GYPSUM ($CaSO_4$)

Gypsum is a naturally occurring mineral that is made up of calcium sulfate and water ($CaSO_4+2H_2O$) that is sometimes called hydrous calcium sulfate. It is the mineral calcium sulfate with two water molecules attached. By weight it is 79% calcium sulfate and 21% water. Gypsum has 23% calcium and 18% sulfur and its solubility is 150 times that of limestone, hence it is a natural source of plant nutrients. Gypsum naturally occurs in sedimentary deposits from ancient sea beds. Gypsum is mined and made into many products like drywall used in construction, agriculture and industry. It is also a by-product of many industrial processes.

Gypsum is also used as a generic name for many types of sheet products made of a non-combustible core with a paper surfacing that adds strength. These include drywall, ceiling tiles, partitions, etc. whose strength is directly related to its thickness and a few trace materials.

Types and Sources of Gypsum

There are several types of naturally occurring gypsum, and many industrial processes also produce gypsum as a by-product of their systems such as phosphoric acid and citric acid manufacture.

Mined Gypsum

Mined gypsum is found at various locations around the world. In North America there are gypsum deposits from Canada to Texas and in many Western States. Chemically raw mined gypsum is primarily calcium sulfate hydrated with water molecules in its chemical structure. Other materials and chemicals in mined gypsum may be small amounts of sand or clay particles and a few trace elements. The trace elements may be boron or iron to arsenic and lead and varies with each deposit. Many deposits in Canada have arsenic while those in Texas may have very little. Primarily mined gypsum is very safe to use and a great amendment for many soils.

Flue Gas Desulphurization (FGD) gypsum and Spray-Dry Absorption materials (SDA)

It is produced by removal of waste gases from the smokestacks from burning of coal and other materials. Approximately 20 million tons of FGD (flue gas desulphurization) residues are produced annually in the USA. These materials are high in calcium sulfate (gypsum) or can be easily converted to calcium sulfate. It may also contain sodium chloride (NaCl), magnesium oxide (MgO), calcium chloride (CaCl), phosphoric oxide P_2O_5, calcium carbonate ($CaCO_3$), silicone dioxide (SiO_2), and other by-products such as fluorine (fluoride compounds). Currently, about 7% is recovered and the rest is either stored in lagoons or landfilled.

However, there are other concerns with the use of calcium sulfate, including a possible deficiency of magnesium (Mg) caused by replacement by calcium (Ca), excessive sulfur (S) in the plants, decreased phosphorous (P) availability, increased levels of aluminum (Al) in ground or surface waters due to leaching from the soil, and contamination from impurities within the gypsum, such as boron (B) or heavy metals. Some studies on SDA gypsum have shown that it is harmful to plants. Depending on the source, it may contain significant amount of radioactive Radon (Ra). This type of gypsum varies greatly in quality and contaminates.

FGD is more soluble than mined gypsum hence it works much faster for removal of aluminum and salts. Its best use is for hardpans in highly weathered soils.

Phosphogypsum

It is a co-product from wet-acid production of phosphoric acid from rock phosphate. It is mainly $CaSO_4+2H_2O$ with small amounts of rock phosphate, sand, and clay. It tends to be a very small particle size and blows easily when dry (unless pelleted). When phosphogypsum is moist it is friable with a slick feel. Due to impurities (sulfuric, phosphoric, fluosilicic or hydrofluoric acids) it tends to be highly acidic between 2-5 pH. It may contain radon or radio nuclides and usage be restricted by EPA guidelines. Depending on where the rock phosphate is mined, it may also contain uranium residues. Other toxic chemicals, depending on the rock sources mined, may be present (radium, radon, radioactive lead, polonium, thorium, etc.).

Pickle Gypsum

This is produced from neutralization of waste sulfuric acid by limestone or lime in pickle production. Generally it is pure gypsum with a few trace elements.

Titanogypsum - byproduct from manufacturing titanium dioxide
Borogypsum - byproduct from manufacturing boron containing compounds
Fluorogypsum - is a byproduct of producing hydrofluoric acid from feldspars
Many other types exist such as Citrogypsum, Kevlar gypsum, etc.

