Incitec Pivot Fertilisers

AGRITOPIC

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SULFUR

1. INTRODUCTION

Sulfur (S) is one of the macronutrients, typically being taken up by plants in slightly smaller amounts than phosphorus. It is a constituent of protein, and consequently plays an important in role in both plant and animal nutrition.

The incidence of sulfur deficiency in plants has increased with greater use being made of high analysis fertilisers with a low sulfur content, e.g. urea in place of sulfate of ammonia, and the ammonium phosphates (DAP and MAP) in place of single superphosphate; and the adoption of reduced tillage practices (resulting in less sulfur being mineralized in the soil).

Sulfur is usually applied in pasture fertiliser programs but may not be required where the soil is cultivated for cropping, especially where the soil organic matter level is high.

2. SULFUR IN THE SOIL

2.1 Forms

70 - 90% of the soil sulfur is present in organic matter. This sulfur is not available for plant uptake until it has been converted to sulfate (SO_4^{2-}) by soil bacteria, a process known as mineralisation.

Compared to phosphate and ammonium ions, sulfate is not as strongly adsorbed onto clay and organic colloids. Much of the sulfate-sulfur present in the surface layers of the soil is in the soil solution. Consequently, leaching losses can be appreciable on light textured soils in areas of high rainfall. In drier areas and in soils of a heavier texture, leaching is less significant. In these situations, crystalline calcium sulfate (gypsum) may accumulate in the sub-soil. Where this occurs, sulfur is seldom limiting as a plant nutrient, provided it is accessible by plant roots.

2.2 Soil Processes

2.2.1 Mineralisation

Mineralisation is the microbial decomposition of organic matter, with sulfate-sulfur being formed in the process. The mineralisation of soil organic matter releases between 1 and 10% of the organic sulfur present in the soil each year.

Mineralisation proceeds most rapidly when the soil is moist, warm and aerated. As a result, soil sulfate levels can be expected to be at their highest when the soil is cultivated and fallowed. Soil sulfate levels will be lower where the soil is not cultivated, e.g. in established pasture or perennial crops, during the winter months, and where plants are growing and taking up sulfate from the soil as it is mineralised.

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Depending on the composition of the organic matter, about one part sulfur (S) is released for every ten parts of nitrogen (N). As most crops require one part S for every fifteen parts N for maximum yields and quality, an adequate supply of sulfur will be available to those crops that rely solely on the decomposition of soil organic matter for their nitrogen supply. Where additional nitrogen is supplied, either as fertiliser or through nitrogen fixation by legumes, sulfur may become limiting due to increasing demand caused by extra growth.

2.2.2 Oxidation

Oxidation refers to the conversion of elemental sulfur (S) to sulfate (SO_4^{2-}) by *Thiobacillus* bacteria in the soil. Being a microbial process, it occurs more quickly under warm and moist conditions. The particle size of the sulfur fertiliser is also important, as the rate of oxidation depends on the surface area available for bacterial attack. The smaller the particle size, the quicker the oxidation process can occur.

If soil air (oxygen) is excluded from the soil, i.e. under waterlogged conditions, sulfate (SO_4^{2-}) is reduced, firstly to sulfite (SO_3^{2-}) and then sulfide (S^{2-}). In these forms, sulfur is no longer available for plant root uptake.

2.3 Effect on Soil pH

Elemental sulfur and certain compounds containing sulfur, when applied in large quantities, can be used to lower the pH of alkaline soils to a more acceptable level. The oxidation of elemental sulfur to sulfate can be likened to the addition of sulfuric acid to the soil. Two positively charged protons or hydrogen (H^+) ions are formed for each divalent negatively charged sulfate (SO_4^{2-}) ion.

On light textured and acid soils, the use of ammonium sulfate as a nitrogen fertiliser may gradually make the soil more acid. Ammonium sulfate is more acidifying (per kg of applied nitrogen) than straight nitrogen fertilisers such as urea. Lime may be required to maintain the soil pH at a satisfactory level.

Potassium sulfate and calcium sulfate (gypsum) have little or no effect on soil pH. These products are the salts of a strong acid (sulfuric) and strong bases (potassium and calcium). Hydrogen ions are not formed when they dissolve in the soil solution.

