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Gypsum – Literature Review for the Standards Oversight Council

The purpose of this paper is to provide a scientific overview on the agricultural use of gypsum. The research referenced provides information about gypsum application and its benefits for crop production, soil physical properties, and water quality. This is not intended to be an exhaustive review of scientific literature. Two thorough summaries of gypsum's use in agriculture are attached for your reference.

- Gypsum as an Agricultural Amendment: General Use Guidelines (Chen and Dick 2011)
- Gypsum for Agricultural Use: The State of the Science. (Greenleaf Advisors, LLC. 2013)

A 2008 publication by the Environmental Protection Agency (EPA) is also attached because it provides a concise review of the agricultural use of flue gas desulfurized (FGD) gypsum. In addition, the publication includes the EPA's and United States Department of Agriculture's (USDA) recommendations for the use of FGD gypsum.

The Wisconsin based research on FGD gypsum has been limited; however, an article was recently published with research conducted in Brown and Douglas counties. Buckley and Wolkowski (2014) looked the effects of varying rates of FGD gypsum on soil physical properties. They found few beneficial effects based on samples taken 12 weeks after gypsum application. It was suggested that further work should be done to determine if additional beneficial effects would be observed if samples were taken longer after gypsum application. This study is attached for your reference and is further discussed on page 3.

Glacierland Resource Conservation and Development (RC&D) is a nonprofit, grass-roots organization that is committed to wise use and conservation of our natural resources and human resources. We promote sustainability on all levels - environmental, social and economic. This is accomplished by bringing together various agencies, organizations and people to work on projects addressing issues of sustainability in northeast Wisconsin.

One of Glacierland's current projects features on-farm gypsum demonstration on four farms in the Lower Fox River watershed. The project objectives are to demonstrate the use of FGD gypsum on agricultural fields, monitor soil physical properties and crop response, and hold field days to share information. In 2015, we are expanding the project to partner with a farm that has drain tile to apply gypsum and monitor changes in soluble phosphorus concentrations in tile water. Our primary project partners include Great Lakes Commission, WE Energies, Brown County Land Conservation

Department, and the University of Wisconsin – Green Bay. We are also in communication with Francisco Arriaga and the Sand County Foundation who have ongoing research investigating the use of FGD gypsum for phosphorus mitigation in the Milwaukee River watershed (2013-2016).

Gypsum: What is it?

Gypsum's use as a soil amendment has been documented as early as the 18th century. Overtime the agricultural use of gypsum declined due to the increasing cost of mining and transporting the product. Today, there are two main sources of gypsum used for agricultural applications; mined and synthetic. The primary source of synthetic gypsum is known as flue gas desulfurized (FGD) gypsum, which is produced as a by-product of the emission scrubbers used to reduce sulfur emissions in coal-fired power plants. An increasing number of electric power plants are using emission scrubbers to comply with air quality regulations, leading to a larger supply of FGD gypsum. Agronomic use of FGD gypsum has increased in the past 20 years due to the lower cost (compared to mined gypsum) and the increased supply and distribution of sources near agricultural areas (Chen and Dick 2011).

Gypsum: Crop Production, Soil Structure, and Water Quality Benefits

Gypsum is approximately 23% calcium and 19% sulfur in its pure form. Today, crops have fewer sulfur sources available to them since sulfur impurities were largely removed from fertilizers. There has also been a decrease in atmospheric sulfur deposits since coal-fired power plants were required to install emission scrubbers. When these decreases are combined with the increased sulfur demand of high yielding crops, a sulfur deficiency is emerging in the Midwest. There is also a significant interaction between how crops utilize sulfur and nitrogen. A study found that gypsum application significantly improved nitrogen use efficiency, suggesting that the crop cannot fully utilize nitrogen available in the soil if the sulfur requirements of the crop are not met (Fisher 2011).

Gypsum is not a liming agent and therefore does not change soil pH, but it is about 200 times more soluble than agriculture lime, allowing it to travel through the soil profile to provide nutrients to deep plant roots while helping to alleviate sub soil issues. When sub soils become acidic (pH below 5), aluminum toxicity can become an issue for plants. Gypsum alleviates this issue when its calcium ions displace aluminum ions from the soil's exchange sites. Gypsum's sulfate ions can also react with aluminum ions to form less toxic aluminum sulfate complexes that are prone to being leached away (Chen and Dick 2011, Dontsova et al 2004).