Drywall Gypsum

Drywall or sheetrock consists of gypsum with a thin paper backing. It may contain very small amounts of other ingredients from impurities such as calcium carbonate (CaCO3), calcium hydroxide ($Ca(OH)_2$), portlandite, or quartz. Extremely small amounts of iron, boron, manganese, phosphorous, cobalt, copper, zinc, etc. may be present depending on the source location of the mined gypsum. Also, metals such as lead, mercury, molybdenum, nickel, selenium in even smaller amounts may be present but well below the EPA 40 CFR Part 503 regulations.

Demolition drywall should be avoided due to potential contamination from wall coverings and paint. Also many years ago arsenic was added to drywall and used to help strengthen the wall board. Modern drywall contains very little contaminates and is well below the EPA standards for Biosolids usage when applied to soils.

Greenboard - a special purpose moisture resistant drywall board

Type X – Is fire resistant gypsum that contains small glass fibers designed to increase the board's ability to withstand high temperatures from fire for a longer period of time. Tests on earthworms have shown that Type-X does not hurt microorganisms or earthworms. The glass fibers used are too large to affect human respiratory systems since glass is amorphous unlike crystalline silicone. Also Type-X contains less limestone, vermiculite and fiberglass as compared to regular wallboard (varies upon manufacturer).

Most waste scraps of drywall from construction sites are a good source of gypsum for soil applications or composting.

Landfill versus Recycling

When old drywall (gypsum) is placed in landfills several things may occur. When the gypsum gets wet it dissolves into calcium and sulfate and may leach into the groundwater causing sulfate contamination. The federal limit for sulfate in drinking water is 250 mg/L. Sometimes concentrations above this limit have been found in groundwater near unlined landfills. It also contributes to high Total Dissolved Solids (TDS) concentrations at many C&D (construction and demolition) debris landfills.

Landfills by design have very little oxygen in them hence anaerobic decay occurs. The microbes in these conditions biologically convert the sulfate in the gypsum into hydrogen sulfide (H_2S) by using the paper (carbon) as an energy source or other organic materials and the water that accumulates in the landfill. This is a foul-smelling gas (rotten egg odor) that can easily escape the landfill. This gas can reach very high levels in a landfill. Humans are very sensitive to this odor and can smell it at concentrations as low as 1/10 of a part per million (<0.1 ppm). This often leads to odor complaints at or near landfills. Concentrations of this gas above 250 ppm are lethal and have been found in landfills. As a result many landfills have been forced to ban drywall gypsum from disposal from landfills in some areas. Several lawsuits or remedial action have occurred due to problems due to the generation of hydrogen sulfide gas.

Green Building – Drywall should contain a 75% or greater recycled content. The primary environmental impacts of raw gypsum are habitat disruption from mining, energy use, associated emissions in processing and shipment to solid waste from disposal. Using recycled gypsum reduces all of these. New green building standards "Leadership in Energy and Environmental Design (LEED)" give certification credits for recycling drywall gypsum from construction projects.

The paper content of gypsum wallboard is 1% or less. Upon grinding with a hammer mill, recycled gypsum is 93% gypsum powder and 7% shredded paper.

Researchers also conclude that wallboard scrap is at least equivalent in effectiveness with commercial gypsum fertilizer and did not negatively affect crop growth and yield. Land applications for disposal which have been at rates up to 22 tons/acre have been studied without negative effects. Often recycled drywall works better than mined gypsum since minor and trace elements have been added as strengthening agents to the drywall board.

Ground scrap drywall could be used as a source of agricultural nutrients as well as a soil amendment, with rates of up to 10-25 tons of drywall per acre, or the equivalent of the scrap from 10-25 average new home construction projects. Such applications could be repeated every 10 years or more frequently, especially if lower application rates are used. Studies have shown that grain yield and test results were not significantly related to application rates, although there was a slight positive trend. Application rates positively affect soil exchangeable calcium levels and cause a modest reduction in soil penetrometer resistance readings. The boron levels did not appear to cause any damage and the paper backing from the drywall all appeared to have decomposed within 11 months.

Common impurities in natural gypsum (or drywall) include clay, anhydrite, limestone and fly ash in synthetic gypsum.

For use in horticulture, agriculture and general gardening it is best to use only recycled gypsum from drywall or mined gypsum.