3. SULFUR IN THE PLANT

3.1 Uptake and Functions of Sulfur in the Plant

Sulfur is absorbed by plant roots almost exclusively as the sulfate ion (SO_4^{2-}). Sulfur is a constituent of protein and is necessary for the development of chloroplasts and in photosynthesis.

3.2 Sulfur Deficiency

3.2.1 Occurrence of Sulfur Deficiency

Responses to sulfur are most likely to occur:

- on soils low in organic matter,
- where gypsum (calcium sulfate) or sorbed sulfate is not present in the subsoil,
- on lighter textured (sandy) soils,
- on older cultivations with low organic matter status,
- under reduced tillage conditions, i.e. where organic matter is being accumulated in the soil without aeration,
- where sulfur is not used, or has only been applied at low rates in fertiliser programs,
- where other nutrients, e.g. nitrogen, are applied at high rates.

In Australia, deficiency most commonly occurs in legume-based pastures, and in canola, which has a high requirement for sulfur.

3.2.2 Symptoms of Sulfur Deficiency

Symptoms of sulfur deficiency will not usually become apparent until after there has been a significant reduction in yield and quality, e.g. protein. Because nitrogen and sulfur are important in the formation of chlorophyll (the green pigment in plant leaves) and the synthesis of protein, deficiency symptoms of both are similar, i.e. poor growth, reduced tillering in cereals, and pale green to yellow foliage. Nitrogen, however, is more readily relocated from old to young leaves within the plant, so that in nitrogen deficiency, symptoms first appear in the old leaves, whereas in sulfur deficiency it is usually evident in the young leaves. Sulfur deficient plants are often rigid and brittle, and the stems remain thin.

As is the case with nitrogen deficiency in grain crops, a shortage of sulfur will at first be reflected by a decline in protein, before yield is affected. In legumes, the nitrogen-fixing root nodules are often reduced in both size and number in sulfur deficient plants.

4. SULFUR RESPONSIVE SITUATIONS

Sulfur fertiliser is most likely to be required in the following circumstances.

i) Permanent grass - legume pastures.

Legumes, when effectively nodulated, are dependent on mineralisation of soil organic matter for sulfur in most soils, but not for nitrogen. If sulfur deficiency occurs, the legumes will gradually die out and the pasture will revert to a grass sward. Yield and quality will then be limited by the amount of nitrogen and sulfur mineralized from soil organic matter.

ii) Shallow-rooted annual pasture species

Sulfur deficiency is less likely to occur with perennial legumes such as lucerne than with annual pasture legumes. Perennial legumes, with their deep root systems, are able to make more effective use of leached sulfate in the subsoil.

iii) Zero, minimum or reduced tillage

Where the soil is cultivated, mineralisation of soil organic matter proceeds at a faster rate than in uncultivated soils. Sulfur deficiency therefore occurs more commonly where the soil is not cultivated at all or where cultivation is infrequent.

iv) High crop or pasture yields.

Where high yields are obtained or yields are increased, sulfur may not initially be required, but as soil sulfur reserves are depleted, a need to apply sulfur in fertiliser programs may emerge, e.g in high rainfall or irrigated areas (provided associated sulfur inputs are low), where double cropping is practiced, or where high rates of other nutrients (particularly nitrogen) are applied.

v) Canola

Of the annual grain and oilseed crops, canola has the highest sulfur requirement. In general, grain legumes are more likely to respond to sulfur than cereals.

5. CRITICAL LEVELS OF SULFUR

5.1 Soil Analysis

The organic carbon content in the topsoil is a good estimate of the soil's total sulfur reserves, except where gypsum ($CaSO_4$) nodules occur at depth. Organic carbon, however, is not a good indication of the available sulfur in the soil.

Two methods are commonly used in Australia to estimate the amount of plant-available sulfur in the soil:

- The MCP method, using 0.01 M $Ca(H_2PO_4)_2$ [calcium orthophosphate] as the extractant, which measures water-soluble and exchangeable sulfate-sulfur.
- A method developed by the University of New England (Armidale, NSW), which uses 1 M KCl (potassium chloride) as the extractant. This test measures sulfate sulfur plus some of the more readily mineralized organic sulfur.

