Presentations
http://www.fgdproducts.org/Presentations09.htm
This page features a collection of PowerPoint presentations on FGD gypsum for agricultural use. Included are two case studies of agricultural fields in Ohio that apply gypsum. Presentations include Powerpoints prepared by Dr. Warren Dick and Dr. Darrell Norton.

Amending Soils with Gypsum
Madeline Fisher; 2011
https://www.agronomy.org/files/publications/crops-and-soils/amending-soils-with-gypsum.pdf
This article highlights the benefits of gypsum as a soil amendment. Several farmers share their experience and recommend gypsum along with other sustainable farming methods to enhance soil quality and increase yields.

Effectiveness of Gypsum in the North-central region of the U.S.
David Franzen, George Rehm, and James Gerwing; 2008
http://www.agronext.iastate.edu/soilfertility/info/EffectGypsumNCRegionUS.pdf
This report highlights the effectiveness of gypsum in the north central region of the United States. Sufficient soil testing should be done to determine if gypsum is a beneficial additive. Gypsum cannot remedy all types of soil. Possible benefits include increased water infiltration resulting in decreased surface runoff and erosion.

Management of Saline and Sodic Soils
Department of Agronomy, Kansas State University
Ray E. Lamond, Extension Specialist, Soil Fertility and Management; David A. Whitney, Extension State Leader, Agronomy Program; 1992
http://www.ksre.ksu.edu/library/CRPSL2/mf1022.pdf
This article discusses how saline and sodic soils decrease productivity. About 25 percent of US irrigated farmland experiences these problems. The application of gypsum can help mitigate the problematic soil. An increase in wheat yields was seen in Kansas fields that added gypsum to its practices.

Effects of Gypsum Soil Amendments on Avocado Growth, Soil Drainage, and Resistance to

Phytophthora cinnamomi B.J. Messenger, J.A. Menge, and E. Pond, Department of Plant Pathology, University of California, Riverside; 2000
http://www.avocadosource.com/Journals/PlantDisease/0417-01R.pdf
This study shows improved avocado crop with gypsum application in California. Of particular importance, the application of gypsum decreased the presence of *Phytophthora cinnamomi*. The research was conducted by the University of California, Riverside.

Use of Gypsum to Improve Physical Properties and Water Relations in Southeastern Soils
University of Georgia Research Foundation
William P. Miller, H.F. Perkins, D.E. Radcliffe, M.E. Sumner, J. Scifres, J. Kim, and S.C. Chang; 1998
http://www1.fipr.state.fl.us/fipr/fipr1.nsf/129fc2ac92d337ca85256c5b00481502/6d76ac4a5bc8d44b85256b2e005a6a54/$FILE/01-020-082Final.pdf
This research demonstrates the beneficial use of surface applied by-product gypsum on agricultural fields in Georgia. It reduced soil crusting, increased water infiltration, and decreased soil erosion. An increase in yields was also seen in several crops including corn, potatoes, cantaloupes and watermelons. The application was especially beneficial in heavier, sandy clay loam as well as in less sandy loam.

Fact Sheet: Gypsum
National Soil Erosion Research Laboratory; 2006
http://www.ars.usda.gov/sp2UserFiles/Place/36021500/gypsumfacts.pdf
A gypsum factsheet prepared in conjunction with the National Soil Erosion Research Laboratory, the United States Department of Agriculture and the Agricultural Research Service. The factsheet highlights the differences between a field with a gypsum application and one without. The field without gypsum had more ponding, resulting in poor water infiltration and drainage. Another attribute of gypsum is that is can dissolve and transport calcium to the lower layers of soil.

Gypsum soil amendment as a management practice in conservation tillage to improve water quality
L. Darrell Norton, 2008
http://www.jswconline.org/content/63/2/46A.extract
A review of gypsum studies looking at nutrient loading reduction conducted in Indiana and Texas. There was significant reduction in phosphorus runoff.

Can Gypsum Improve Water Penetration?
Bill Peacock
http://cetulare.ucdavis.edu/files/82042.pdf
This article includes recommendations on when and how to use gypsum as an agricultural supplement. Gypsum is a good addition to farming practices to remedy impermeable soil due to high alkali levels.

Impacts of gypsum as a soil amendment on clayey soils
DeAnn Presley and Ian Kenney, Kansas State University; 2012
http://www.agprofessional.com/resource-centers/crop-fertility/micronutrients/news/Impacts-of-gypsum-as-a-soil-amendment-on-clayey-soils-148270815.html
This is a one year pilot study that was conducted in Marion County, Kansas to study the impacts of gypsum on clayey soils. Some information from a Wisconsin study is also referenced. More improvements are expected with additional gypsum applications, although it may take more than one year to see noticeable differences with this particular soil.

