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Improving soil structure with gypsum and lime

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CONTENTS

Cover photograph:

The effect of gypsum on the trafficability of a sodic grey clay several days after heavy rain. The boot on the left shows how boggy the untreated soil was. The boot on the right shows how much less boggy the soil was after treatment with gypsum.

Gypsum is the common name for calcium sulfate, one of a group of chemicals called salts. Unlike common salt (sodium chloride) gypsum contains calcium and sulfur, and is only slightly soluble in water.

Gypsum occurs naturally as colourless, white or brown crystals in various locations throughout NSW. One crystalline variety is known as 'seed' gypsum because the crystals are about the size of wheat grains. There is also a fine earth variety called 'kopi'. In some areas gypsum deposits occur in old lake beds or adjacent dunes; these deposits are often mined.

Phosphogypsum is a form of gypsum that contains a small amount of phosphorus. It is a by-product of the manufacture of concentrated phosphatic fertilisers.

The main reason for applying gypsum to soils used for agriculture is to maintain or improve their structure*. Gypsum, rather than other forms of calcium, is most commonly used for this purpose because it is easy to obtain, relatively cheap, easily handled and can be used on all types of soils.

SOIL STRUCTURE, SODICITY AND GYPSUM

'Soil structure' means the ***arrangement*** of sand, silt and clay particles and organic matter in the soil to form aggregates (crumbs). It differs from 'soil texture' which indicates the ***proportions*** of sand, silt and clay in soils.

Soils with an excess of exchangeable sodium cations (positive ions) attached to clay particles are called sodic soils. Sodicity should not be confused with salinity. Salinity refers to the total amount of salts dissolved in the water in soil, whereas sodicity refers to the exchangeable sodium cations bound to clay particles. Sodicity is expressed as the ESP (exchangeable sodium percentage), which is the amount of exchangeable sodium expressed as a percentage of the soil's CEC (cation exchange capacity).

Salinity can be reduced by leaching (draining rainwater or non-saline irrigation water through the soil), but leaching has little effect on sodicity. Some soils in NSW are both sodic and saline, but many more are sodic without being saline, particularly in the subsoil.

The sodium ions in NSW soils originated from:

- wind-blown dust during drought
- wind-blown salt spray near the coast
- salt-rich bedrock in the upper catchment areas
- near-surface saline groundwater
- seawater flooding.

Since European settlement some soils have become more sodic due to irrigation with sodium-rich groundwater and, less often, surface waters, or because of rising watertables carrying dissolved sodium salts.

Two aspects of soil structure that are particularly important for agriculture are:

- the numbers of pores (holes) of various sizes, and how these change as the soil swells and shrinks
- the stability of the soil structure to wetting.

Pore size and swelling/shrinking

The two types of soil pores important for plant growth are transmission pores and storage pores. Transmission pores are large (greater than 0.03 mm in diameter) and include cracks and channels created by roots and soil organisms such as earthworms. They transmit water through the soil and drain easily after rain or irrigation. The storage pores are small (less than 0.03 mm in diameter) and their main role is the storage of water for plant use.

A good balance of both types of pores is very important in plant production to encourage water intake and drainage (through transmission pores) and water retention (by storage pores).

Most soils that contain a high proportion of clay (the clay loams and clays) swell on wetting and shrink on drying. Clay soils that have high sodicity and low salinity tend to swell and shrink the most. Swelling and shrinking affect soil pores in two important ways:

- the total amount of pore space filled with water increases as the soil swells, and decreases as it shrinks
- swelling changes the distribution of pore sizes — from a combination of transmission pores and storage pores to almost entirely storage pores in a fully swollen soil.

One of the effects of gypsum on clay soils is to reduce the degree of swelling, helping to preserve a favourable balance of transmission pores and storage pores.

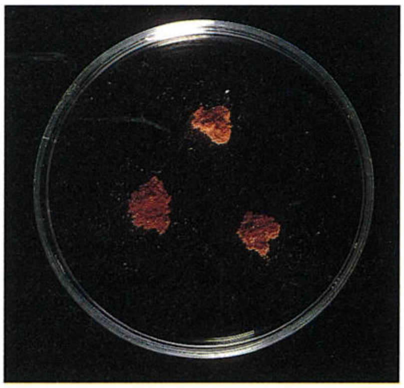
Structural stability to wetting

There are two main types of soil structural breakdown:

- Slaking, which is the breakdown of soil aggregates in water to smaller aggregates, known as micro-aggregates. This is a rapid process that occurs mainly within the first few minutes of wetting and is promoted by low levels of organic matter.
- Dispersion, which is the breakdown of micro-aggregates in water to individual sand, silt and clay particles. This is a slower process

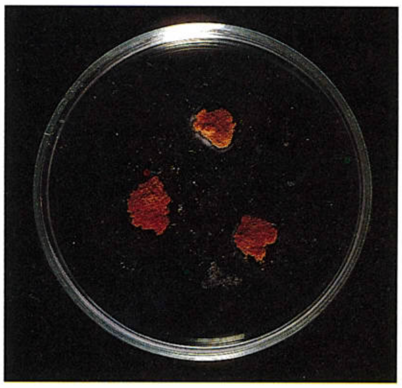
* Gypsum is sometimes applied to soils to correct a calcium or sulfur deficiency (see Agfacts P2.8.4 *Using sulphur on pastures* and P5.2.1 *Canola*). This use is not discussed here.

Fine sandy loam



5 minutes

2 hours



24 hours

Medium clay

5 minutes

2 hours

24 hours

M. HILL

Illustration 1. Structural breakdown of aggregates of two different soils in water.

The fine sandy loam soil slaked within the first 5 minutes but clay dispersion was negligible, even after 24 hours.

The medium clay soil also slaked within the first 5 minutes but, unlike the fine sandy loam, it dispersed strongly. After only 5 minutes some dispersion was evident, and after 2 hours the soil dispersed almost completely.

than slaking, often taking hours to complete. Clay dispersion is usually greatest in clay soils that are sodic but not saline.