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5.2 Plant Tissue Analysis

Plant tissue analysis generally allows for a more accurate assessment of the sulfur status of a crop or pasture than soil analysis. Analyses can also be performed on the harvested produce, e.g. grain. The percent sulfur (%S) and nitrogen:sulfur (N:S) ratio are both used for diagnostic purposes.

6. SULFUR FERTILISERS

Sulfur can be applied in the elemental form, or as sulfate.

6.1 Elemental Sulfur

Elemental sulfur is only of use to plants once it has been oxidized to sulfate in the soil. This is a biological process that is dependent on warmth and moisture. It is slowed or blocked under cold and dry soil conditions.

A fine particle size is essential. This maximises the surface area exposed to soil bacteria. Australian State fertiliser legislation requires that the particle size, according to the following size fractions, be declared on the product label:

- Fine Grade - less than 0·25 mm.
- Medium Grade - 0·25 to 0·50 mm;
- Coarse Grade - more than 0·50 mm.

If the fertiliser is to be applied by ground application equipment, i.e. truck or tractor, at least 50% of the sulfur particles must be capable of passing through a 0·25 mm sieve. Finely ground sulfur is classified as a Dangerous Good (Class 4.1 Flammable Solid). Its dust may form explosive mixtures in air.

Elemental sulfur is often coated onto or added into other fertilisers as a fine powder or in the molten form during the manufacturing process. This allows the end product to be declassified as being a Dangerous Good, and for elemental sulfur to be applied simultaneously with other nutrients.

Fertilisers in which elemental sulfur has been infused into the fertiliser granules in the molten state tend to give the best results. The fertiliser granules dissolve in the soil leaving very fine particles of elemental sulfur behind.

An example of such a product was SF45 (sulfur fortified superphosphate), which was manufactured by Incitec Pivot at Newcastle until the early 2000s. This facility has now closed, and SF45 is no longer being made. SF45 was used in legume-based pastures on soils high in phosphorus, the superphosphate basically being a carrier for the elemental sulfur.

Degradable sulfur granules, e.g. Sulfur Bentonite, are being used in place of SF45.

Sulfur Bentonite products typically contain 90% elemental sulfur and 10% dispersible clay (bentonite). Following application, the granules (clay) absorb moisture and disperse, releasing fine sulfur particles.

Dispersible sulfur fertilisers tend to be less effective than products such as SF45, and give variable results, depending on how readily the granules disperse, and the size of the sulfur particles they release.

The application of the sulfur in a concentrated granule (90% S) also reduces its exposure in the soil, and the opportunity for biological oxidation to sulfate.

6.2 Sulfate

Sulfur is applied in the sulfate form as a companion ion to other nutrients, e.g. ammonium sulfate (Sulfate of Ammonia), potassium sulfate (Sulfate of Potash), calcium sulfate (gypsum).

Incitec Pivot manufactures a granulated ammonium sulfate fertiliser, known as Gran-am, in Brisbane. Gypsum is mined from naturally occurring deposits at various locations in Australia. It is used both as a sulfur fertiliser, and at higher rates as a soil ameliorant.

Gypsum's analysis varies with its purity. State fertiliser legislation in Australia specifies that gypsum be graded as follows:

- Grade 1 > 15% S
- Grade 2 >12.5% S
- Grade 3 > 10% S

Gypsum (calcium sulfate) is also a constituent of Single Superphosphate, which is comprised of approximately one-third monocalcium phosphate and two-thirds gypsum. Incitec Pivot manufactures single superphosphate at Geelong and Portland in Victoria. It is marketed as SuPerfect.

Sulfate sulfur is immediately available to plants. This is the form in which sulfur is taken up by plant roots.

6.3 Product Analyses

The analyses of Incitec Pivot fertiliser products that contain sulfur are given in the following table. These products are also used as ingredients in blended fertilisers, the sulfur content of which will reflect the constituents used in their formulation.