Common Uses of Gypsum

- Ceiling tiles, paints, joint compound
- Calcined gypsum used as plaster
- Plaster of Paris and Plaster board
- Stucco additive
- Cement
- Filler and pigment uses
- Glassmaking
- Chemicals
- Kitty Litter
- Animal bedding
- Dietary supplement in foods for nutrition or a flavor additive that controls tartness in wines.
- Water treatment
- Sludge drying for stability and odor control
- Cement production (reduces setting time)
- Waster treatment
- Salty soil treatment
- Manure treatment
- Flea powder - Recycled gypsum makes up over 90% of the inert ingredients in flea powders.
- Grease absorption
- Athletic fields - Gypsum or recycled gypsum is used to mark lines on sports field.

- Absorbents - Gypsum is a better absorbent than a typical clay absorbent and due to its white color, it is often preferred by those facilities that clean up all the absorbent after a spill, since it is very visible when saturated with the contaminate from the spill area.

Markets for Gypsum Products

- General agriculture
- Horticulture
- Mushroom growing (30 pounds per ton of horse manure)
- Spent Mushroom Substrate (mushroom compost) - reduces salt effects by leaching sodium in nursery container media
- Forestry and mine reclamation
- Wetlands establishment
- Nurseries
- City parks and recreation areas
- Residential lawns (sod)
- Golf courses
- Composting
- Manure management

General Benefits of Gypsum for Soils

- Improves water penetration and workability of an impermeable sodic soil (alkaline)
- Softens and improves soil structure that have clay content by flocculating the clay particles
- Increases aeration of many soils (improves sour soils)
- Adds plant nutrients calcium (Ca) and sulfur (S)
- Leaches sodium salts out of soils by exchanging with the calcium in the gypsum
- Reduces aluminum (Al) toxicity
- Prevents soil crusting hence aids seed emergence
- Increases the solute concentration of low-solute irrigation water
- Helps break up compacted soil
- Makes slightly wet soils easier to till
- Reduces water runoff and erosion
- Decreases the pH of sodic soils
- Increase the pH of acidic soils
- Decreases the swelling and cracking of some types of clays like montmorillonite with high levels of exchangeable sodium
- Reduces water logging of poorly drained soils
- Helps to make stable organic material (humus)

- Makes water-soluble polymer soil conditioners more effective
- Reduces excess magnesium toxicity
- Corrects sub-soil acidity
- Increases water use efficiency of crops
- Creates favorable soil buffered solute concentration (EC)
- Makes possible to use irrigation water with a high sodium adsorption ration (SAR)
- Decreases dust wind erosion
- Helps plants absorb nutrients
- Decreases heavy metal toxicity
- Increase value of organics in the soil
- Improves fruit quality and helps prevent some diseases
- Provides sulfur and calcium
- Helps prepare soil for no-till management
- Decreases bulk density of soil
- Decreases the effects of salt (NaCl) toxicity
- Makes other inputs more effective such as fertilizer
- Can improve the pH of the rhizosphere
- Keeps clay off tubers and root crops
- Decreases loss of fertilizer nitrogen to the atmosphere
- Can be a source of oxygen to plants
- Helps earthworms to flourish
- Can clear muddy water in ponds by aggregating soil particles
- Bind odors associated with ammonia
- Improves uptake of fertilizers on many soils and other amendments
- Promotes uptake of nutrients by plants (N, P, K, Ca, S, Cu, and Mn)
- Increases uptake of water by root systems
- Increases moisture holding capacity of many soils
- Helps leach toxic metals such as selenium
- Decrease Heavy-Metal toxicity
- Makes subsoiling and chiseling more effective
- Reduces phosphorous leaching from soils in drainage water
- Reduces sulfur leaching from flooded soils
- Reduces ammonium nitrogen and total nitrogen in runoff (not nitrate N) and sediment
- Gypsum lasts longer as a sulfur source than elemental sulfur on crusting soils (particularly in arid areas) gypsum significantly increases water availability, emergence or both
- Helps to bind up toxic metals and contaminants in soils rendering them unavailable for plants
- Does not affect pH except if soil is very alkaline due to high bicarbonate ions. The calcium will combine with the bicarbonate and form calcium carbonate which may raise the pH slightly 0.2-0.3 of a pH scale.
- Reduces the absorption of heavy metals by plants

- Reduces phosphorus and nitrogen in runoff
- Removes excess Boron from sodic soils
- Increases value of organic amendments
- Source of oxygen for plant roots
- Helps earthworms to flourish

An easy test to see if gypsum will benefit a soil is to take a teaspoon of soil and ½ ounce of distilled or rain water in a test tube (or straight walled jar and more soil fill 2/3 full of water), shake it up and allow to stand for two hours or more. If the upper liquid remains cloudy, the soil is likely to respond to an application of gypsum.

