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Use of Gypsum in Agriculture: A Review

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ABSTRACT: Gypsum is one of the earliest forms of fertilizer used in the United States. It has been applied to agricultural soils for more than 250 years. Gypsum is a moderately soluble source of the essential plant nutrients, calcium and sulfur, and can improve overall plant growth.

Gypsum is a soft sulfate mineral composed of calcium sulfate dihydrate, with the chemical formula $CaSO4 \cdot 2H2O$.[4] It is widely mined and is used as a fertilizer and as the main constituent in many forms of plaster, drywall and blackboard or sidewalk chalk.[5][6][7][8] Gypsum also crystallizes as translucent crystals of selenite. It forms as an evaporite mineral and as a hydration product of anhydrite. The Mohs scale of mineral hardness defines gypsum as hardness value 2 based on scratch hardness comparison.

Fine-grained white or lightly tinted forms of gypsum known as alabaster have been used for sculpture by many cultures including Ancient Egypt, Mesopotamia, Ancient Rome, the Byzantine Empire, and the Nottingham alabasters of Medieval England.

KEYWORDS-gypsum, agriculture, nutrients, plant, growth

I. INTRODUCTION

Gypsum is a common mineral, with thick and extensive evaporite beds in association with sedimentary rocks. Deposits are known to occur in strata from as far back as the Archaean eon.[16] Gypsum is deposited from lake and sea water, as well as in hot springs, from volcanic vapors, and sulfate solutions in veins. Hydrothermal anhydrite in veins is commonly hydrated to gypsum by groundwater in near-surface exposures. It is often associated with the minerals halite and sulfur. Gypsum is the most common sulfate mineral.[17] Pure gypsum is white, but other substances found as impurities may give a wide range of colors to local deposits.

Because gypsum dissolves over time in water, gypsum is rarely found in the form of sand. However, the unique conditions of the White Sands National Park in the US state of New Mexico have created a 710 km2 (270 sq mi) expanse of white gypsum sand, enough to supply the US construction industry with drywall for 1,000 years.[18] Commercial exploitation of the area, strongly opposed by area residents, was permanently prevented in 1933 when President Herbert Hoover declared the gypsum dunes a protected national monument.

Gypsum is also formed as a by-product of sulfide oxidation, amongst others by pyrite oxidation, when the sulfuric acid generated reacts with calcium carbonate. Its presence indicates oxidizing conditions. Under reducing conditions, the sulfates it contains can be reduced back to sulfide by sulfate-reducing bacteria. This can lead to accumulation of elemental sulfur in oil-bearing formations,[19] such as salt domes,[20] where it can be mined using the Frasch process[21] Electric power stations burning coal with flue gas desulfurization produce large quantities of gypsum as a byproduct from the scrubbers.

While farmers have used gypsum (calcium sulfate dihydrate) for centuries, it has received renewed attention in recent years. This resurgence is due in large part to ongoing research and practical insights from leading experts that highlight the many benefits of gypsum.[1,2,3]

Here are five key (and overlapping) benefits of gypsum

1. Source of calcium and sulfur for plant nutrition. “Plants are becoming more deficient for sulfur and the soil is not supplying enough it,” said Warren Dick, soil scientist and Professor Emeritus, School of Environment and Natural Resources, The Ohio State University. “Gypsum is an excellent source of sulfur for plant nutrition and improving crop yield.”
Meanwhile, calcium is essential for most nutrients to be absorbed by plants roots. “Without adequate calcium, uptake mechanisms would fail,” Dick said. “Calcium helps stimulate root growth.”
2. Improves acid soils and treats aluminum toxicity. One of gypsum’s main advantages is its ability to reduce aluminum toxicity, which often accompanies soil acidity, particularly in subsoils. Gypsum can improve some acid soils even

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beyond what lime can do for them, which makes it possible to have deeper rooting with resulting benefits to the crops, Dick said. “Surface-applied gypsum leaches down to to the subsoil and results in increased root growth,” he said.
3. Improves soil structure. Flocculation, or aggregation, is needed to give favorable soil structure for root growth and air and water movement, said Jerry Bigham, Professor Emeritus, School of Environment and Natural Resources, The Ohio State University. “Clay dispersion and collapse of structure at the soil-air interface is a major contributor to crust formation,” he said. “Gypsum has been used for many years to improve aggregation and inhibit or overcome dispersion in sodic soils.”