Incitec Pivot Product	Analysis				
	% N	% P	% K	% S	%Ca
Gran-am	20.2			24	
SuPerfect		8.8		11	19
Sulfate of Potash			41	18	
Sulfur Bentonite				90	

6. PRODUCT CHOICE AND USE (SOIL APPLICATION)

As sulfur is not normally applied on its own, the time and way in which it is applied is usually dictated by what is best for the other nutrients applied in combination with it, e.g. nitrogen and phosphorus. The decision on which fertiliser to use as a source of sulfur usually comes down to Gran-am and SuPerfect. Gran-am is generally used where nitrogen is required, e.g. non-leguminous crops such as cereals, vegetables, sugarcane and tree crops. SuPerfect is usually the preferred product on legume-based pastures.

6.1 Gran-am

Gran-am (granulated ammonium sulfate) is manufactured in Brisbane by reacting sulfuric acid with ammonia and granulating the finished fertiliser. The resultant product stores and handles better than crystalline by-product Sulfate of Ammonia and can be used in blends with other granular fertilisers.

Gran-am contains 20.2% N and 24% S. When used as a nitrogen fertiliser, it supplies sulfur well in excess of plant requirements. Plants take up ten or more times as much nitrogen as sulfur. Hence, Gran-am is normally used in combination with other fertilisers, e.g. in blends, so as to provide the required rate of sulfur, and no more.

In annual crops, the most common time at which sulfur is applied is at planting, although it can be applied before and/or after planting (provided irrigation or rain carries the fertiliser into the soil if top-dressed). In sugarcane, tree crops, plantation crops and vines, sulfur is usually applied in combination with other nutrients, e.g. in NPK fertilisers.

As a guide to application rates, where soil sulfur is low, and non-leguminous crops or nitrogen fertilised grass pastures are to be grown, sulfur will need to be applied at about one tenth of the nitrogen rate. This Rule of Thumb does not apply to legumes, which fix their own nitrogen.

Where used in rain grown cereal crops, sulfur rates are typically in the range of 5 - 15 kg/ha S. Higher rates may be required under irrigation. In legume grain crops, sulfur rates (if required) are usually a little higher, e.g. 10 - 20 kg/ha S. Legume crops are rich in protein, and therefore have a higher sulfur requirement than cereals.

Higher still in its requirement for sulfur is canola. Responses to sulfur are obtained in canola on soils in which responses do not occur in other crops. In total, around 20 - 30 kg/ha S needs to be applied in fertiliser programs in each canola crop.

If it is necessary to apply sulfur in sugarcane, a suggested application rate is 25 kg/ha S per year or crop. In vegetable and tree crops, 15 - 30 kg/ha S should suffice in most situations where sulfur is required.

The use of Gran-am as the primary nitrogen source in NPK fertilisers for horticulture often means that sulfur is applied at rates well in excess of crop requirements. However, unlike some other nutrients, this is not detrimental and is of no concern.

Note: Gran-am may also be applied in solution, e.g. in fertigation programs. It does, however, contain granulation and coating agents that may settle to the bottom of mixing tanks, or form a scum on the water surface in the mixing tanks, which may block filters and nozzles. This is most likely to be of concern in drip and trickle irrigation systems, and in foliar sprays, and of less concern where large irrigation nozzles are used, e.g. travelling irrigators.

If using in solution for the first time, trial in small amounts before ordering in larger quantities.

Gran-am should not be used as a spray adjuvant for agricultural chemical sprays. The granulation agents used in its manufacture may react adversely with active ingredients such as Glyphosate.

6.2 SuPerfect

SuPerfect is manufactured at Geelong and Portland in Victoria by treating imported phosphate rock with sulfuric acid. This increases the solubility of the phosphorus and its availability for plant root uptake. The resultant product contains 8.8% phosphorus (P) and 11% sulfur (S).

As plants take up phosphorus and sulfur in approximately equal amounts, this makes SuPerfect an ideal fertiliser for top-dressing perennial pastures. Its use as a phosphorus fertiliser on soils that are low in phosphorus simultaneously supplies sulfur in adequate amounts.