The differences between slaking and dispersion are illustrated in Illustration 1. Gypsum prevents clay dispersion but has little effect on slaking (see Illustration 2).

Clay dispersion is particularly undesirable for agricultural production. Together with swelling of clay it is the main cause of physical and mechanical problems in clay loam and clay soils. These problems include:

- low water intake
- poor drainage
- low aeration
- surface crusting
- cloddiness.

Clay dispersion at the surface after rain or irrigation typically results in a hardsetting or crusting topsoil that remains cloddy after cultivation. Plant establishment may be severely affected.

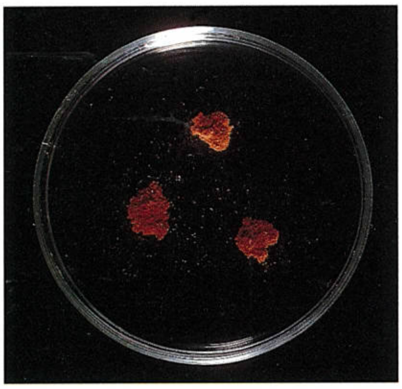
In clay subsoils, swelling and sometimes clay dispersion can result in low permeability, poor aeration and high soil strength. This leads to waterlogging after heavy rain or irrigation, and restricted root development.

HOW GYPSUM IMPROVES SOIL STRUCTURE

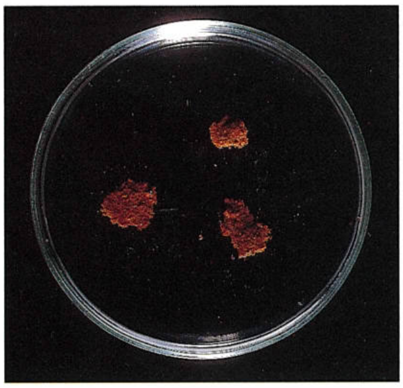
Gypsum works in two ways. Both depend upon the gypsum being dissolved by rain or irrigation water and entering the soil solution.

The first is called the electrolyte effect ('electrolyte' means 'salt solution'). This effect is based on the fact that swelling and clay dispersion of sodic clay soils decrease as the salinity of water infiltrating the soil increases. It occurs with all types of salts, not only gypsum. It is short-term in nature because it ceases when all the applied gypsum has disappeared.

Fine sandy loam



water



water + gypsum

Medium clay

M. HILL

water

water + gypsum

Illustration 2. The effect of gypsum on the structural breakdown of aggregates of two different soils in water after 2 hours.

Gypsum had little effect on the structural breakdown of the fine sandy loam soil because only slaking was involved. However, gypsum completely prevented clay dispersion in the medium clay soil.

The second effect is specific to calcium salts, including gypsum. It is based on the fact that cations in the soil, such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}), are bound to clay particles by electrical forces and are exchangeable. This means that if a high concentration of calcium cations are introduced to the soil solution (by adding gypsum) they will exchange for other cations, particularly sodium, on the clay.

By this process a sodic clay is changed to a calcic clay (that is, one dominated by exchangeable calcium), thereby reducing swelling and clay dispersion. At the same time the sodium cations are released into the soil solution, but are leached below the root zone where their presence is less important than nearer the surface. This second effect is a long-term benefit, lasting well after all the applied gypsum has disappeared from the root zone.

Topsoils

Gypsum improves the structure of hardsetting or crusting sodic clay topsoils, not only by reducing swelling, but also by preventing clay dispersion. The result is a more friable soil that is less likely to be waterlogged when wet and which has lower strength when dry. Such a soil forms a seedbed that promotes a higher plant density due to increased seedling emergence.

This factor alone may be sufficient to economically justify the use of gypsum. It is most apparent when rainfall follows sowing, resulting in little or no emergence in untreated areas and almost complete emergence in areas treated with gypsum. Illustration 3 shows the effect of gypsum on the emergence of wheat on a sodic grey clay in north-western NSW.

Other likely benefits of gypsum application to sodic clay topsoils include:

- increased intake of water, resulting in improved water storage* for subsequent plant growth, and reduced risk of tunnelling and other types of soil erosion
- less wear on implements
- reduced fuel consumption
- fewer problems with soil adhering to produce when harvesting root crops such as potatoes
- improved trafficability after heavy rain or irrigation — the cover photo shows how boggy a sodic clay was without gypsum (boot

* It is sometimes claimed that gypsum improves water storage by increasing the soil's water holding capacity. It is true that gypsum improves water storage, but it does this by improving the soil's ability to take in water. Gypsum decreases water retention because it reduces swelling, but this effect is small compared with that of increased water intake.

Illustration 3. The effect of gypsum on the emergence of dryland wheat on a sodic grey clay in the Moree district of NSW. The soil on the left was untreated, that on the right was treated with gypsum. The friability of the soil was greatly improved by gypsum application.

on left), and how much less boggy with gypsum (boot on right).

Also, it may be possible to use lighter machinery in some circumstances, such as a rod weeder for weed control instead of a heavy duty scarifier.

Subsoils

Many soils in NSW have sodic clay subsoils of low permeability. These soils waterlog easily after heavy rain or irrigation. Under these circumstances subsoil oxygen levels remain low for long periods during which root development is seriously restricted. Waterlogging also favours the development of root diseases, including crown rot and ***Phytophthora***, and the loss of nitrogen by denitrification.

Gypsum can improve these soils by reducing swelling and, possibly, clay dispersion. This increases permeability and reduces the time taken for the oxygen content to return to levels satisfactory for root growth. However, treatment with gypsum is rarely as successful for subsoil as it is for topsoil, because of the difficulties of applying gypsum to the subsoil (see 'Application of gypsum').

An important step in developing land for surface irrigation is landforming, which often involves cutting and filling. This reduces the depth of the topsoil in some places, frequently exposing sodic clay or bringing it closer to the surface. These cut areas are notorious for their poor production and often require gypsum, increased fertiliser application and extra organic matter to improve soil fertility.