Gypsum is well known for its ability to improve soil structure by increasing flocculation or aggregation of soil particles. Large concentrations of ions with a charge greater than positive 1, such as calcium (Ca^{2+}), helps soil to hold together in stable aggregates. To put it in perspective, if sodium's relative aggregation value is set to 1, then potassium's is 1.7, magnesium's is 27, and calcium has the highest with 43. Stable soil aggregates increase soil pore space, infiltration rates, thereby decreasing surface crusting, erosion, and runoff (Fisher 2011).

Research in Wisconsin (Buckley and Wolkowski 2014) on clay and loam soils in Douglas and Brown counties looked at the effects of FGD gypsum on soil physical properties when applied to agricultural fields. They had four application rates (0, 0.5, 1, and 2 tons/acre) at 11 sites. Bulk density and aggregate stability were measured 12 weeks after the gypsum application. Decreases in bulk density and increases in aggregate stability would represent improvements in soil structure because those measurements would imply increased infiltration rates, less surface crusting and less compaction. There was a decrease in bulk density at 2 of the 10 measured treatment sites and there was an unexpected decrease in aggregate stability with the highest application rate, the lower rates were not different from the control. The authors suggest that measuring soil physical properties 12 weeks after application may not allow sufficient time for changes to occur with in the soil and that further research should monitor changes after longer time periods. It can often take several years of gypsum application to observe changes in soil physical properties (Fisher 2011).

The improvements in soil structure and soil chemistry can also provide water quality benefits. Wolkowski et al (2010) released preliminary results on gypsum's effect on dissolved reactive phosphorus (DRP) concentrations from research conducted in conjunction with the Buckley and Wolkowski (2014) study in Brown County. DRP is the soluble phosphorus that can be removed from fields in runoff. Their preliminary data show reductions in DRP in samples collected 30 days after application (Table 1.). This significant response suggests that FGD gypsum may be a tool for reducing DRP concentrations in agricultural runoff.

Table 1. Dissolved reactive phosphorus measured 30 days after application from two sites (Brown Co., WI) treated with FGD gypsum (Wolkowski et al 2010)

	Site	
Treatment	SVG	VWG
	----------- ppm -----------	
Control	1.97	5.93
FGD 0.5 t/acre	1.33	4.74
FGD 1 t/acre	0.92	2.33
FGD 2 t/acre	0.78	1.83
Pr > F	0.15	<0.01
LSD	NS	2.27

The mechanism for this decrease in SRP is likely due to chemical changes in the soil after gypsum application. The calcium ions in the gypsum are able to precipitate phosphorus in the soil water into a less soluble form (Watts and Dick 2014). Norton (2008) also found a decrease in SRP with gypsum application (Figure 1 and Figure 2). In the same study, erosion and runoff also decreased when gypsum was applied to fields under no-till practices on a fine sandy loam soil in Texas (Figure 1). Figure 2 shows four different treatment effects gypsum and manure application on a loam soil in Indiana. The two treatments with gypsum show significant decreases in total phosphorus and total nitrogen compared to the manure treatment.

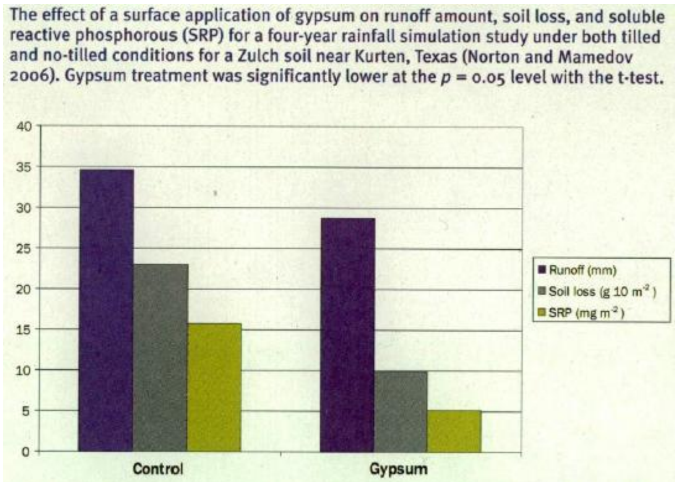


Figure 1. Effect of gypsum application on runoff amount, soil loss, and SRP (Norton 2008)