Soluble calcium enhances soil aggregation and porosity to improve water infiltration (see below). “It’s important to manage the calcium status of the soil,” he said. “I would argue it’s every bit as important as managing NPK.”
In soils having unfavorable calcium-magnesium ratios, gypsum can create a more favorable ratio, Bigham added. “Addition of soluble calcium can overcome the dispersion effects of magnesium or sodium ions and help promote flocculation and structure development in dispersed soils,” he said.

“Agricultural soils have been degraded by centuries of farming practices that disturb soils’ physical properties and create imbalances in soil chemistry resulting in compromised soil biology,” adds Ron Chamberlain, an agronomist with GYPSOIL. “As a result, many soils are no longer able to provide enough natural nutrition and adequate root environment for profitable crop growth. By restoring soil physical properties, gypsum facilitates the natural restoration of soil microbiological complexes which in turn improve soil structure and bring balance to soil chemistry.”[4,5,6]
4. Improves water infiltration. Gypsum also improves the ability of soil to drain and not become waterlogged due to a combination of high sodium, swelling clay and excess water, Dick said. “When we apply gypsum to soil it allows water to move into the soil and allow the crop to grow well,” he said.

Increased water-use efficiency of crops is extremely important during a drought, added Allen Torbert, research leader at the USDA-ARS National Soil Dynamics Lab, Auburn, AL. “The key to helping crops survive a drought is to capture all the water you can when it does rain,” he said. “Better soil structure allows all the positive benefits of soil-water relations to occur and gypsum helps to create and support good soil structure properties.”

5. Helps reduce runoff and erosion. Agriculture is considered to be one of the major contributors to water quality, with phosphorus runoff the biggest concern. Experts explained how gypsum helps to keep phosphorus and other nutrients from leaving farm fields. “Gypsum should be considered as a Best Management Practice for reducing soluble P losses,” said Torbert, who showed studies on how gypsum interacts with phosphorus.

Darrell Norton, retired soil scientist at the USDA-ARS National Soil Erosion Research Laboratory at Purdue University, added: “Using gypsum as a soil amendment is the most economical way to cut the non-point run-off pollution of phosphorus.”

II. DISCUSSION

Warren Dick has worked with gypsum for more than two decades. You’d think he’d be an expert on drywall and plastering because both are made from gypsum. But the use of gypsum that Dick studies might be unfamiliar to you: on farmland.

“Gypsum is a good source of both calcium and sulfur, which crops need for good yields,” says Dick. “We also found that it improves many other soil characteristics. Gypsum helps soil better absorb water and reduces erosion. It also cuts down on phosphorus movement from soils to lakes and streams and improves the quality of various fruits and vegetables, among other benefits.”

Gypsum is a mineral that is naturally found concentrated in various places and can be mined out of the ground. But Dick’s research focuses on gypsum recovered from coal-fired electricity generating power plants.

Gypsum that comes from coal plants is called flue-gas desulfurization gypsum, as it comes from the process that ‘scrubs’ sulfur out of the smoke stacks to reduce air pollution. “The gypsum that is recovered has good quality,” says Dick. “The gypsum particles are small and uniform in size making them quite reactive. This can be a real benefit in agriculture. We also determined that it is safe for agricultural use through many studies.[7,8,9] Reusing it for agricultural purposes, instead of putting it in landfills, provides multiple wins.”

Gypsum is high in both calcium and sulfur. In addition, the chemical formula of gypsum makes those nutrients more available to plants than some other common sources of these nutrients. Chemically speaking, gypsum is calcium sulfate. Its use is often confused with that of lime, which is calcium carbonate.