A typical sulfur rate in rain-grown legume-based pasture is 10 - 25 kg/ha S per annum. Higher rates, e.g. 50 kg/ha S per annum, are required in highly productive intensively managed pastures in high rainfall areas, and under irrigation. Irrigated dairy pastures and irrigated stands of lucerne may receive up to 80 kg/ha S per annum.

In clover-based pastures, sulfur is usually applied as superphosphate in the autumn, at the start of the main growing season. If leaching is likely to occur during winter, it may be better to apply it, or at least some of it, in the spring.

In highly productive irrigated pasture, e.g. nitrogen fertilised ryegrass, it may be necessary to apply sulfur on more than one occasion during the growing season. SuPerfect, for example, may be used at planting, and Gran-am included in the top-dressing program.

Note: The further SuPerfect is transported from the sites of its manufacture in Victoria, the more costly it becomes. SuPerfect is a competitively priced source of phosphorus and sulfur in the southern States but becomes less so in Queensland. This has led to the use of Gran-am in leguminous crops and pastures, where the nitrogen is not necessarily of benefit.

Examples include:

MAP + Gran-am Blends for use at planting in legume grain crops, supplying the required amounts of phosphorus and sulfur. The starter nitrogen may even be of assistance, particularly where soil nitrogen is low, in meeting the crops nitrogen requirements during the first few weeks of growth, before the crop is properly nodulated and the *Rhizobium* bacteria are fully active.

The use of Gran-am on its own as a sulfur fertiliser in irrigated lucerne stands on soils with a high phosphorus status, e.g. in the Lockyer Valley. Gran-am is best applied in the winter when the *Rhizobium* is least active (slowed by the cold weather). This is the time of year that winter-active lucerne varieties are most likely to respond to fertiliser nitrogen.

6.3 Sulfate of Potash

Sulfate of Potash (potassium sulfate) contains 41% K and 18% S. It is an expensive way to apply sulfur, compared to Gran-am and SuPerfect. As a source of potassium, Sulfate of Potash is much more costly than Muriate of Potash (potassium chloride). This means that the latter should be chosen, unless there are reasons to avoid using Muriate of Potash on account of its chloride content. Sulfate of Potash is preferred to Muriate of Potash on saline soils, where poor quality irrigation water is used, and in crops that are sensitive to root burn.

Muriate of Potash is more soluble than Sulfate of Potash, and has a higher Salt Index (114, versus 46 for Sulfate of Potash). Consequently, Muriate of Potash is more likely to burn the roots of shallow rooted tree crops, such as avocado and macadamia, and the roots of sensitive annual crops such as French Beans, if used in planting fertilisers.

6.4 Sulfur Bentonite

Sulfur Bentonite is primarily intended as a replacement for SF 45 (sulfur fortified superphosphate), for use in legume-based pasture on basaltic soils that are high in phosphorus. Where phosphorus, or nitrogen is required, as well as sulfur, it is recommended that SuPerfect or Gran-am be used.

Sulfur Bentonite is not recommended for use in planting fertilisers, or for application during the growing season in annual crops. To be of use at planting, the sulfur must be applied in the sulfate form, or if applied as elemental sulfur, be rapidly converted to the sulfate form. This may happen with products in which molten sulfur has been infused at low concentrations into the product during the manufacturing process but will not occur with Sulfur Bentonite.

Firstly, the sulfur particles in Sulfur Bentonite, once released, are larger in size, so there is effectively less surface area for the *Thiobacillus* bacteria to attack, when converting elemental sulfur to sulfate.

Secondly, banding Sulfur Bentonite Granules into the soil at planting with or near the seed restricts their dispersion. The sulfur particles will be confined to a small volume of soil, greatly reducing *Thiobacillus* activity, compared to where sulfur particles are distributed more evenly though the topsoil. This is compounded by Sulfur Bentonite's concentration, 90% S, meaning there will be relatively few sites in the soil at which the *Thiobacillus* bacteria can operate.

To achieve a more even distribution of sulfur particles through the soil, and speed up its conversion to sulfate, Sulfur Bentonite would need to be broadcast onto the soil surface before planting and the granules allowed to disperse, before being incorporated into the soil. The conversion of elemental sulfur to sulfate, being a microbial process, occurs most rapidly under warm moist conditions, and more slowly in the winter.