PREDICTING SOIL RESPONSE TO GYPSUM

Soil properties

Soils that are most likely to show economic responses to gypsum application have the following features in the topsoil, subsoil or both:

- high clay content—greater than 30%, particularly greater than 40%
- high sodicity level—ESP greater than 5, particularly greater than 10
- low salinity level—electrical conductivity of a 1:5 soil:water suspension (EC 1:5) less than about 0.4 decisiemens per metre (dS/m), particularly less than about 0.2 dS/m, depending on sodicity level.

Sodicity and salinity are related: the higher the sodicity, the higher the salinity level needed to prevent dispersion. For example, a clay soil with an ESP of 8 may disperse in rainwater, and therefore respond to gypsum, if the EC 1:5 is 0.1 dS/m, but not if the EC 1:5 is 0.3 dS/m. However, a similar soil with an ESP of 15 may disperse in rainwater and respond to gypsum if the EC 1:5 is 0.3 dS/m, but not if the EC 1:5 is 0.8 dS/m. If the salinity is very low the critical ESP may be as low as 2, as found in the surface of some hardsetting red-brown earth soils.

Other soil properties that can affect gypsum response include:

- Ratio of exchangeable calcium to exchangeable magnesium (Ca/Mg ratio). The lower the Ca/Mg ratio, the greater the likelihood of response, particularly for marginally sodic (ESP about 5) clay soils. Values of Ca/Mg ratio between 1 and 2 are considered low; less than 1, very low.
- Organic matter content. Organic matter usually helps to prevent clay dispersion, particularly when present with calcium ions. Sodic clay soils with low organic matter levels (less than 2%, particularly less than 1%) are more likely to respond to gypsum. However, remoulding of soil can cause some types of soil organic matter to aggravate dispersion problems.
- Concentration of free lime (calcium carbonate) in alkaline soils. Naturally occurring free lime can assist in reducing clay dispersion, particularly if it is present as fine earth particles rather than nodules. Thus sodic clay soils with high free lime levels (more than about 0.3% calcium carbonate) are less likely to respond to gypsum.
- Clay type. Different types swell and disperse to varying degrees, thereby affecting gypsum response. Illites disperse more easily than smectite clays. Kaolinitic clays become more dispersive as pH increases.
- Degree of mechanical damage. Remoulded clods are more prone to dispersion than natural aggregates.

The application of gypsum to saline non-sodic clay soils is *not* recommended for two reasons:

- gypsum is unlikely to improve the structure of saline soil
- gypsum is a salt, so it may have an adverse effect on salt-sensitive plants such as lettuce, particularly if applied at high rates to marginally saline soils.

However, gypsum is usually required for the reclamation of saline sodic clay soils because salinity levels are reduced by leaching, thereby resulting in swelling and clay dispersion when rain falls or low salinity irrigation water is applied.

Testing soils for gypsum response

There are three main ways in which soils can be tested for likely gypsum response. These are:

Illustration 4. Dispersion caused separation of light coloured sand on the soil surface following irrigation of a clay soil.

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- on-farm tests
- laboratory tests
- trial strips.

On-farm tests. These are the quickest but least reliable means of assessing likely gypsum response. The simplest test is to drop about eight small (3–5 mm diameter) air-dry aggregates of soil into a container of rainwater or irrigation water. Leave undisturbed for approximately 2 hours, then look for clay dispersion, which is seen as a murky cloud around the slaked aggregate (see Illustration 1). Observe again after 24 hours. Test topsoils and subsoils separately. Clay soils that disperse strongly, particularly after only 2 hours, usually respond to gypsum application.

If gypsum is available, add some to rainwater or irrigation water in a bottle and shake vigorously to partially dissolve it. Repeat the test using this solution. Dispersion should be prevented if gypsum is to be successful in improving soil structure (see Illustration 2).

Another sign of dispersion in the field is the separation on the soil surface of light coloured sand from clay after heavy rain or irrigation and subsequent drying (see Illustration 4).

A more reliable on-farm test compares water movement through soil with and without the addition of gypsum. Follow these steps:

1. Take two tin cans, punch a few holes in the bottom of each and put a piece of porous material such as hessian or coarse cloth on the bottom.
2. Sample the soil (topsoil and subsoil separately) and spread out to dry.
3. Break the soil down to aggregates no bigger than about 5 mm diameter.
4. Add air-dry topsoil to the cans, filling each about three quarters full.
5. Pack the soil as uniformly as possible by tapping the cans several times on a hard surface.
6. Add rainwater or irrigation water to one can, and water containing gypsum to the other.
7. Time the outflow of water from the cans.

Repeat the test using the subsoil. If the outflow rate is at least three times greater from the can with gypsum for the topsoil, subsoil, or both then a good field response to gypsum application is likely.

Laboratory tests. This method is intermediate in speed and reliability. It is particularly useful to confirm or refute on-farm test results. It provides information about the nature of the structural instability problems.

The following tests are useful:

- texture (to estimate clay content)

Illustration 5. Testing clay dispersion of soils in the laboratory.

- ESP (to estimate sodicity)
- electrical conductivity (to estimate salinity)
- Ca/Mg ratio
- free lime content
- organic matter content
- dispersion (see Illustration 5).

Soil maps that are sufficiently detailed to provide information about sodicity at the paddock scale are occasionally available.

Trial strips. The third method, application of trial strips of gypsum, is the slowest of the three, but is often the most reliable and realistic. For best results choose the most uniform and representative part of the paddock. Use several different rates of gypsum application, including nil, and replicate each rate two or three times. If possible, apply the gypsum well before sowing (for annual crops and pastures) or before the start of the irrigation season (for irrigated perennial crops and pastures).

Be sure to treat the whole trial area in the same way, for example, for fertiliser application* or pest control. Look for increased friability and improved seedling emergence (if applicable) in gypsum treated plots. Measure yields, even if responses are not visible. These observations should help you to decide whether

* Nitrogen deficiency is sometimes observed in gypsum treated crops (see 'Plant yield response'). For this reason it may be useful to apply nitrogen across one end of the gypsum strips at, say, twice the normal rate used for the remainder of the trial area.

or not the soil is responsive to gypsum and, if so, what rate to use over the entire paddock.