Soil Crusting

Soil Crusting is often caused by the collapse of soil aggregates into subunits, a process sometimes called "slaking." This is often followed by separation of the subunits into sand, silt, and clay portions, a process called dispersion. Crusting occurs when the highly dispersible clay particles that remain suspended in water for a period of time slowly settle, sealing the soil surface. The action of rain drops or irrigation often causes slaking and dispersion to occur. This process reduces water infiltration into the soil and increases additional run-off which creates more erosion. Excess exchangeable magnesium on clay surfaces increases this effect. This effect on clays increases with increasing pH. This same sealing effect also makes it harder for newly emerging plants (from seed) to push through. Gypsum applied at a rate of 500-2,000 pounds per acre after seed bed preparation has been shown to be effective in preventing soil dispersion and surface sealing. Many soil types can be dispersive with the presence of sodium salts being the most common. Gypsum is most effective when it is less than 1/16 inch in size as the smaller sizes result in more surface area hence it dissolves quicker and starts working. However, smaller sizes tend to be very dusty. Note: Organic matter application can reduce dispersion if accompanied by calcium (Ca^{++}) ions hence compost made with gypsum added works well.

On clay soils, gypsum helps the clay particles become flocculated (keeps the clay particles from sticking together) preventing dispersion.

Acid Subsoil

Acid subsoil often has high amounts of Aluminum (Al) and low amounts of calcium (Ca). Since high levels of aluminum are toxic to plants, this effect often forms a barrier and prevents root penetration. This is a common problem in weathered soils from humid areas with lots of rainfall.
If we use enough lime to correct this problem it changes the pH to the point where other nutrients become locked up and unavailable to plants. Gypsum adds the required calcium to the soil without changing the pH.

Sodic or Salt Contaminated Soils

On salty soils (sodic) the calcium (Ca) in gypsum substitutes for the sodium (Na), allowing for the sodium to leach away. When gypsum is exposed to moisture it dissolves and the ions separate into calcium (Ca^{++}) and sulfate (SO_4^{--}) ions. When sodium is on the surface of clay particles it causes hydration and the dissociation of the particles, hence swelling and dispersion. The calcium ion from gypsum replaces the sodium ion and allows it to be dissolved and leach away, removing it from the soil profile. Note: An increase in soil sodicity (Na) increases soil susceptibility to crusting, seal formation, runoff, and erosion

Soils with lots of surface area, such as those with high clay content, tend to have higher matrix potential at a given water concentration. In osmotic flow, water moves from an area of low salt content to an area of higher salt content. Soils with lots of salt may look moist but plants can not absorb this moisture due to this effect. Hence, gypsum helps reduce this effect and helps plants use the moisture stored in the soil. Note: We use salt to preserve food items from pickles to salted meats. The same osmotic pressure pulls water out of the microbes that would cause spoiling hence preserving the food. The same thing happens in soils except the water is pulled from mycorrhizal fungi, nitrogen fixing bacteria and other good microbes, killing them.

Nutrient Availability

Weathered soils which are chemically stable do not release electrolytes (nutrients) and respond readily to gypsum applications. On young soils which weather readily and release electrolytes, the addition of gypsum will have fewer effects. Note: On sandy soils excess gypsum may cause a tie-up of Mg and K.

The sorption of Ca and SO_4 by plants is higher in woodland soils that in cultivated soils. Microbes in the woodlands soil help plants take up the nutrients more efficiently.

Runoff and Water Absorption

Some studies have found that gypsum application reduces run-off to less than half of untreated soils and by increasing surface roughness and flow path tortuosity it decreases runoff velocity. This reduces interrill erosion and other erosion effects from raindrops.

Animal Bedding

Recycled gypsum can be mixed with ground wood chips for animal bedding. It can substitute for sawdust or sand to absorb moisture and reduce odors.