Gypsum will change soil pH very slightly, yet it can promote better root development of crops, especially in acid soils, even without a big pH change. This is because the gypsum counteracts the toxic effect of soluble aluminum on root development. Aluminum occurs naturally in soil and often isn't a problem for crops. But when soil becomes acidic, the aluminum is available to plants—and it can stunt or kill them.

Another bonus of gypsum is that it is a moderately-soluble mineral. This means the calcium can move further down into the soil than the calcium from lime (calcium carbonate). This can inhibit aluminum uptake at depth and promote deeper rooting of plants. When roots are more abundant and can grow deeper into the soil profile, they can take up more water and nutrients, even during the drier periods of a growing season.

Although moderately soluble, gypsum can be an excellent source of sulfur over several growing seasons. Research found that the sulfur is available not only in the year applied, but can continue to supply sulfur for one or two years after, depending on the initial application rate. Gypsum as a sulfur fertilizer has benefitted corn, soybean, canola, and alfalfa.

Gypsum can also help improve soil structure. Many of us look at soil as a uniform, static substance. In reality, soil is a mixture of inorganic particles, organic particles, and a complex mixture of pore spaces, water, and soil microbes. Its composition changes through weather events like rainstorms, by tillage, or as plants pull nutrients for growth. Farmers have to manage their soil well in order to maintain good crop yields year after year.

Improving soil structure helps farmers with some common agricultural problems. Adding gypsum to the soil reduces erosion by increasing the ability of soil to soak up water after precipitation, thus reducing runoff. Gypsum application also improves soil aeration and water percolation through the soil profile. A recent study showed the benefit of gypsum application to improve movement of water through the profile to tile drains. It also reduces phosphorus movement out of the field.

No matter what solutions farmers are trying to implement when using gypsum, they have several options for application. Of course, the type of application method will be determined by the reasons to use gypsum. Finely crushed gypsum can be dissolved in irrigation water and applied that way. Farmers can take gypsum and apply it to the topsoil prior to planting or right after harvest. It can also be applied to hay fields after hay cutting. If tilling is needed (again, dependent on the soil conditions), gypsum can be worked into the soil with the tilling equipment.[10,11,12]

Although gypsum has been used in agriculture for more than 250 years, the benefits it provides are still being studied. In addition, the re-use of gypsum by-products from coal power plants reduces the need to mine gypsum from geologic deposits. It also saves landfill space. Gypsum can't solve every agricultural problem, but it is a proven resource to add nutrients and improve soil structure.

"It's a great example of recycling a waste product and using it in a beneficial way," Dick says.

Dick, Professor Emeritus at The Ohio State University, presented "Crop and Environmental Benefits of Gypsum as a Soil Amendment" at the November 2018 meeting of the American Society of Agronomy and the Crop Science Society of America. The meeting abstract and recorded presentation can be found here. Research funding was obtained from a variety of federal, state, and commercial sources.

III. RESULTS

Gypsum is calcium sulfate ($CaSO_4$). Refined gypsum in the anhydrite form (no water) is 29.4 percent calcium (Ca) and 23.5 percent sulfur (S). Usually, gypsum has water associated in the molecular structure ($CaSO_4 \cdot 2H2O$) and is approximately 23.3 percent Ca and 18.5 percent S (plaster of paris). Gypsum fertilizer usually has other impurities so grades are approximately 22 percent Ca and 17 percent S. Gypsum is sparingly soluble (the reason wallboard gets soft but does not immediately dissolve when it gets wet, at least if only damp occasionally). Gypsum is the neutral salt of a strong acid and strong base and does not increase or decrease acidity. Dissolving gypsum in water or soil results in the following reaction: $CaSO_4 \cdot 2H_2O = Ca_2+ + SO_42- + 2H_2O$. It adds calcium ions ($Ca_2+$) and sulfate ions ($SO_42-$), but

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does not add or take away hydrogen ions (H+). Therefore, it does not act as a liming or acidifying material. The Ca_2+ ions simply interact with exchange sites in soil and sulfate remains dissolved in soil water.

