Teagasc
Agriculture and Food Development Authority

The role of Sulphur (S) in Crop Production

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10 Things to know about Sulphur (S)

1. Sulphur is an essential plant nutrient
2. Sulphur increases N use efficiency
3. Sulphur is a negatively charged anion & easily leached
4. Soil organic matter is the main source of soil S
5. Sulphur is supplied in the sulphate fertilizer form
6. Sulphur deficiency symptoms is yellowing on the youngest leaf
7. Sulphur advice is similar to phosphorus advice
8. In Ireland sulphur is recommended as total S (Elemental S)
9. The UK & the EU sulphur advice is declared in oxide form (SO^3)
10. Conversion oxide (SO^3) to elemental S multiply by 0.4

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Figure 1. Sulphur deficiency in spring barley showing potassium plots treatments + / - Sulphur. *(Source Mark Plunkett, Teagasc, K trial from Rathdrum, Co. Wicklow, 2018.)*

1. Introduction

Sulphur (S) is an essential plant nutrient and a key component of a number of amino acids, the building blocks of proteins, and vitamins that are vital to both plants and animals. Both in Ireland and the EU, S deposition is decreasing and projected to decrease further in the years ahead. Due to reduced S from the atmosphere S will now play a greater role in improving yields, nitrogen use efficiency (NUE) thus reducing N losses to the environment.

In plants, S is required for photosynthesis, and closely associated with nitrogen use in many plant processes. There is no soil test available to accurately predict S deficiency in soils. The plant S concentration and the plant N to S (N:S) ratio are useful indicators for assessing the likelihood of a response to applied S fertilizers. The S content in healthy plant material should be greater than 0.2% in dry matter, and the N:S ratio should be less than 15:1 (Teagasc, 2020).

Sulphur is applied as sulphate which is immediately available to plants.

Sulphur in this form is very prone to losses and soil and weather conditions akin to nitrogen losses must be considered to reduce potential losses.

2. Sulphur Role & Function

Sulphur is part of every living cell and is a major constituent of two of the twenty plant amino acids (cysteine & methionine) which form protein. Sulphur plays a role in N fixation in legume plants such as clovers, peas & beans. At high N rates, S plays an important role in plant N efficiency & utilisation in producing higher grass / crop yields.

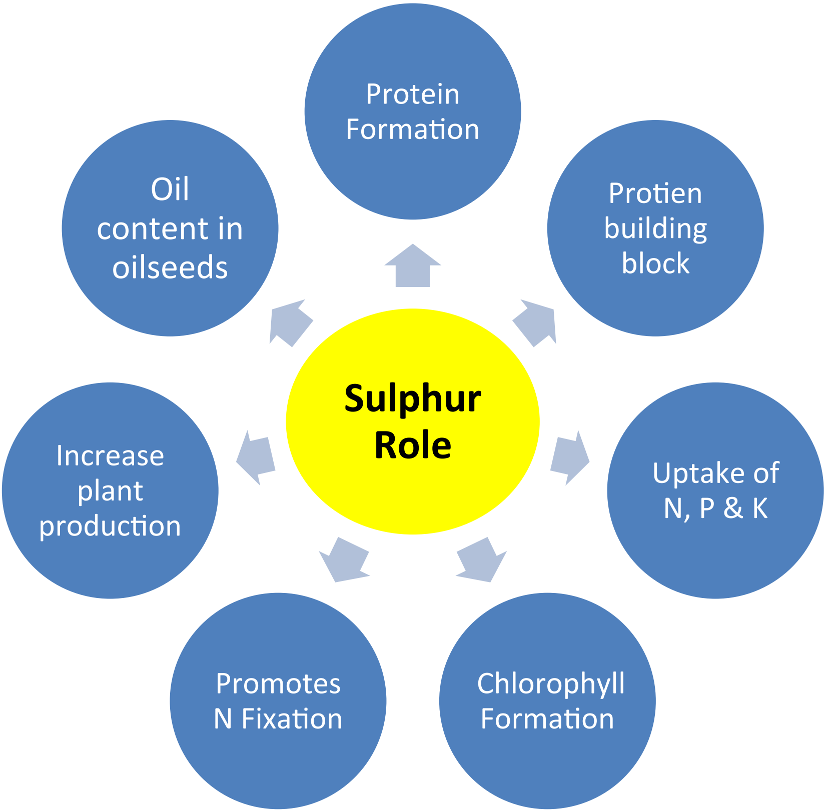

Figure 2. The functions and roles of S in plants

3. Sulphur & Soils

Soil S supply depends on soil type & soil organic matter (SOM) levels. The majority (95%) of S is stored in the SOM and needs to be mineralized for it to become plant available. Soils with greater than 50% sand content and <3% carbon (low SOM matter level) are likely to be responsive to S application.