Continued observations in subsequent years, preferably backed up by routine soil testing, will indicate when to reapply gypsum. Consult your local NSW Agriculture advisory officer or agribusiness adviser for assistance. This method is subject to seasonal and other effects (see 'Plant yield response').

CHOOSING WHICH GYPSUM TO BUY

Quality of gypsum

Gypsum quality is assessed by considering two main factors: purity and fineness.

Gypsum may contain a variety of impurities, including water, soil, limestone, sodium chloride, cadmium and fluoride. In NSW the purity of gypsum is defined in terms of percentage sulfur (S) on a wet weight basis, that is, percentage S of gypsum as supplied. Most of the gypsum sold in NSW is calcium sulfate dihydrate ($CaSO_4.2H_2O$), which has 18.6% S when completely pure.

Fineness refers to the size of the gypsum particles. It is important because it largely determines how quickly the gypsum dissolves in water. Lumpy gypsum may be unsuitable, not only because of difficulties in spreading, but also because it is very slow to dissolve.

There are two main sources of gypsum: from mining and as industrial by-products.

Mined gypsum. Mined gypsum may contain a high proportion of impurities (mainly soil) and is often quite lumpy or coarsely crystalline (see Illustration 6). Its quality can be quite variable, as the gypsum type and content change with depth in the pit. Solubility in water tends to be low (see Table 1). Mined gypsum is usually sold by volume (cubic metres). Transport can be expensive because the major deposits are in isolated locations in western NSW. However, because of its generally lower levels of cadmium and fluoride than by-product gypsum, mined gypsum is usually preferable when these impurities are of concern.

By-product gypsum. By-product gypsum comes mainly from the manufacture of concentrated phosphatic fertilisers and is often called 'phosphogypsum' (see Illustration 6). It contains a small amount (0.1–0.3%) of phosphorus as phosphoric acid and is usually sold by weight (tonnes). By-product gypsums tend to have a higher purity, and be more

Illustration 6. Examples of mined (A and B) and by-product (C and D) gypsum products that are available in NSW.

A: mined gypsum, Bourke;

B: mined gypsum, Riverina;

C: waste plasterboard, Kurnell;

D: phosphogypsum, Newcastle.

Purity and solubility of these gypsum products are shown in Table 1.

Table 1. Purity and solubility of the gypsum products shown in Figure 6.

Gypsum product	Purity*	Solubility (dS/m)**
A (mined, Bourke)	17.1% S; 92% $CaSO_4.2H_2O$	0.4
B (mined, Riverina)	15.0% S; 81% $CaSO_4.2H_2O$	1.0
C (waste plasterboard, Kurnell)	18.3% S; 98% $CaSO_4.2H_2O$	2.1 (particle size less than 2 mm) 1.0 (particle size 2–4 mm)
D (phosphogypsum, Newcastle)	15.8% S; 85% $CaSO_4.2H_2O$	1.9

* Percentage S and percentage $CaSO_4.2H_2O$ expressed on wet weight basis (product as supplied).

** Solubility expressed as electrical conductivity of solution obtained by adding the equivalent of 10 g pure $CaSO_4.2H_2O$ to 1 L demineralised water, gently shaking (20 times end-over-end) and centrifuging for 10 minutes.

soluble in water, than mined gypsums (see Table 1). However, phosphogypsum has a high free water content which lowers its purity (see Table 1) and can cause problems in spreading. Phosphogypsum supplies at Newcastle and Brisbane are expected to run out by 2002 because concentrated phosphatic fertilisers are no longer made there.

Another source of by-product gypsum is at Kurnell in Sydney, where large quantities of waste plasterboard are dumped each year (see Illustration 6).

Cadmium. Cadmium, a heavy metal that is harmful to animal and human health, is present in phosphogypsum, typically at concentrations ranging from 8–15 mg/kg. Levels of cadmium in pasture plants and food crops that might prove harmful to animals and people may be reached without reducing plant growth or causing any plant symptoms.

Cadmium is found naturally in soil, at levels varying from 0.01–0.5 mg/kg. It is adsorbed by soil and accumulates easily in it so that, in the long term, continual application of phosphogypsum could significantly increase the level of soil cadmium. For example, applying phosphogypsum at 5 t/ha, a fairly common application rate, could increase the cadmium content of the top 10 cm of soil by up to 0.05 mg/kg. Four or five such applications could more than double the original background soil level and significantly increase the uptake of cadmium by plants.

Cadmium is most available to plants in acid and sandy soils, and least available in alkaline and clay soils. High levels of organic matter in soil help to limit cadmium uptake. High chloride concentrations in the soil and/or irrigation water may increase cadmium uptake.

The uptake of cadmium by plants also depends on the species. Subterranean clover takes up much more cadmium than oats; generally the roots of wheat, oats and peas contain more cadmium than the grain; but in tobacco most of the cadmium is found in the leaves. Some vegetables are of special concern because cadmium accumulates in the edible portion of the plant; for example in the leaves of silver beet and lettuce, in the roots of carrots, and the tubers of potatoes. Potatoes are particularly prone to cadmium uptake because they are frequently grown on acid, sandy soils.

The following practices help to minimise accumulation of cadmium in soil, and uptake of cadmium by plants:

- Use only mined gypsum for high risk crops, such as potatoes, and for all crops grown on acid soils. This is particularly important if high rates (5 t/ha or more) of gypsum are used.
- Test soil pH ($CaCl_2$)* regularly. If it is less than 4.8 use lime instead of gypsum. If it is between 4.8 and 6 use a gypsum/lime blend (see 'Gypsum/lime blends'). Aim to maintain pH ($CaCl_2$) in the range of 6 to 6.5.
- At least maintain, preferably increase, levels of soil organic matter.

Fluoride. By-product gypsums also contain a small proportion of fluoride compounds. Most of this is calcium fluoride, which is highly insoluble in water. The remainder of the fluoride compounds are water soluble, but in clay soils most of these are quickly rendered unavailable for plant uptake.

