Sulphur needs of crops and pastures

J S. Yeates
Sulphur deficiency has long been recognised as a potential problem of legume pastures in the higher rainfall areas (over 750 mm a year) of southwest Western Australia. Before the introduction of granulated superphosphate (about 1970), sulphur deficiencies commonly developed in spring on susceptible soils despite autumn applications of superphosphate (containing about 10.5 per cent sulphur).

In low and medium rainfall areas sulphur deficiency is rarely reported, at least partly because of annual superphosphate applications. However large areas of the sandy-surfaced soils of Western Australia would become sulphur deficient for pastures and crops if sulphur inputs in fertilisers were substantially reduced.

This could occur as a result of widespread use of 'high analysis' nitrogenous and phosphatic fertilisers containing little sulphur (Table 1) and reduced rates of superphosphate application on older land.

Research over a number of years into the behaviour of sulphur in soil and plants has led to a better understanding of the role of sulphur nutrition in Western Australian agriculture. This article discusses the research findings and sulphur fertiliser recommendations which have been developed from the work.

By J. S. Yeates, Research Officer, Division of Plant Research

Soil sulphur

The various components of the soil sulphur ‘cycle’ are shown in the diagram on page 68. The total sulphur content of soils varies widely. Only the sulphate form of sulphur, which is usually a small proportion of the total, can be used by plants. Except on some arid saline soils, and some soils high in sulphide minerals, most sulphur is held in plant and animal organic residues which are not readily ‘available’ to plants.
Sulphate reacts in a similar way to phosphate in soils, but is held much less tightly on clay minerals. It is therefore more likely to be leached from sandy soils.

However, unlike phosphorus, sulphate also occurs in rainfall from marine origin (or from pollutant sulphur dioxide—acid rain—in highly industrialised countries). Western Australia’s agricultural areas gain from 1 to 10 kg/ha/year of sulphur from rainfall depending on distance from the sea. This is low compared with rates of 100 kg/ha or more in some European countries.

Dr N. J. Barrow of CSIRO in Perth did much of the initial work on soil sulphur in Western Australia. His research during the 1960s demonstrated that relatively high amounts of rainfall sulphate are adsorbed (attached to reactive surfaces) by the acid to neutral clays and gravel soils in the south-west. Sufficient sulphate usually accumulates in these soils for plant growth without the need for additional sulphur from fertilisers. These heavy soils appear to reach an ‘equilibrium’ state in which sulphate accumulation is determined by its concentration in rainfall and the soil adsorption capacity. Any additional sulphate added as fertiliser, or mineralised (made available by microbial action) from organic matter, temporarily raises soil sulphate levels, but is subsequently lost through leaching or possibly conversion to organic sulphur by plants or microbial action.

Consequently, the sulphate levels in these soils are largely independent of fertiliser history. Sulphur deficiencies are unlikely to appear on the heavier soils under most agricultural practices as annual inputs from rainfall usually exceed the amounts of sulphur removed in farm products (Table 2), even if no sulphur is applied from fertilisers.

In contrast to the heavier soils, sandy soils absorb very little sulphate. Sulphate added to these soils, either in rainfall or in fertilisers, may be rapidly leached beyond the plant root zone, depending on rainfall. Deficiencies are likely to develop unless regular substantial sulphur fertiliser dressings are made.

**Table 2. Sulphur content of fertilisers commonly used in Western Australia.**

<table>
<thead>
<tr>
<th>Fertiliser</th>
<th>Sulphur %</th>
<th>Phosphorus %</th>
<th>Nitrogen %</th>
<th>Other %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superphosphate</td>
<td>10.5</td>
<td>9.1</td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>Double superphosphate</td>
<td>4.5</td>
<td>17.5</td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>Triple superphosphate</td>
<td>1.5</td>
<td>19.7</td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>New coastal superphosphate</td>
<td>30.0</td>
<td>9.0</td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>3:2 super-phos</td>
<td>6.3</td>
<td>5.3</td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>5:1 super-phos</td>
<td>8.7</td>
<td>7.4</td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>3:2 new coastal super-phos</td>
<td>17.0</td>
<td>5.0</td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>Rock phosphate</td>
<td>0</td>
<td>15.9</td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>Sulphate of potash</td>
<td>18.4</td>
<td>0</td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>Agras No. 1</td>
<td>16.0</td>
<td>7.6</td>
<td>17.5</td>
<td>—</td>
</tr>
<tr>
<td>Agras No. 2</td>
<td>13.0</td>
<td>10.4</td>
<td>12</td>
<td>—</td>
</tr>
<tr>
<td>Mono-ammonium phosphate</td>
<td>1</td>
<td>22.6</td>
<td>12</td>
<td>—</td>
</tr>
<tr>
<td>Diammonium phosphate</td>
<td>1</td>
<td>20</td>
<td>18</td>
<td>—</td>
</tr>
<tr>
<td>Sulphate of ammonia</td>
<td>24</td>
<td>0</td>
<td>21</td>
<td>—</td>
</tr>
<tr>
<td>Agran</td>
<td>0</td>
<td>0</td>
<td>34</td>
<td>—</td>
</tr>
<tr>
<td>Urea</td>
<td>0</td>
<td>0</td>
<td>46</td>
<td>—</td>
</tr>
<tr>
<td>Gypsum</td>
<td>16-18</td>
<td>0</td>
<td>0</td>
<td>Iron (18)</td>
</tr>
<tr>
<td>Ferrous sulphate (copperas)</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>—</td>
</tr>
</tbody>
</table>