6.5 Gypsum

While more commonly used as a soil ameliorant, gypsum may also be used as a sulfur fertiliser. One situation where this is done is in legume-based pastures on high phosphorus soils in the elevated parts of the southern highlands in New South Wales, e.g. around Cooma. Elemental sulfur fertilisers are not effective in this environment. The winters are too cold and the summers too dry for oxidation by *Thiobacillus* bacteria to occur at a satisfactory rate.

6.6 Ammonium Thiosulfate (ATS) Solution

Ammonium thiosulfate (ATS) has the chemical formula of $(NH_4)_2S_2O_3$. On application to the soil, ammonium thiosulfate decomposes to form sulfate and elemental sulfur, in approximately equal amounts of each.

Plants take up sulfur as sulfate, so this part is immediately available for root uptake. The elemental sulfur has a fine particle size and becomes available once it is oxidised by soil bacteria to the sulfate form. This gives a slow-release effect over several weeks, depending on prevailing soil and weather conditions

Ammonium thiosulfate solutions have a typical analysis of 16 % w/v N and 34 % w/v S. This is a much higher sulfur concentration than can be achieved by dissolving other sulfur fertilisers in water, making ATS the product of choice to add sulfur where concentrated fertiliser solutions are being prepared. ATS can be applied or injected into the soil in a variety of ways, e.g. soil sprays, fertigation programs. ATS is toxic to foliage and crop roots. It should not be used in foliar sprays or hydroponic solutions or applied in direct contact with crop seeds or the roots of transplants.

7 FOLIAR SPRAYS

Foliar sprays are not commonly used with the sole intention of applying sulfur. It is normally applied in combination with other nutrients. Foliar sprays are used to supplement, rather than replace soil applications of sulfur. Solution grade ammonium sulfate products may be used as a source of sulfur. Gran-am is not recommended, as the granulation and coating agents it contains may block filters and nozzles.

8 AMMONIUM SULFATE COMPATIBILITY IN SOLUTION

Ammonium sulfate is compatible in solution with urea, ammonium nitrate, monoammonium phosphate, monopotassium phosphate and magnesium sulfate. If mixed with potassium chloride or potassium nitrate, less soluble potassium sulfate may form as a reaction product in concentrated solutions.

The solubility of these potassium salts in water at 20^{O} C is:

- Potassium chloride 34 kg/100 L
- Potassium nitrate 32 kg/100 L
- Potassium sulfate 11 kg/100 L

Ammonium sulfate should not be mixed with calcium nitrate or calcium chloride, as calcium sulfate (gypsum) will be precipitated.

9 USE OF SULFUR AS A SOIL AMENDMENT

In addition to being an essential plant nutrient, sulfur and some of its compounds may be used to lower the pH of alkaline soils, and to improve soil structure in sodic soils.

pH adjustment

Finely ground elemental sulfur can be used to reduce the pH of alkaline soils. Its oxidation to sulfate by *Thiobacillus* bacteria results in the formation of sulfuric acid in the soil. Being a biological process, this will take time to occur.

Application rates may range from 500 – 3 000 kg/ha S, the higher rates being used on clay soils, and where the pH is very high. Some other sulfur compounds may also be used to acidify the soil, e.g. aluminium sulfate (Hydrangea Blue) in potted plants.

Treatment of Sodic Soils

Sodic soils are characterised by the presence of sodium in excess amounts in the soil. As the exchangeable sodium percentage (ESP) of total cations increases above 5%, evidence of poor soil structure becomes noticeable. The soil disperses when wet, has low infiltration rates, crusts on drying, and is difficult to work. In contrast, soils with high calcium and low exchangeable sodium levels have a well-developed granular structure.

Gypsum (calcium sulfate) can be used to improve the structure of sodic soils. On dissolving, the calcium replaces the adsorbed sodium on the clay particles. The sodium combines with the sulfate to form soluble sodium sulfate that can be removed by leaching, either by rainfall or good quality irrigation water.