Nevertheless, it should be recognised that the application of a by-product gypsum to the soil may result in some uptake of fluoride by plants, and possibly some movement of fluoride to groundwater. This factor should be considered particularly for plants (such as grapevines) and grazing animals (such as dairy cattle) that are sensitive to fluoride, especially in areas where there are high inputs of fluoride from other sources. In such cases the use of mined gypsum, which generally contains less fluoride than by-product gypsums, may be preferable.

Gypsum/lime blends. Gypsum and lime (calcium carbonate) can be mixed to form gypsum/lime blends. Any ratio can be used but 75:25 and 50:50 are the most common. Hyrock Pty Ltd at Lidsdale, NSW supplies 75:25 and 50:50 gypsum/lime blend products for treating sodic soils.

For discussion on the use of gypsum/lime blends see 'Gypsum compared to lime'.

Fertilisers Act. The *Fertilisers Act, 1985* requires the registration and labelling of all gypseous materials sold in NSW. The label (for bagged gypsum) or invoice (for bulk gypsum) must show the purity as percentage S (wet weight basis), the fineness as percentage passing a 2 mm sieve, the percentage water content and the percentage chloride (Cl) (wet weight basis).

The regulations prohibit the sale of gypsum that has:

- less than 12% S (wet weight basis)**; or
- more than 20% failing to pass a 5.6 mm sieve; or
- a water content of more than 15%.

Also, a warning must be shown if the percentage Cl (wet weight basis) exceeds 1.2.

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* Most soil testing laboratories provide pH ($CaCl_2$) values. However, field pH testing kits usually measure pH (water). If you are using one of these kits, subtract 0.8 from pH (water) values to estimate pH ($CaCl_2$) values.

** Equivalent to approximately 65% $CaSO_4.2H_2O$ (wet weight basis).

Table 2. Ratings of gypsum quality.

Purity as percentage sulfur (S) (wet weight basis) and equivalent percentage $CaSO_4.2H_2O$

S (%)	Equivalent % $CaSO_4.2H_2O$	Purity rating	Remarks
Less than 12	Less than 65	Low	Cannot be registered for sale in NSW
12.0–14.0	65–75	Medium	Mostly mined gypsums
14.1–16.0	76–86	High	Mostly by-product gypsums; some mined gypsums
16.1–18.6	87–100	Very high	Some mined and by-product gypsums

Fineness as percentage passing a 2 mm sieve

Fineness(%)	Fineness rating	Remarks
0–50	Low	Some mined gypsums
51–80	Medium	Most mined gypsums
81–100	High	Most by-product gypsums

Water content (%)

Water content (%)	Water content rating	Remarks
0–5	Low	Most mined gypsums; some by-product gypsums
6–10	Medium	Some by-product gypsums
11–15	High	Some by-product gypsums
Greater than 15	Very high	Cannot be registered for sale in NSW

Chloride content as percentage Cl (wet weight basis)

Cl (%)	Chloride rating	Remarks
0–1.2	Low	Suitable for all agricultural purposes
Greater than 1.2	High	Suitable for reclamation of saline sodic soils but not for other agricultural purposes

Table 2 gives a guide to the interpretation of figures for purity, fineness, water content and chloride content.

Choice of gypsum

In deciding what type and brand of gypsum to buy, the main points to consider are:

- the total cost of supply and application of gypsum, expressed on the basis of pure $CaSO_4.2H_2O$
- how quickly the gypsum dissolves in water
- how easily and evenly it spreads.

Cost and purity. To obtain the total cost of supply and application of gypsum per tonne of pure $CaSO_4.2H_2O$, the following information is required:

A. the cost at the farm gate of gypsum per tonne or cubic metre;

B. the cost of spreading or mixing in irrigation water per tonne or cubic metre of gypsum;

C. the purity, as percentage S (wet weight basis); and

D. if buying by volume, the density in tonnes/cubic metre of gypsum as supplied.

Then, the total cost of supply and application of gypsum per tonne of pure $CaSO_4.2H_2O$ is calculated as:

either $\$ \frac{(A + B) \times 18.6^*}{C}$, if buying by weight,

or $\$ \frac{(A + B) \times 18.6^*}{C \times D}$, if buying by volume.

Examples:

1. The cost of a by-product gypsum is quoted as $25.00 per tonne at the farm gate and $6.00 per tonne to spread. Its purity is 15.8% S (wet weight basis).

   The total cost of supply and application of gypsum per tonne of pure $CaSO_4.2H_2O$ =

   $\$ \frac{(25 + 6) \times 18.6}{15.8} = \$36.49.$

* Pure calcium sulfate dihydrate ($CaSO_4.2H_2O$) has 18.6% S.