**Table 2. Sulphur removal in farm products.**

<table>
<thead>
<tr>
<th>Product</th>
<th>Sulphur (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hay (6 tonnes)*</td>
<td>—</td>
</tr>
<tr>
<td>Cereal or grass hay</td>
<td>7</td>
</tr>
<tr>
<td>Legume hay</td>
<td>10</td>
</tr>
<tr>
<td>Grain (2 tonnes)—</td>
<td>—</td>
</tr>
<tr>
<td>Wheat</td>
<td>4</td>
</tr>
<tr>
<td>Barley</td>
<td>4</td>
</tr>
<tr>
<td>Oats</td>
<td>5</td>
</tr>
<tr>
<td>Field peas</td>
<td>5</td>
</tr>
<tr>
<td>Lupins</td>
<td>5</td>
</tr>
<tr>
<td>Linseed</td>
<td>5</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>14</td>
</tr>
<tr>
<td>Sunflower</td>
<td>6</td>
</tr>
<tr>
<td>Wool—5 kg (greasy)</td>
<td>0.2</td>
</tr>
<tr>
<td>Meat—50 kg liveweight</td>
<td>0.4</td>
</tr>
<tr>
<td>Milk—1000 litres</td>
<td>0.6</td>
</tr>
</tbody>
</table>

*Removal only if all hay fed off the paddock.

**Predicting sulphur deficiency**

**Soil testing**

There are a number of theoretical reasons for expecting sulphur soil tests not to work.

However, despite these potential problems, a relationship between soil sulphate (extracted with dilute phosphate solution) and response to applied sulphur has been established for legume pastures in the high rainfall areas of Western Australia. Because sulphate content increases with depth in some soils (Figure 1), the usual 0 to 10 cm sampling is a poorer predictor of sulphur responsiveness than sampling to 25 cm, which gives a better indication of sulphur readily available to plant roots.

Sulphur responsive sites were limited to those soils with extractable sulphate and sulphate adsorption capacity (using the AQS measurement, Barrow, 1967) of less than 10 parts per million, and most were less than 6 ppm. Some sites however did not respond to added sulphur even where soil levels were lower than 6 ppm.

Unlike many soil tests, sulphur adsorption capacity is a measurement of a soil property rather than a measurement of nutrient content (as in phosphorus and potassium tests, although phosphorus adsorption capacity is used in phosphorus fertiliser recommendations).

Sulphur adsorption capacity changes little over time, so that a once-only measurement is needed to determine if a soil is likely to respond to sulphur. If adsorption capacity is high enough,
sufficient sulphur accumulates from rainfall to replace losses from the soil, and sulphur fertilisers are not required with most agricultural practices. Sulphur-free fertilisers can be used for pastures and crops for long periods of time without sulphur deficiency occurring.

Many sulphur-responsive soils are easily recognised without adsorption measurements as they are predominantly sands and pale sandy clays. However, there are exceptions. The red-brown sandy loams of the Avon Valley, and possibly some alkaline clays are susceptible to sulphur deficiency. In drier areas, this deficiency may take a number of years to develop after sulphur fertiliser applications cease (because of low leaching intensity). On some soils deficiency may occur only in years of above average rainfall (when leaching losses of mineralised sulphate are unusually high).

The usefulness of soil testing to predict sulphur deficiency has not been verified in low rainfall areas, and a test has not been developed yet for crops. So far sulphur deficiency has only been observed on soils with sulphate levels similar to those of responsive soils in the high rainfall areas. For deep-rooted plants (for example cereals and lupins) it is likely that soil sampling would be necessary to a metre or more to include high sulphur sub-soils which roots explore during the growing season.