If the soil is calcareous, and contains free calcium carbonate (lime), elemental sulfur can be used instead of gypsum. As the sulfur is oxidised, the sulfuric acid it forms will react with and release insoluble calcium. Calcium sulfate will be formed in situ in the soil.

An important consideration in determining the application rate for gypsum is the depth of incorporation. A typical application rate where gypsum is used to improve the tilth of the entire plough layer, e.g. irrigated cotton, vegetables, sugarcane, is 7.5 – 10 t/ha. The gypsum should be applied well ahead of planting and be incorporated into the soil. Where gypsum is used to reduce crusting at the soil surface and is not incorporated deeply into the soil, e.g. in rain-grown grain crops, a typical application rate is 2.5 t/ha.

Sodic soils are often saline as well, i.e. soluble salts have accumulated in the soil as a result of poor internal drainage. Reclamation of saline sodic soils with gypsum or elemental sulfur will exacerbate salinity problems, by displacing adsorbed sodium from clay particles, if the sodium salts cannot be leached from the soil. Reclamation should only be attempted after seeking specialist advice. Where gypsum or elemental sulfur is applied as a soil ameliorant, there will be no need to apply additional sulfur in fertiliser programs.

10. SULFUR IN RAINFALL, IRRIGATION WATER AND CROP PROTECTION PROGRAMS

As well as that applied as soil ameliorants and in fertiliser programs, sulfur additions to the soil can occur from the atmosphere and in rainfall, in irrigation water, and in plant protection programs. The amount of sulfur received through rainfall is higher close to the sea and industrial areas. The use of low sulfur fuels and added emphasis on air pollution control is helping reduce the amount of atmospheric sulfur reaching agricultural land through rainfall in many parts of the world.

In Australia, annual sulfur inputs through rainfall in many coastal areas and near industrialized centres can exceed 10 kg/ha S; but in inland areas, e.g. the New England Tableland, are often no more than 1 - 2 kg/ha S per year.

The amount of sulfate-sulfur in irrigation water is quite variable. The sulfur content of most streams is lowest near the source and increases as the flow is supplemented by drainage water from cultivated and fertilised areas and may be concentrated by evaporation. In some areas, the amount of sulfate present in surface or underground water supplies may be sufficient to meet crop or pasture demands, overcoming the need to apply extra sulfur in fertiliser programs.

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11. SULFUR IN ANIMALS

Sulfur plays an in important role in determining both the quantity and quality of pasture on offer to grazing animals. It is a major constituent of protein. As with plants, sulfur is essential for protein synthesis in animals. In sheep, sulfur is important in the formation of wool.

The principal sources of protein (and sulfur) to animals are green feed and grain. As pasture matures and protein levels drop, sulfur intake diminishes. Non-ruminant animals are dependent on plant-synthesized amino acids for protein metabolism (synthetics are available for pigs and poultry), but ruminants (cattle and sheep) can have part or all of their amino acid requirements satisfied by bacterial synthesis from simple forms of nitrogen and sulfur in the rumen.

Low protein feed is low in nitrogen (N) and sulfur (S). Urea is the most commonly used non protein nitrogen supplement. Supplementary sources of sulfur for ruminants include sulfate of ammonia, sodium sulfate, and flowers of sulfur (finely ground elemental sulfur). A target N:S ratio of 10:1 is generally recommended in the diet and supplements for ruminants. This can be achieved by adding 1 kg of Gran-am to every 5 kg of urea in the supplement; or where elemental sulfur is used, 1 kg of elemental sulfur to every 20 kg of urea. Australian molasses is high in sulfur (ranging from 0.4 to 1.4% S, typically around 0.7% S). Where it is used as an energy source, additional sulfur is unlikely to be required.

FURTHER READING

Separate Agritopics are available on "Mineral Supplements for Ruminants", "Fertigation ", and "Foliar Fertilisers".

WARNING

The information contained in this publication is for use as a guide only. The use of fertilisers and soil amendments are not the only factors involved in producing a high yielding pasture or crop. Local soil, climatic and other conditions should also be taken into account, as these could affect pasture or crop responses to applied fertiliser.

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