Gypsum as a fertilizer?

Gypsum is a fertilizer product and supplies the crop-available form of calcium (Ca_2+) and sulfur ($SO_4$2-). If these forms are deficient in soil, then crop productivity will benefit if gypsum is applied. This is a big "if" for Iowa soils. Research has not shown deficiency of Ca and normally any potential problem with low Ca levels is taken care of with application of limestone (CaCO3). Acidity problems will occur before a deficiency of Ca, so liming effectively takes care of Ca also. Table 1 lists typical exchangeable Ca levels of several Iowa soils, and they are very high. For calcareous soils (containing free lime) the soil system is saturated with Ca, and Ca supply and soil pH is controlled by the free lime.

For S, it's basically the same. Research conducted for more than 35 years in numerous field trials across Iowa has shown only isolated and very small corn or soybean yield response to S fertilization (two positive and one negative). Table 2 gives results for recent S trials on corn and soybean conducted in 2000 and 2001 at six sites across Iowa. These results are typical of research conducted for many years in that there was no yield increase to applied S, gypsum, or Ca. So, if there is no need for fertilizer application of Ca or S, then gypsum application is simply not needed for fertilization reasons.[13,14,15]

Gypsum as a soil amendment

Soil structure is impacted by exchangeable cations (positively charged ions). Multivalent cations (more than one positive charge) help hold soil particles together because they can have electrostatic (magnetic) attraction between two or more negative charge sites (soil clay and organic matter have a net negative charge). Multivalent cations include Ca_2+, Mg_2+, Zn_2+, and Al_3+. Monovalent cations (only one positive charge) cannot help with soil structure because of only one positive charge, and with sodium (Na+), for example, can degrade soil structure when large amounts occupy the soil exchange sites (also impacted by large ionic size of Na); thus, soils with low salt but high levels of exchangeable sodium (Na+) have poor soil structure. Except for a very small acreage of Napa soil in the Missouri River valley, excess Na is not a problem on Iowa soils, including those with high pH. In arid regions where salt and Na accumulates (saline-sodic soils), reclamation can include use of gypsum. Gypsum is used to add large amounts Ca_2+ ions that displace the Na+ ions from the exchange sites, and when flushed with clean water both salts and Na are removed from the soil (gypsum is used instead of limestone because of higher solubility and no increase in soil pH). However, even in these sites this practice is not effective when subsoils have low permeability to water. If a soil only has high soluble salt, then gypsum is not used because it would add to the salt problem.

Soil structure also is greatly improved by soil organic material, which help "glue" soil particles together. Iowa soils have high organic matter content, which is just as important for good soil structure as exchangeable multivalent cations. The most detrimental effect on surface soil structure comes from the physical impact of raindrops. Surface residue is the best defense against this impact, and it comes at no cost from crop residue. Thus, improving water infiltration can be best achieved by limiting tillage to leave the most crop residue as possible rather than applying gypsum. Table 2 shows the lack of corn and soybean yield response to applied gypsum.

In summary, gypsum is an excellent fertilizer source of Ca and S. If application of these plant-essential nutrients is needed, then it works well. However, for Iowa soils both Ca or S are in good supply. Iowa soils inherently have a capacity for providing adequate levels of exchangeable Ca and S for crop production. Thus, more is not necessarily better.

Table 1. Exchangeable calcium and magnesium of several Iowa soils.

Soil	CEC	Ca	Mg	Ca	Mg
		meq/100 g	lb/acre		
Kenyon	14.0	8.5	2.6	3,400	624
Readlyn	19.5	14.5	4.2	5,800	1,008
Klinger	26.2	20.0	5.2	8,000	1,248
Dinsdale	20.5	14.6	4.2	5,840	1,008
Tama	20.6	13.9	3.4	5,560	816
Muscatine	28.3	20.4	7.1	8,160	1,704

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Primghar	32.7	22.4	7.4	8,960	1,776
Sac	29.8	20.6	5.5	8,240	1,320
Marcus	43.9	37.5	11.9	15,000	2,856
Ida	22.4	16.9	5.3	6,760	1,272
Monona	22.4	18	6.2	7,200	1,488
Napier	27.6	23.5	3.2	9,400	768

CEC in the table above is cation exchange capacity.