**Seasonal influences**

The frequency and severity of sulphur deficiency varies greatly with seasonal influences. Factors affecting the development of sulphur deficiency are:

- Total rainfall incidence and intensity.
- The ability of plant roots to intercept and absorb sulphate, and of shoots to store excess sulphate before soil levels are greatly reduced by leaching.
- The plant's ability to redistribute stored sulphate during periods of inadequate uptake from the soil.

During rapid plant growth and periods of low leaching, such as following an early 'break' to the season, sulphate uptake from the soil is high. In contrast, slow plant growth and rapid leaching (for example following a late 'break' to the season in high rainfall areas) results in poor sulphate uptake from the soil.

In annual pasture and cropping systems on susceptible soils, conditions following the 'break' of the season will greatly influence the severity of deficiency, and the efficiency of plant use of applied soluble fertilisers. High leaching losses may occur early in the growing season before annual seedlings have developed deep roots. In perennial pastures established plant root systems are important in recycling sulphate leached from the soil surface.

In lower rainfall areas however, little water may pass through the soil profile. Sulphur deficiency is rare because of low leaching and effective recycling of small, but sufficient quantities of sulphur.

On unfertilised soils, soil sulphate reaches maximum levels in early autumn because of the release of sulphate from organic sulphur, lack of leaching and low plant and microbial sulphate use. During winter, extractable sulphate levels fall and are lowest in spring (Figure 2).
The total sulphur content of soils varies widely but only the sulphate form of sulphur can be used by plants.

A simple sulphur cycle

**INPUTS**
- Atmosphere
- Fertilisers
- Weathering of rocks

**LOSSES**
- Leaching
- Plant uptake
- Animal and plant returns

Pastures

Because of the combined effects of soil sulphate accumulation in autumn and relatively slow plant growth rates, sulphur deficiencies are rare before July on legume pastures. They are most common during spring when soil sulphate levels are low and plant growth rates and therefore sulphur requirements are highest.

Grazing by livestock further complicates deficiency development because any sulphate accumulated in plant tops during periods of excess supply is removed. Although about 95 per cent of the sulphur is recycled in urine and dung, its redistribution to pastures is often very uneven.

Sulphur deficiency in pasture grasses is rare in Western Australia, even in a mixed sward with sulphur deficient legumes, because nitrogen deficiency usually appears first.

Crops

In contrast to pastures, sulphur deficiency in crops on susceptible soils is likely to develop early in the season and become less severe with time because:

- Crops are usually planted later than pasture germination so that weeds can be killed. Sulphate accumulated over autumn will often leach out before seeding.
- Nitrogen applied at or just after seeding will increase plant demand for sulphur (for protein formation). This demand falls as nitrogen is depleted from the soil.
- Roots penetrate soil layers higher in sulphate.

Often crop sulphur deficiencies are transient, causing yield losses only in very severe situations. Deficiency is much less common than on legume pastures because of the combined effects of lower leaching intensities in cropping areas, deeper rooted species, and the effects of nitrogen deficiency. In crop pasture rotations, deficiency will be apparent first in the pasture phase.

Role of sulphur in plants

Sulphur, along with nitrogen, phosphorus and potassium, is one of the major plant nutrients. It is required in concentrations of 0.1 to 0.5 per cent. It is a component of several amino acids essential in the formation of protein and is also important in other metabolic processes.

Deficiency symptoms

Sulphur is referred to as being 'partially mobile' within plants. This is because most plant sulphur is bound in leaf protein, and therefore not readily redistributed to young growing tissue from older leaves until they die.

Deficient plants are usually stunted and pale green to lemon-yellow, with both old and young leaves equally affected (in contrast to nitrogen deficiency which shows yellowing most severely in old leaves). In severely deficient subterranean clover plants, leaflets are small and tend to fold and stand erect, and petioles may redden. Production may fall by up to 60 per cent.

Symptoms on cereals may vary with nitrogen topdressing practice. Without fertiliser nitrogen, or with applications at seeding, sulphur deficiency is characterised by a gradual development of pale young leaves and retarded growth and maturity. Often plants appear flaccid. When nitrogen is applied to standing crops, sulphur deficiency symptoms may rapidly appear, with all leaves becoming an even lemon-yellow, stems reddening and growth rates severely retarded.
Effects

Sulphur deficient pastures are often patchy and of poor nutritional value because of reduced legume content. There is also evidence that some pastures not showing plant deficiency symptoms may have inadequate sulphur levels for animals. The nitrogen-to-sulphur ratio may also be important. Although not clear cut, dietary nitrogen-to-sulphur ratios exceeding 10:1 may be higher than desirable for ruminants.