Erodibility of a Sodic Soil Amended with Gypsum
Fred E. Rhoton, Daniel S. McChesney and Harry H. Schomberg; 2011
http://www.flyash.info/2011/171-Schomberg-2011.pdf
A FGD study in the lower Mississippi River valley resulted in improved soil structure and infiltration and decreased runoff and soil loss concluding that FGD application can positively impact agriculture.

Gypsum: Essential for Maximized Water Use Efficiency and 40 Other Purposes
Brent Rouppet, Ph.D., Soil Scientist - International and Domestic Agricultural Consulting Nutrient Management and Production Specialist; 2008
http://www.awgypsum.com/pdfs/Rouppet-Article-May-08.pdf
Gypsum is beneficial for use in orchards, vineyards and for other crops. This author has experience using gypsum in North America, China and Australia. Not only has the application of gypsum enhanced crops, but it has also saved them from failure. Gypsum application also helps with water infiltration.

Effects of bedding materials in applied poultry litter and immobilizing agents on runoff water, soil properties, and bermudagrass growth
Jing Sheng, Ardeshir Adeli, John Brooks, Michael McLaughlin; 2012
http://www.ars.usda.gov/research/publications/publications.htm?seq_no_115=279746
Poultry litter, made up of bedding material and manure, is an alternative to chemical fertilizer, however it has a high rate of nutrient runoff. This study shows that adding gypsum in addition to the poultry litter can significantly reduce nutrient runoff, including phosphorus.

Reducing Phosphorus Export from Croplands with FBC Fly Ash and FGD Gypsum
William L. Stout, Andrew N. Sharpley, William J. Gburek, Harry B. Pionke; 1998
http://www.soilsolutions.net/uploads/Reducing%20Phosphorus%20Export%20from%20Croplands%20using%20Gypsum.pdf
This Pennsylvania study highlights gypsum's ability to reduce phosphorus in agricultural runoff. Gypsum reduced water-soluble phosphorus by 50%. The soil was shaley, silt loam.

Agricultural Uses for Flue Gas Desulfurization (FGD) Gypsum
United States Environmental Protection Agency; 2008
http://nepis.epa.gov/Exe/ZyNET.exe/P1001II9.txt?ZyActionD=ZyDocument&Client=EPA&Index=2006%20Thru%202010&Docs=&Query=FNAME%3DP1001II9.TXT%20or%20%28%20gypsum%20or%20as%20or%20a%20or%20soil%20or%20amendment%29&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=&IntQFieldOp=1&ExtQFieldOp=1&XmlQuery=&File=D%3A%5CZYFILES%5CINDEX%20DATA%5C06THRU10%5CTXT%5C00000004%5CP1001II9.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=10&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1
This is an EPA publication on gypsum and its uses in agriculture, specifically FGD gypsum. FGD gypsum is used to improve soil quality, increase calcium and sulfur levels and decrease surface runoff.

Using Gypsum in Southwestern Soils

The University of Arizona Cooperative Extension
James L. Walworth; 2006
http://cals.arizona.edu/pubs/garden/az1413.pdf
This article discusses how to determine soil composition and when the application of gypsum is beneficial. Gypsum can help improve soil structure, which is vital for proper irrigation.

Impact of Gypsum Applied to Grass Buffer Strips on Reducing Soluble P in Surface Water Runoff
D.B. Watts and H.A. Torbert – USDA-ARS; 2009
http://www.ncbi.nlm.nih.gov/pubmed/19465727
This study evaluates the effectiveness of gypsum when applied to grass buffers after poultry litter application. Gypsum significantly reduced soluble phosphorus after the first runoff event.

We Energies
http://www.we-energies.com/environmental/gypsum.htm
We Energies serves Wisconsin and Michigan and supplies gypsum from southeastern Wisconsin. FGD gypsum is more pure than mined gypsum. This page includes the benefits of gypsum application for agricultural use.

Using Flue Gas Desulfurization (FGD) Gypsum in Wisconsin
Dick Wolkowski, Birl Lowery, Ana Tapsieva, and Meghan Buckley; 2010
http://www.soils.wisc.edu/extension/area/horizons/2010/NHSS_2010_2_Wolkowski.pdf#search="gypsum"
This is a Wisconsin study in the Kenosha area on gypsum use. Gypsum has the potential to reduce production costs. The article identifies gypsum as a good source of calcium and sulfur for plants.