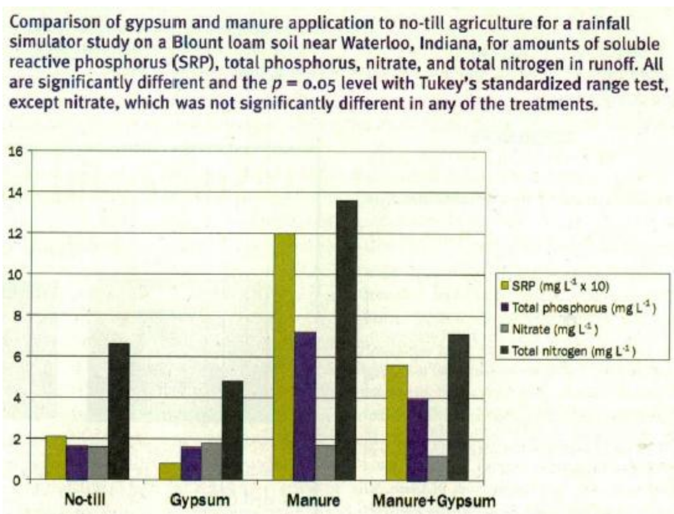


Figure 2. Four treatments effects on amounts of SRP, total P, Nitrate, and total N (Norton 2008)

A field experiement by Brauer et al (2005) conducted in Texas on a fine sandy loam compared soil amendment effects on soil test phosphorus (P) on soils amended annually from 1999 to 2001 with 7 treatments (Figure 3). The soil test P measurement is representative of the amount of crop available P in the soil. The high Ca and low Ca are applications of high (2.25 tons/acre) and low (0.68 tons/acre) gypsum. Soil test P and dissolved reactive P (DRP) levels were monitored from 1999 to 2004. The soil amendment treatments did not significantly affect soil test P values. Only one treatment, high Ca, significantly reduced soil DRP. Three annual applications of the low Ca did not affect DRP values, however DRP was significantly lower after the first application of high Ca. Additionally, dissolved reactive P decreased to minimal levels after two applications of high Ca, but increased in 2003 and 2004 (Figure 4). These results suggest that soil dissolved reactive P can be decreased if gypsum is applied in amounts close to the soil test P values (Brauer et al 2005).

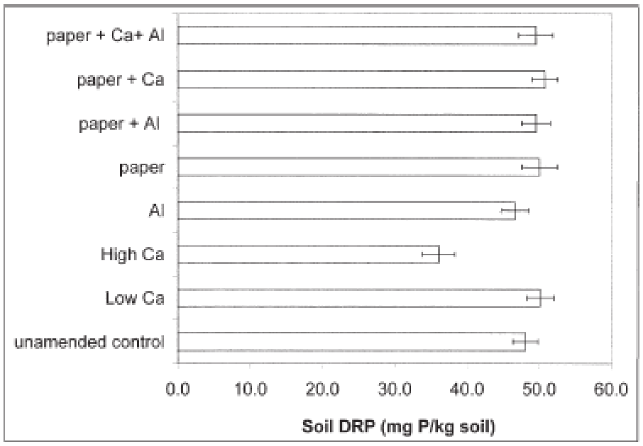


Figure 3. Treatment effects on DRP levels averaged across depths, years, and replications (Brauer et al 2005)