In addition to possible effects on yield, recent eastern States work has shown that sulphur deficiency in wheat can have adverse effects on grain quality by reducing dough strength and extensibility, both important qualities in bread-making. Similar results have been found on wheat from experimental plots in Western Australia.

Even marginally sulphur deficient wheat may have poor quality characteristics. This aspect of sulphur nutrition of cereals may be as important as yield losses on Western Australian soils potentially deficient in sulphur, such as those of the West Midlands and southern sandplain, on which di-ammonium phosphate and triple superphosphate are being increasingly used. It warrants further research.

Diagnosis

Considerable attention has been given to the development of diagnostic criteria for sulphur in plant tissues because of the difficulties in predicting deficiency, and the similarity of nitrogen and sulphur deficiency symptoms. Because of its partial mobility in plants, critical levels for sulphur in whole plant tops change with plant age and sample composition (leaves, stems), making whole tops analysis of limited diagnostic use.

Data from field experiments with subterranean clover in high rainfall areas show a total sulphur content of young actively growing tissue (youngest open leaf plus petiole and all younger tissue) of 0.20 per cent is a stable critical level over a range of sites and sampling times.

Young tissue is preferred to the ‘youngest open blade’ (youngest leaf, without petiole) because of difficulties in collecting enough of the latter tissue for analysis.

Critical level data for cereals and pasture grasses have yet to be established in Western Australia. From studies elsewhere and from analysis of plants showing visual symptoms of sulphur deficiency, a critical nitrogen-to-sulphur ratio on the ‘youngest emerged blade’ of wheat of 19:1 is currently used.

Grain analysis can also be used to diagnose sulphur deficiency of wheat. Grain from deficient crops has a sulphur content of less than 0.12 per cent and nitrogen-to-sulphur ratios greater than 17:1 (Randell et al 1981).

Treatment

In Western Australia, most potential sulphur deficiency is masked by the widespread use of superphosphate. If superphosphate (or other sulphur-containing fertiliser) application rates to light soils are low, farmers should be aware of the consequences for sulphur nutrition.

Superphosphate

High rainfall areas

On sandy soils carrying legume pasture in high rainfall areas, experimental results have shown that 15 to 20 kg/ha of sulphur as superphosphate (150 to 200 kg/ha) applied in autumn is enough to prevent sulphur deficiency in the following spring. At lower rates, severe deficiency may develop during spring in some seasons (Figure 3).

If leaching is severe, delaying superphosphate application for four to eight weeks after the ‘break’ (until plant roots are established) may increase the efficiency of sulphur uptake, and reduce required application rates. However, superphosphate application may even need to be delayed until spring before these effects become significant if plant growth is very poor in winter because of cold conditions and waterlogging.

In practice delayed application is often not acceptable to farmers because of difficulties in topdressing wet paddocks.

Residual value data for sulphur has been collected for a number of years following a single application of superphosphate to pastures in high rainfall areas. Because of leaching losses, superphosphate has a very poor sulphur residual value after the season of application in these areas (Figure 4). Severe sulphur deficiency will occur on susceptible soils within one or two years of reducing superphosphate application rates below recommended levels, unless alternative sulphur fertilisers are applied.
Low rainfall areas

Much less information is available for lower rainfall areas. However, monitoring soil sulphate levels following superphosphate application in the high rainfall areas has provided data on which estimates of the residual value of applied superphosphate can be made.

More than 500 mm of rainfall is needed before applied sulphate from superphosphate is undetectable in the top 10 cm of soil. Even if dissolved sulphate is completely leached out of the root zone, unlikely in the lower rainfall areas, superphosphate will provide some sulphur for two years after application.

Though the rate of sulphur required has not been accurately defined, observations and limited trial work suggest that 10 kg/ha of sulphur (100 kg/ha superphosphate) should be applied every two or three years to prevent sulphur deficiency occurring on susceptible soils. This may involve topdressing pastures, or replacing di-ammonium phosphate or triple superphosphate in cropping programmes.

Other sources of sulphur

Gypsum

Phosphorus in superphosphate has a significant residual value, even on leaching sands, in contrast to the poor residual value of sulphur. Farm paddocks may therefore eventually reach soil phosphorus levels where only sulphur is required for one or more years to maintain optimum production levels.