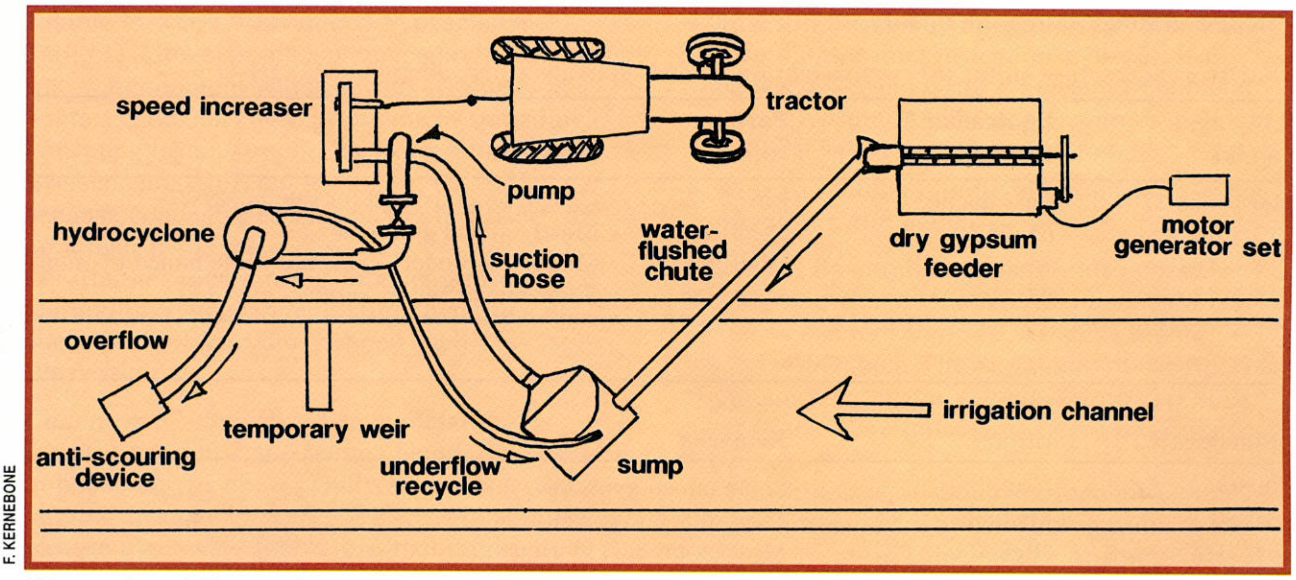

Illustration 7. The equipment used for dissolving gypsum in irrigation water.

2. A by-product gypsum costs $27.00 per tonne at the farm gate and $6.00 per tonne to spread. Its purity is 18.3% S (wet weight basis).

   The total cost of supply and application of gypsum per tonne of pure $CaSO_4.2H_2O$ =

   $$\$\ \frac{(27 + 6) \times 18.6}{18.3} = \$33.54.$$

3. A mined gypsum costs $22.00 per cubic metre at the farm gate and $7.00 per cubic metre to spread. Its purity is 12.9% S (wet weight basis) and its density is 1.2 tonnes per cubic metre of gypsum as supplied.

   The total cost of supply and application of gypsum per tonne of pure $CaSO_4.2H_2O$ =

   $$\$\ \frac{(22 + 7) \times 18.6}{12.9 \times 1.2} = \$34.84.$$

In this hypothetical comparison, gypsum no. 2 is the cheapest in terms of the cost of pure $CaSO_4.2H_2O$, despite being the dearest on the basis of gypsum as supplied, because its purity is the highest of the three.

Other factors. Purity and cost are not the only factors to consider in choosing which gypsum to buy. Other important factors are how quickly the gypsum dissolves in water, and how easily and evenly it spreads. Usually, the finer the particle size, the more quickly the gypsum dissolves in water. Fine grade gypsum, therefore, is the most suitable for application through irrigation water. It is also the best to use if an immediate effect is required, for example, improved seedling emergence in the current season.

However, sometimes a longer term effect is needed, for example, improved subsoil water storage over a long fallow. In this case a slower dissolving, coarser grade of gypsum, such as gypsum A in Illustration 6, may be acceptable and possibly more desirable, particularly if it is cheaper than alternative fine grade types. Also, slow dissolving gypsum may be preferable for salt sensitive plant species, especially if you are using a high application rate, or where rapid loss by excessive leaching below the root zone is likely. The presence of sodium chloride (common salt) in soil also makes gypsum dissolve more quickly.

Ease of spreading on the ground largely depends upon fineness and water content — fine grade gypsum of low water content is the easiest to spread. For even coverage, fine, evenly sized particles are the best, and spreader design is very important. However, a coarse grade is more suitable for aerial spreading because it is less likely to be blown off target.

APPLICATION OF GYPSUM

The three important factors in applying gypsum are method, rate and frequency of application. In considering these factors much depends on whether the agriculture is dryland or irrigated, whether the topsoil or subsoil (or both) is to be treated, and the nature and extent of the problem.

Methods of application

The most immediately effective way of applying gypsum to treat topsoils and subsoils is to dissolve it in irrigation water. As little as 0.85 t/ha* applied in the water at one irrigation can

* The rates stated in the section 'Application of gypsum' refer to tonnes of pure $CaSO_4.2H_2O$ per hectare. To calculate equivalent rates of commercial gypseous materials multiply by 18.6 and divide by the purity as percentage S (wet weight basis). For example, a rate of 2.0 tonnes pure $CaSO_4.2H_2O$ per hectare is equivalent to $\frac{2.0 \times 18.6}{14.3}$ = 2.6 t/ha of gypsum having a purity of 14.3% S (wet weight basis).

have the same effect at that irrigation, mainly via the electrolyte effect, as 2.5 t/ha (or more) broadcast. This is because much of the broadcast gypsum may be very slow to dissolve. Of course, gypsum broadcast at high rates will provide an electrolyte effect for longer than one water application at 0.85 t/ha. Broadcast gypsum at high rates also either reduces the sodicity of a given depth of soil by a greater amount, or reduces sodicity by about the same amount to a greater depth.

Because gypsum is only slightly soluble in water, special equipment is needed to ensure it is mixed effectively with irrigation water. NSW Agriculture's Agricultural Engineering group rebuilt and refined equipment originally developed by CSIRO for dissolving gypsum in irrigation water.

A diagram of this equipment is shown in Illustration 7. The dry gypsum feeder, powered by a portable motor generator, is mounted on a trailer. A screw feeder gives a constant rate of addition of gypsum, of approximately 300 kg/h, that can be varied if desired. Gypsum travels through a water flushed chute to a sump located in the irrigation channel. The centrifugal pump, powered by tractor power take-off through vee-belt pulleys, is also trailer-mounted. It draws water containing gypsum particles from the sump, partly dissolves the gypsum by vigorous agitation, and discharges gypseous water plus undissolved gypsum particles into a hydrocyclone. The latter consists of a heavy duty 200 L drum. Its purpose is to reject the undissolved gypsum particles, which are returned to the sump in a small stream of water via the underflow pipe. Gypseous water enters the channel via the overflow pipe from the hydrocyclone.