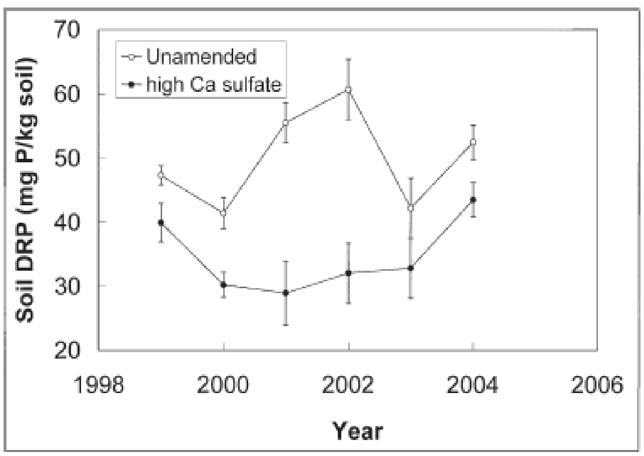
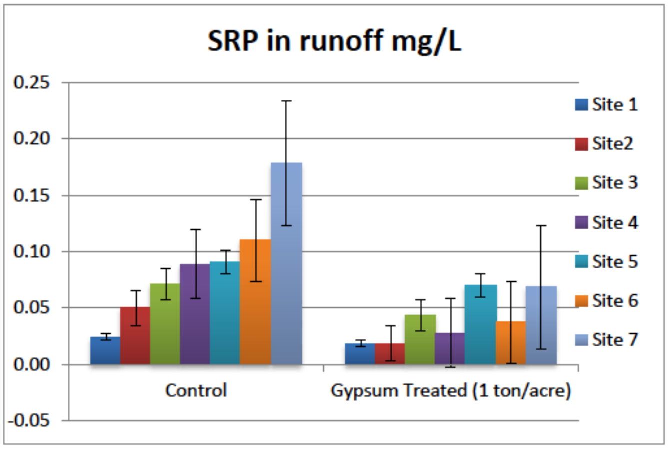


Figure 4. Comparing changes in DRP levels over time for the unamended and high Ca (gypsum) treatments (Brauer et al 2005)

In 2014 Dr. Warren Dick (Ohio State University) and Greenleaf Advisors, LLC released preliminary results from their Ohio study measuring soluble reactive phosphorus (SRP) levels in drain tile samples on seven farms in the Maumee River watershed. After one gypsum application (1 ton/acre), the treated plots showed an average of 55% reduction in SRP compared to the control plots. (Greenleaf Advisors 2014)



Data collected from drainage tiles on multiple farms in the Maumee River watershed

Figure 5. (Greenleaf Advisors 2014)

The research on agricultural use of gypsum for various functions (crop health, soil physical properties, water quality, etc.), is summarized in a publication by Ohio State University Extension (Chen and Dick 2011). Gypsum application rates and guidelines are summarized (Table 2) based on the intended function of gypsum application.

Table 2. Rate, time, and method of application of gypsum for various functions (Chen and Dick 2011)

Function	Suggested Rates of Application (lbs/acre)			Suggested Time of Application	Suggested Application Method	Reference
	Low	Normal	High			
Sulfur fertilizer to enhance crop production	100	300	500	Before planting	Soil surface or incorporated	Chen et al., 2008 DeSutter and Cihacek, 2009
Calcium fertilizer to enhance crop production (especially root crops, e.g., peanuts)	1,000	2,000	4,000	Before peanut pegging	Soil surface	Grichar et al., 2002
Soil amendment to remediate subsoil acidity	3,000	6,000	10,000	1–180 days before planting	Soil surface	Chen et al., 2005
Soil amendment to remediate sodic or sodium-affected soils	2,000	10,000	20,000	90–180 days before planting, before rainy season	Soil surface or incorporated	Xu, 2006
Soil amendment to improve water quality (e.g., by reducing phosphorus concentrations in surface water runoff)	1,000	6,000	9,000	1–180 days before planting	Soil surface	Norton and Rhoton, 2007
Soil amendment to improve soil physical properties and water infiltration and percolation	1,000	3,000	9,000	1–180 days before planting	Soil surface	Sumner, 2007
As a lawn care product and sport field application	4,000	8,000	14,000	Spring, summer, or autumn	Soil surface	Schlossberg, 2007
As a component of synthetic soils for nursery	5%	10%	20%	Preparation of synthetic soils	Mixing with other components	Bardhan et al., 2004

There are specific soil types and conditions where gypsum application has been shown to be most beneficial. Soils with high levels of sodium (Na), poorly drained clay soils, soils with acidic subsoils, and soils deficient in calcium or sulfur will likely benefit most from gypsum application (Watts and Dick 2014). Gypsum could be a valuable tool for improving WI soils that have poor structure or high phosphorus concentrations.

Gypsum: Recommended use in Agriculture

Gypsum has several beneficial uses in agricultural applications. There is supporting evidence for gypsum's use in agriculture by the peer-reviewed literature mentioned above. Additionally, Watts and Dick (2014) provide a summary of potential gypsum uses in agriculture, citing the research-identified benefits (Table 3).