Poultry bedding – Studies have shown the percentage litter moisture was significantly lower for refined gypsum than for the wood shaving treatments at 21 and 41 days, although on a weight basis the gypsum contained the same amount of or more water. Litter material had no influence on room or brooding temp. Although it is quite dusty initially when placed in the house, refined or recycled gypsum can be used for bedding, as a base with wood shavings.

Manure treatment - Recycled gypsum can be mixed with animal wastes to combine with ammonium (NH_4) to form ammonium sulfate to prevent loss of nitrogen and thus reduce odors. Ammonium sulfate is odor free.

Crops Known to Benefit From Gypsum

Alfalfa - source of sulfur (1 ton per acre provides 17 pounds of sulfur). Alfalfa needs 25 pounds per acre of sulfur to make a good crop. Another report indicated that it helped grow stronger healthier stems. One study found that 16 tons per acre gave best yields. Another study found that only 200 pounds per acre doubled yields. No harmful effects have been found.

Alliums - increased growth rates and bulb size

Almonds - increased growth and yields

Barley - increased yields

Citrus - significantly reduced root rot caused by *Phytophthora parasitica,* reduced salinity effects of salts and improved plant growth (citrus is salt sensitive).

Coffee - increased yields

Corn - 25% higher yields, corn needs about 25 pounds of sulfur per acre

Cranberries - increased yields, less disease

Desert Salt Grass (Distichilis spicata var. stricta) - gypsum increased growth rates and increased biomass, corrected nutrient imbalances due to sodium.

Ginseng - did not affect tissue calcium but a significant increase in both shoot growth and root dry weight.

Grapes - in California gypsum has been used for over 25 years. Used by many wineries to increase production.

Lawns - 50 pounds per 1,000 square feet or one ton/acre

Lilium sp. - reduced upper leaf necrosis (associated with a calcium deficiency)

Marsh vegetation and wetlands remediation - had significantly higher dry matter production than the control without gypsum

Papaw - increased total lateral branching by 60-73% as compared to unamended control and total dry matter accumulation and net uptake of N, P, and K per tree was 100% greater

Peanuts - 600-880 pounds per acre have been used

The peanuts grown had higher calcium content but less zinc. All peanuts grown in gypsum treated fields had less Aflatoxin produced on them when compared to unsupplemented peanuts.

Legumes - require lots of sulfur to form nitrogen fixing nodules on the roots.
Gypsum has been particularly useful to peanut farmers and to some extent to watermelon farmers.

Plants that can benefit from gypsum include:

Flowers - clematis, lilacs, irises, delphiniums, alyssum stock, candy-tuft, nasturtium, tulips, gladioli, roses, camellias and gardenias

Landscape plants - evergreens, rhododendrons, mountain laurel, pin oak, sweet gum and flowering dogwood

Potatoes
- Significantly reduced incidence of internal brown spot and soft rot, in several locations around the country.
- The best control of the disease of common scab of potato (S. aureofaciens) was obtained by soil application of gypsum (25 g and 12.5 g/pot), and a corresponding increase in yield
- The mean tuber yield response due to sulfur addition was 1.1 t/ha. Addition of sulfur (S) by gypsum was effective in overcoming the sulfur deficiency symptoms and in increasing the sulfur concentration in the leaves.
- One study found that growers using 500-1,200 pounds of gypsum per acre had potatoes with stronger cells, they were more uniform in appearance, a decrease in internal brown spotting, and increased storage time

Strawberries - increased yield and reduced soil disease

Tomatoes
- earlier ripened fruit with larger fruit
- the fruit also had higher levels of some nutrients
- worked better in reducing blossom end rot as compared to other calcium sources calcium chloride ($CaCl_2$), calcium nitrate ($Ca(NO_3)_2$), etc.

Raspberries - it controlled *Phytophthora* root rot better, significantly increased plant growth, fruit yield, and root growth compared to other methods and control

Sugarcane – increased growth rates

Vegetables - cabbage, broccoli, cauliflower, radishes, turnips, kale and onions have all been shown to benefit from gypsum

Wheat – increased yields

Wheatgrass (Agropyron elongatum) - gypsum increased growth rates and increased biomass, corrected nutrient imbalances due to sodium.