Some caution is required in applying gypsum to water used for surface irrigation. Because gypsum is very effective in increasing water movement into and through sodic clay soils it causes increased seepage losses from channels constructed from such soils. Therefore, gypsum should be introduced as close to the bay as practicable, possibly even directly into the top of the bay, or channels should be lined to reduce seepage losses.

A more common way of applying gypsum, suitable for both dryland and irrigated areas, is to broadcast it as a solid using a gypsum spreader (see Illustration 8). To treat topsoils, the gypsum should be lightly incorporated by shallow cultivation (perhaps in conjunction with another operation such as weed control) immediately after application to reduce loss by wind or water. Rain and/or irrigation water will then start to dissolve the gypsum and carry it through the root zone; some will return to the surface as water evaporates. Gypsum is best applied well before sowing to maximise subsoil water storage, particularly under dryland conditions.

However, for the treatment of subsoils, broadcasting is less satisfactory because the gypsum may not reach the zone requiring treatment. Deep tillage helps to incorporate gypsum into the subsoil (see Illustration 9), but should not be done unless the subsoil is dry, otherwise considerable structural damage will result. The subsoil can be dried by growing a deep rooting crop such as safflower.

Concentrated gypsum suspensions can be injected into or deeply mixed with subsoils, but the machinery is expensive. Deep placement via shrinkage cracks appears to be the most economic approach.

Illustration 8. Gypsum application using a gypsum spreader.

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Illustration 9. Incorporation of gypsum by chisel ploughing.

To improve seedling emergence under row cropping, gypsum can be applied to the surface as a band, considerably increasing effectiveness and reducing the quantity required. However, be wary of using high rates and of applying it shortly before planting, particularly for salt sensitive plants.

Aerial spreading is another method of gypsum application. It is used mainly for fertilising pastures.

Rates of application

Broadcasting fine grade gypsum at a rate as low as 2.5 t/ha usually prevents clay dispersion in the short term in marginally sodic to sodic clay soils*, assuming a water application rate of up to 10 mm/h (equivalent to moderately intense rain). Higher application rates are needed to prevent clay dispersion under the following circumstances:

- coarse grade gypsum is being used; or
- a longer term effect is required; or
- the soil is highly sodic*; or
- the water application rate is greater than 10 mm/h (increasing the water application rate decreases the time available for dissolving gypsum).

Broadcast rates of 2.5–5 t/ha usually give successful results although higher rates can be economic, particularly for high value crops or where cheap gypsum is available from a local source.

If gypsum is applied in the irrigation water, a practical rate is 850 kg/ML. At this rate an irrigation of 100 mm of water applies 0.85 t/ha. A gypsum concentration of 850 kg/ML is approximately equivalent to that obtained from broadcasting fine grade gypsum at 2.5 t/ha, and applying water at a rate of 10 mm/h. Therefore, it should be sufficient to prevent clay dispersion in marginally sodic to sodic soils. For highly sodic soils a gypsum concentration higher than 850 kg/ML is needed to prevent clay dispersion.

Although it is possible to calculate the theoretical amount of gypsum required to reduce the sodicity (as measured by the ESP) of a given depth of soil from its present value to about zero, this is usually of little practical value. The calculated rate is frequently very high (exceeding 10 t/ha) and therefore unlikely to be economically viable. Also, this approach ignores the value of the electrolyte effect in reducing swelling and preventing clay dispersion.

Frequency of application

A question often asked is: if I apply gypsum to my soil at, say, 2.5 t/ha, how long will it last? There is no simple answer to this question because several factors are involved. The main ones are:

- seasonal conditions (particularly rainfall)
- chemical composition of the irrigation water
- quality of gypsum used
- method of application
- severity of the problem
- whether topsoil or subsoil, or both are being treated.

In particular, much depends on whether the main aim is to improve structure by means of the electrolyte effect, as is frequently the case if the soil is marginally sodic to sodic, or whether it is to achieve a substantial reduction in sodicity, in the case of highly sodic soils.

In the former instance, low application rates of 2.5 to 5 t/ha every few years may be the best strategy. The latter situation is likely to require a

* Marginally sodic to sodic soils are defined as having ESP levels of 5 to 10; highly sodic soils have ESP levels greater than 10.

high initial rate of more than 5 t/ha (the actual rate depending mainly on the degree of sodicity of the soil and the irrigation water, and the depth of soil to be treated), followed by further applications at lower rates every few years. Soil testing and trial strips can help to determine whether or not gypsum is required initially, and whether or not a response to a further application is likely (see 'Testing soils for gypsum response').

If gypsum is applied in the irrigation water, it is advisable to add it at each irrigation in the first year. This will give a total application rate for the year of approximately 2.5–3.5 t/ha for 3–4 irrigations, assuming a rate of 850 kg/ML and a water application of 100 mm at each irrigation.

The strategy in subsequent years will depend largely on the soil sodicity and the chemical composition of the irrigation water. Continued application for several years at every irrigation, or perhaps every alternate irrigation, may be required for highly sodic soil or irrigation water of high sodicity and low salinity. Alternatively, application at the first irrigation of the season only may be sufficient to maintain desirable soil structure.

PLANT YIELD RESPONSE

Since the early work of CSIRO and NSW Agriculture on the application of gypsum in irrigation water to pastures in the Riverina, much research has been done throughout Australia on the effect of gypsum on plant yields. There are many reports of gypsum increasing yields of crops and pastures.

The increases in yield following gypsum application to sodic soils most commonly result from improved seedling emergence and/or increased root growth. These improvements are due to reduced soil strength under dry conditions, and reduced waterlogging when the soil is wet.

In some cases, particularly where gypsum has improved seedling emergence, spectacular improvements in yield have been observed. Illustration 10 shows the excellent response of a wheat crop to gypsum application to a sodic clay soil. The response was mainly due to increased seedling emergence.

However, results are sometimes variable. For example, in NSW there are large areas of topsoils that have a low clay content (less than 30%, and frequently less than 20%) but a high proportion of fine sand or silt. Such soils often slake strongly on wetting, then set hard and/or crust on drying, causing severe infiltration, aeration and seedling emergence problems.