Table 3. Summary of potential gypsum uses for agricultural and other land application uses (Watts and Dick 2014)

Potential use	Reference
1. Source of Ca and S for plant nutrition	Chen et al., 2005, 2008; Adams and Hartzog, 1991; Adams et al., 1993; Scott et al., 1993; Maloney et al., 2005; Simmons and Kelling, 1987.
2. Source of SO_4 and exchangeable Ca to ameliorate subsoil acidity and Al^{3+} toxicity	Sumner, 1993; Toma et al., 1999; Farina and Channon, 1988; Wendell and Ritchey, 1996; Feldhake, and Ritchey, 1996; Kinraide et al., 1992; Wright et al. (1989).
3. Source of Ca and electrolytes to remediate high sodic and high magnesium soils	Amezketa et al., 2005; Keren et al., 1983; Oster and Frenkel, 1980; Shainberg et al. (1982). Armstrong and Tanton, 1992.
4. Source of Ca to improve soil structure, water infiltration, soil aeration and reduce soil erosion	Norton 2008; Yu et al., 2003; Ben-Hur et al., 1992; Radcliffe et al., 1986; Dontsova and Norton, 2002; Norton et al. (1993); Baumhardt et al. (1992).
5. Improved rooting of many crops	Farina and Channon, 1988, Sumner M.E., 1993, Alcordo and Rechcigl, 1993; Shainberg et a., 1982; Wendell and Ritchey, 1996;
6. Control of soluble phosphorus runoff from fields	Norton, 2008; Watts and Torbert, 2009; Bryant et al., 2012; Torbert and Watts, 2014; Endale et al., 2014.

The use of gypsum as an agricultural amendment also has support at the federal and state government level. A 2008 publication by the Environmental Protection Agency provides an overview of gypsum, discussing current and future sources, and gypsum's use in agriculture. Three main uses for gypsum in agricultural applications are discussed; source of plant nutrients, improving soil physical and chemical properties, and reducing runoff and transport of nutrients, sediment, and other pollutants to surface waters. The Environmental Protection Agency and the United States Department of Agriculture support the agricultural use of FGD gypsum under the appropriate soil and crop conditions. Prior to application of any soil amendment, the agencies recommend assessing the amendment material and soil conditions to determine the appropriate application rate (US EPA 2008).

On the state level, the update of the Ohio 590 Standard in 2012 included recommendations on the use of gypsum to improve soil structure, increase water infiltration, promote active rooting at deeper depths, improve nutrient use efficiencies, and reduce soluble phosphorus transport in surface and subsurface drainage water (NRCS 2012). Specifically, the references to gypsum in the standard include:

- “Balance the Calcium to Magnesium ratio in the soil to flocculate clays, improve soil structure and increase water infiltration. If the soil pH needs to be raised this can be accomplished with the use of high calcium lime. If the soil pH does not need to be raised, this can be accomplished with gypsum. See The Ohio State University Extension Bulleting 945, Gypsum as an Agricultural Amendment and Amending Soils with Gypsum for more information.”,
- “Use of soil amendments, like lime and gypsum that promote active rooting at deeper depths and improve nutrient use efficiencies”, and
- “Gypsum, when applied as a soil amendment, can precipitate soluble phosphorus and reduce phosphorus transport via surface or subsurface drainage.”(NRCS 2012)

The use of FGD gypsum can also benefit the farmer’s bottom line. The positive effects on soil physical properties, allowing for increased infiltration, provides more available water for the crop and farmers could realize financial benefits through savings on irrigation costs and increased yields (Truman et al 2010). FGD gypsum is often less costly than mined gypsum and is becoming more available as coal-fired power plants install emission scrubbers to comply with air regulations (US EPA 2008).

In addition to potential improvements in water quality, the beneficial reuse of FGD gypsum in agriculture provides several other environmental benefits such as:

- diverting FGD gypsum from being landfilled,
- utilizing FGD instead of mined gypsum will reduce the environmental impacts of mining, and
- agricultural lands are often closer to sources of FGD gypsum than gypsum mines, reducing the costs and environmental impacts of transportation (US EPA 2008).

In conclusion, Wisconsin continues to face overwhelming challenges to meet quality goals for phosphorus and sediment in impaired waters throughout the state. Agriculture has a major role to play in these efforts. The use of gypsum could be a valuable tool to meet the needs of crop production and water quality goals in Wisconsin.

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