Many vegetables including potatoes and corn have been shown to benefit from gypsum application

Used for all crops that requires calcium, especially on alkaline soils where they cannot withstand the pH adjustment from lime

Arbuscular mycorrhizal fungi - increased colonization and growth rates of these beneficial fungi

Nursery potting media - 6-8 pound per cubic yard

ANIMALS:

General - has been used as part of animal feed at a rate of 100-250 pounds per ton of feed

Pigs/Hogs - when used as litter on the floor of pig pens gypsum has reduced scouring

Cows - when used as part of bedding in barns the animals were reported to be healthier, reported to reduce mastis cases, absorbs liquid which helps keep animals dryer

Dogs - gypsum has been reported to neutralize the effects of dog urine on grass

Earthworms - used in bedding to increase growth rate and increase minerals in castings

APPLICATION:

Gypsum can be spread as a solid or dissolved in irrigation water. Typical application on sodic clay soils ranges from 1-3 tons per acre every few years as needed.

Often irrigation water is a preferred method of application. Application via water offers many benefits. For gypsum to go readily into solution it must be finely ground to minus 200 to minus 300 mesh size. Some benefits of this method:

- Increases the solute concentration of irrigation water that is too pure to give good water infiltration into soil.
- It decreases the sodium absorption ratio (SAR) of saline irrigation water including reclaimed water (grey water, etc.) so that water does not result in sodicity of the soil by increasing the exchangeable sodium percentage.
- Avoids unsightly gypsum granules of gypsum lying on turf of golf courses
- Promotes solute calcium to fruit crops and other plants to avoid low calcium fruit disorders like blossom end rot in tomatoes and bitter pit in apples. Over 30 disorders prevented by gypsum.
- Preserve effects of soil stabilization.
- Convenience of use.
- Decreases the length of time for soils to respond to gypsum application
- Increases uniformity of gypsum application
- Decreases existing ESP of the soil surface so that better water infiltration will occur.

Gypsum may need to be reapplied every couple years in wet climates or on irrigated fields as the gypsum will leach out of the soil profile.

Gypsum is often applied to soil with cracks that allow the gypsum to penetrate further into the soil, allowing its effects to be quicker and move deeper into the soil profile.

Notes:

Before the mid-1970s, asbestos may be found in joint compound made from gypsum

Before 1978 gypsum wallboard may have lead-based paint.

Sample Material Safety Data Sheets (MSDS):

Louisiana Pacific:

Gypsum	81-96%
Paper	4-6%
Water resistant additives	0-8%
Organic binders	<1%
Soap for foam	<1%
Organic dispersant	<1%
Glass fibers	<1%
Gypsum crystal modifiers	>1%

Product 2 MSDS:

Gypsum	63%
Paper	15%

Perlite	13%
Water	7%
Other	<2%

Product 3: Gypsum, Quartz, Cellulose

Product 4:	gm/kg	Product 5:	ppm
Ca	260		160,360
Mg	22		8,475
Na	0.2		<60
P	0.2		<22
K	0.5		<62
S	116		133,821
Zn	n/a		11-16
B	n/a		42
Mn	n/a		45
Fe	n/a		850-940
Cu	n/a		7-11
Co	n/a		9
Mo	n/a		2.6
N	n/a		280
Ni	n/a		20
Li	n/a		<2
Cl	n/a		193
Al	n/a		294
As	<0.010		<27
Ba	<0.0197		n/a
Cd	<0.01		<3
Cr	<0.059		<11
Pb	<0.01		<15
Hg	<0.026		n/a
Se	<0.01		<19
Ag	<0.002		n/a

Boron: some drywall contains less than 0.15 g per kilogram (<50 ppm) other gypsum has been tested at 120 ppm. For most cropland boron levels were low enough not to cause a problem and leaching from rainfall or irrigation removes it from the soil.

The Gypsum Association *Gypsumation* newsletter of December 1997 highlights the results of tests for gypsum drywall recycling, with the following conclusions (also see item 163):

1. The material should be pulverized to quickly disintegrate into the soil. This means that the pieces should be 1/2" or less in size.
2. The pulverized material may be put on the top of the soil or mixed into the soil
3. The material should be spread evenly over the entire lot if conditions permit
4. Application may be as much as 22 tons per acre
5. Gypsum board should be used only on lots that have adequate drainage and aeration
6. Federal, state and local regulations should be considered

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