Table 2. Corn and soybean yield response to gypsum and elemental S application, average across six sites in Iowa.

	2000	2001					
	Gypsum Application	Corn	Soybean	Corn	Soybean		
S Rate	Product	Calcium	$CaSO_4$	S	$CaSO_4$	S	$CaSO_4$
lb S/acre	lb/acre	lb Ca/acre	bu/acre	bu/acre			
0	0	0	162	159	50.0	50.1	147
10	62.5	14	158	160	49.3	49.6	143
20	125	28	158	159	48.9	49.7	147
40	250	56	158	159	49.0	49.6	149
Significance (0.05)			NS	NS	NS	NS	

$CaSO_4$, calcium sulfate (gypsum); S, elemental sulfur (90% S); applied before planting in the spring of 2000.[16,17,18]

Fertilizer: In the late 18th and early 19th centuries, Nova Scotia gypsum, often referred to as plaster, was a highly sought fertilizer for wheat fields in the United States.[39] Gypsum provides two of the secondary plant macronutrients, calcium and sulfur. Unlike limestone, it generally does not affect soil pH.[40]

Reclamation of saline soils, regardless of pH. When gypsum is added to sodic (saline) and acidic soil, the highly soluble form of boron (sodium metaborate) is converted to the less soluble calcium metaborate. Exchangeable sodium percentage is also reduced by gypsum application.[41][42] The Zuiderzee Works uses gypsum for the recovered land.[43]

Other soil conditioner uses: Gypsum reduces aluminium and boron toxicity in acidic soils. It also improves soil structure, improving water absorption and aeration.[40]

Soil water potential monitoring: a gypsum block can be inserted into soil, its electrical resistance measured to derive soil moisture.[44]

The gypsum flora of Nova Scotia refers to a small group of plants that are restricted to naturally-occurring outcrops of gypsum. Nova Scotia is unique in northeastern North America for the extent of sites having gypsum bedrock at or near the soil surface. The distinctive set of plants associated with these gypsum exposures includes Packera paupercula (Balsam groundsel), Carex eburnea (Ebony sedge), Erigeron hyssopifolius (Hyssop-leaved fleabane), Cypripedium parviflorum (Small yellow lady's-slipper).[1] Karst landscapes have also formed. Some of these species appear to be associated with sunny clearings created by natural erosion from gypsum cliffs, which provides a distinctive sunny and calcareous habitat within landscapes that are otherwise forested.

IV. CONCLUSION

Land application of gypsum has been studied and utilized in agriculture and environmental remediation for many years. Most of the published literature has focused on gypsum application impacts on soil properties rather than crop yields. This literature review was conducted to (i) gather results from gypsum application studies relevant to crop grain yield, soil physical–chemical properties, and environmental impact; (ii) report different methods for determining gypsum application rates; (iii) suggest recommendations for future studies on land application of gypsum. Improvement in plant nitrogen use efficiency was rarely discussed as a potential mechanism for improving yield.[19,20,21] Free Al activity has been demonstrated to be more correlated with plant yield responses to gypsum application than exchangeable Al or Al saturation. However, few authors reported Al speciation and Al activity. While gypsum is reported to improve soil chemical properties in most cases, these changes do not necessarily translate to increases in yield. Improvements in

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physical properties for nonsodic soils are not consistent. It is difficult to exactly determine the positive effects from gypsum application that are responsible for yield increases, since there are often many simultaneous physical and chemical changes occurring in the soil. Improvement in crop yield may be a result of an additive or synergistic effect of each of these potential changes. In addition, these potential changes, as varied as they are, appear to also vary with crop, soil type, and rainfall regime. Therefore, meta-analysis of gypsum experiments is highly recommended in order to improve gypsum recommendations across diverse environments.[22]

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