These soils rarely respond strongly to gypsum because there is very little swelling and clay dispersion, and because slaking is largely unaffected by gypsum. Other techniques are

Illustration 10. Effect of gypsum on wheat growth on a sodic grey clay.

D. McKENZIE

D. HALL

Illustration 11. Mouldboard ploughing a red-brown earth that has a hardsetting fine sandy topsoil above a sodic clay subsoil. Gypsum was later applied to treat the subsoil brought to the surface.

likely to be more successful in managing these soils. They include:

- build-up of organic matter content of topsoil
- protection of surface soil with vegetative cover
- reduced tillage
- inclusion of a perennial pasture phase in crop rotations
- reduced size and travel of droplets under sprinkler irrigation.

Another possible approach for these soils is to mix topsoil and subsoil by mouldboard ploughing, but subsequent gypsum application will be required if the subsoil is a sodic clay (see Illustration 11).

Dr J. Loveday, formerly of the CSIRO Division of Soils, Canberra, regards interaction with seasonal conditions as another reason for variable yield responses to gypsum. He quotes two examples:

- For dryland wheat cropping in a season with inadequate rainfall in the latter part, the greater plant density resulting from gypsum application could lead to premature haying off and possible yield reduction.
- For irrigated summer crops, greater yield increases may occur in drier seasons when increased infiltration and water storage become important.

Another factor affecting the response in plant yield to gypsum is the interaction between water and nutrient movement through soils. The most common example of this is the greater leaching of nitrogen from the root zone in gypsum treated areas, leading to nitrogen deficiency in plants (see Illustration 12). This effect is especially prevalent in areas that were cut during landforming, resulting in low levels of nitrogen (and other nutrients) in the root zone.

There are other soil factors that can affect the response of plants to gypsum. For example, the presence of a hardpan or compacted layer may prevent the infiltration of water containing dissolved gypsum and the leaching of sodium cations. Also, low levels of soil nutrients such as phosphorus and zinc can reduce gypsum response.

Therefore, increased yields are not necessarily obtained from gypsum application (or any other strategy) if one or more other factors are limiting. Furthermore, gypsum application is not a substitute for good soil, water and plant management. In particular, it does not lessen the continual need to maintain adequate levels of organic matter in soil.

GYPSUM COMPARED TO LIME

Lime is another calcium compound — calcium carbonate ($CaCO_3$). Whether you should use

Illustration 12. Wheat yellowing (in the region of the soil auger) was caused by nitrogen deficiency resulting from a heavy gypsum application. Healthier plants in the foreground are growing on untreated soil.

D. McKENZIE

gypsum, lime or a mixture of lime and gypsum for improving the structure of sodic clay soils depends largely on the pH of the soil.

Gypsum can be used to treat soils of any pH because it only has to dissolve in water to produce benefits. Gypsum itself has little effect on soil pH (generally a decrease of 0.1 or 0.2).

However, if the pH ($CaCl_2$) of the soil is less than 4.8 it is better to use lime because the soil benefits in two ways. The lime not only improves structure, it also increases pH, helping to overcome the nutritional problems associated with strongly acid soils.

For soils of pH ($CaCl_2$) in the range of 4.8 to around 6, a mixture of gypsum and lime—such as a 75:25 or 50:50 gypsum/lime blend—may be the best option (see 'Gypsum/lime blends'). The gypsum provides almost immediate benefits to soil structure. The lime provides a slow release source of electrolyte and calcium for long term benefits to soil structure, in addition to improved soil nutrition as a result of increasing the pH. Use a 75:25 gypsum/lime blend for soils of pH ($CaCl_2$) in the high part of the range 4.8 to 6, a 50:50 blend for soils of pH ($CaCl_2$) in the low part.

Lime is not recommended for soils with pH ($CaCl_2$) above about 6 because lime is only very slowly soluble in such soils and deficiency of some trace elements such as zinc may be induced at pH ($CaCl_2$) levels above about 6.5.

Fineness and neutralising value are two important factors that determine how quickly and how well lime reacts with acid soils. A fine grade known as 'agricultural lime' is recommended.

For further information on the use of lime on strongly acid soils, see Agfact AC.19 ***Soil acidity and liming***. Agfact AC.15 ***Liming materials*** provides information on a range of different types of liming materials.

USING GYPSUM ON RICE-GROWING SOILS

Some soils used for rice growing disperse when flooded before aerial sowing. This results in muddy water that prevents sunlight and heat reaching the interface between soil and water, where the germinating seed is situated. Seedling development is retarded and under cool conditions the seedling fails to emerge.

Gypsum can be used to clear muddy water (see Illustration 13), but it should only be used on soils that have a highly sodic clay subsoil, to minimise addition of water to the watertable. Gypsum should be broadcast at 2 t/ha as the last operation before filling up for sowing. Do not incorporate it into the soil. A higher rate of 2.5 t/ha may be needed for extreme situations, e.g. lower bays.

To maximise the effectiveness of gypsum in clearing muddy water, you need to maintain a

Illustration 13. A muddy water experiment conducted in rice bays at Deniliquin, NSW. In the dark coloured bays gypsum was applied, and the water cleared. In the white coloured bays no gypsum was applied, and the water remained muddy.

high concentration in the water. Practices such as leaving the gypsum on the surface, filling up quickly (4–5 days maximum), and keeping the water depth shallow (5–10 cm) will help to achieve this. Further advice may be found in the Agnote ***Muddy water update 1995*** by P. Beale and J. Fowler, NSW Agriculture, Deniliquin.

Gypsum should ***not*** be applied at rates of more than 2.5 t/ha on soils used for rice growing. Heavy applications increase subsoil permeability, thereby increasing water use and addition of water to the watertable. For the same reason, application of gypsum should be avoided (or, at the most, limited to a light application to assist seedling emergence) for other crops or pastures following rice, if another rice crop is to be grown subsequently.

FURTHER INFORMATION

Further information may be obtained by contacting your local NSW Agriculture soils advisory officer, district agronomist or district horticulturist.

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