The cheapest source of sulphur is gypsum (calcium sulphate), which occurs naturally near salt lakes in the drier areas of the Western Australian wheatbelt. It is also a by-product of phosphoric acid manufacture by CSBP and Farmers at Kwinana. This gypsum is fine, difficult to apply with conventional machinery, and is rapidly leached. Some natural gypsum also has a high salt content.

Trials with gypsum have shown that as little as 150 mm of rainfall will completely leach 80 kg/ha of sulphur (500 kg/ha gypsum) from the top 10 cm of soil pastures in high rainfall areas. Therefore if fine gypsum is applied in autumn it is often an ineffective source of sulphur for spring growth although large variations in effectiveness occur between years, depending on seasonal conditions.

However, if gypsum is applied in late winter–early spring, as little as 5 kg/ha of sulphur (30 kg/ha gypsum) is adequate for near maximum pasture yields (Figure 5) because a very high proportion of the applied sulphur is used by plants.

Coarser particles (4 to 6 mm in diameter) of gypsum are not as readily leached. They are equally as effective as superphosphate as a source of sulphur in the year of application, and have a better residual value. Current work is aimed at developing a suitable granulation procedure for fine gypsum. Although there are some naturally occurring coarse gypsum deposits in the State, these are either small, difficult to mine, or are some distance from potential markets.

The use of gypsum as a sulphur fertiliser should not be confused with its use as a soil amendment on saline or hard setting clays. For heavy soils, high rates (2 to 5 tonnes/ha) are required to improve soil structure.

Elemental sulphur

Research by the Western Australian Department of Agriculture has confirmed the work of Barrow (1971) that elemental sulphur in the particle size range 0.15 to 0.50 mm is an effective sulphur source for pastures for at least two years after application.

In the field, fertilisers containing elemental sulphur in this size range have a contrasting pattern of sulphur availability to that of sulphur in superphosphate. Elemental sulphur, which is insoluble and must be oxidised by soil microbes to be used by plants, does not leach during winter and is available at a maximum rate during spring, making it well suited to intensively leached soils. This pattern matches plant growth requirements. Fine particles oxidise most rapidly, and particles greater than 0.50 mm oxidise too slowly in the initial years to be an effective sulphur source.

In the high rainfall area soils susceptible to sulphur deficiency need about 25 kg/ha of elemental sulphur in the first year for optimum legume pasture growth. Because of significant residual value, rates needed in the long term require further study.

Fine elemental sulphur cannot be applied directly to pastures because of mechanical difficulties and potential fire hazards. It must be granulated or incorporated into other fertilisers.

A new fertiliser—New Coastal Superphosphate containing ‘slow release’ phosphorus and elemental sulphur—is now manufactured by CSBP and Farmers for use on sandy soils in high rainfall areas.

Because of the build up of soil phosphorus from past superphosphate applications, many old pastures on sandy soils need only a small amount of phosphorus which is best supplied in a ‘slow release’ form to maintain optimum production levels. These pastures still need sulphur.

Often superphosphate has been used primarily (and unknowingly) by farmers to provide adequate sulphur on these soils. New Coastal Superphosphate contains phosphorus and sulphur in a suitable ratio for these situations (1:3 compared with superphosphate 1:1). It is an economical and practical alternative to...
superphosphate for autumn topdressing, avoiding the problems of applying gypsum in spring.

Gyplap, iron sulphate, iron pyrites

Three other sulphur fertilisers have been used experimentally in Western Australia. Gyplap (waste product iron sulphate plus lime) is effective, but has problems similar to those of gypsum. It is no longer available. Iron sulphate has similar drawbacks. Sulphur in iron pyrites is poorly available to plants and is not commercially available as a fertiliser.

The future

As the use of ‘high analysis’ phosphorus and sulphur fertilisers grows, sulphur requirements of crops and pastures will become increasingly important. Fertilisers with a range of phosphorus-to-sulphur, and nitrogen-to-sulphur ratios, possibly produced by adding elemental sulphur to a range of existing phosphatic and nitrogenous fertilisers, will be necessary to supply specific requirements.

Although superphosphate will remain extremely important in the State’s agriculture for many years, numerous situations exist where nutritionally and commercially it is not the most appropriate form of phosphorus and sulphur. This will provide the necessary stimulus for the development of additional fertilisers, as has already occurred for pastures on the leaching sands of high rainfall areas.

Acknowledgements

This article has drawn in part on unpublished data of R. N. Glencross and T. O. Albertsen, Western Australian Department of Agriculture. The financial support of the Australian Wool Corporation (1978-80) and the Rural Credits Development Fund (1981-83) is acknowledged.

References and further reading