In Ireland, sulphur levels in the soil tend to be lower than in many parts of Europe, because we lack heavy industry and the associated S depositions from the atmosphere are low (typically 1-2 kg/ha).

In sandier textured and well-drained soils (Brown Podzolics, and Brown Earths) S can be leached especially due to over winter drainage water from the topsoil and crops grown on these soils can be very responsive to S applications. Sulphur deficiencies may be more apparent on these soil types when high levels of N fertilizers are being used, or where high yielding tillage and silage crops are grown due to removal of large quantities of S. Therefore, applications of N+S fertilizers are required to meet crop demand.

More poorly drained, heavier textured and high OM soils (such as Gley soils, Peats, or Brown Earths under long term grassland) have greater potential to release S from SOM reserves, making it available to meet the demands of crop uptake and less responsive to S applications compared to lighter textured soils. These soils have a greater ability to retain available S than silty or sandy soils therefore less leaching on heavy soils.

Figure 3. Soil type and organic matter levels will have a large influence on soil S supply and response to applied fertilizer S.

4. Sulphur Deficiency

The symptoms of sulphur deficiency is quite similar to N deficiency as plants show a pale yellow colour. However, in the case of S deficiency the youngest leaves are affected first due to the poor mobility of S in the plant (see figure 4). While for a N deficiency the oldest leaves shows similar symptoms.

Figure 4. Grass showing S sufficiency (left) & S deficiency (right).
Source Patrick Forrestal & Claire Aspel, Teagasc, Johnstown Castle.

5. Crop Yield Response to Sulphur - Grassland

Grass yield response to S

Research from Teagasc, Johnstown Castle (*Aspel et al, 2022*), carried out on a free draining sandy loam (Cambisol) shows yield responses of up 30% to S + CAN over the application of CAN alone (Figure 5). This highlights the potential magnitude of sulphur response that may occur on some soils. Therefore, S potentially plays an important role in increasing grass yields and N efficiency. The addition of S to slurry + CAN resulted in a 24% yield increase. The slurry + CAN treatment supplied 9kg S/ha of total S but the grass yield was similar to the CAN only grass yield. This indicates that the S in slurry is not immediately available in the growing season of application as it is in organic forms and maybe mineralised more slowly.

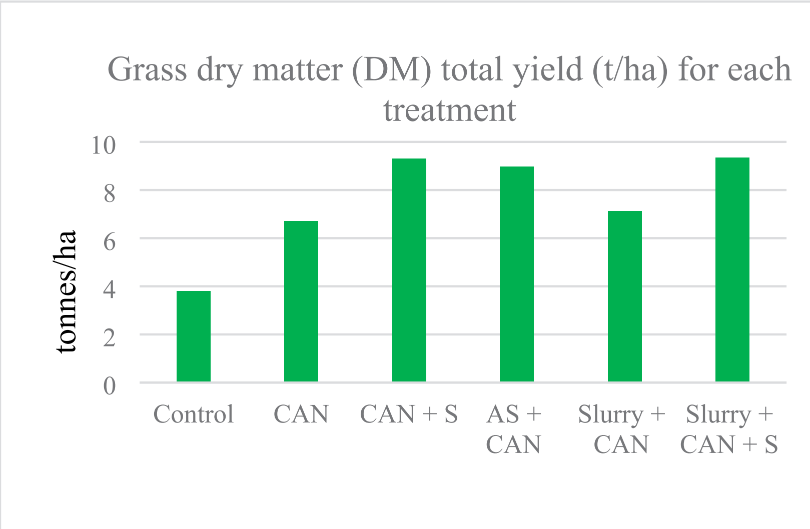

Figure 5. Effect of S on grass yield on a sandy loam *(Aspel et al, 2022)*.

Herbage S & N Uptake

The sulphur uptakes for the different fertilizer treatments applied to grassland soils are shown in figure 6 below. The S uptake in control treatments are 7 to 8kg S/ha to 23 to 24 kg S/ha in the fertilizer containing mineral S treatments. The apparent fertilizer S recovery (AFSR%) ranged from 26 to 34%. This trial showed no difference in the uptake of S in March across the treatments. Sulphur uptake increased as grass growth rates increased with the highest uptakes in April and May.

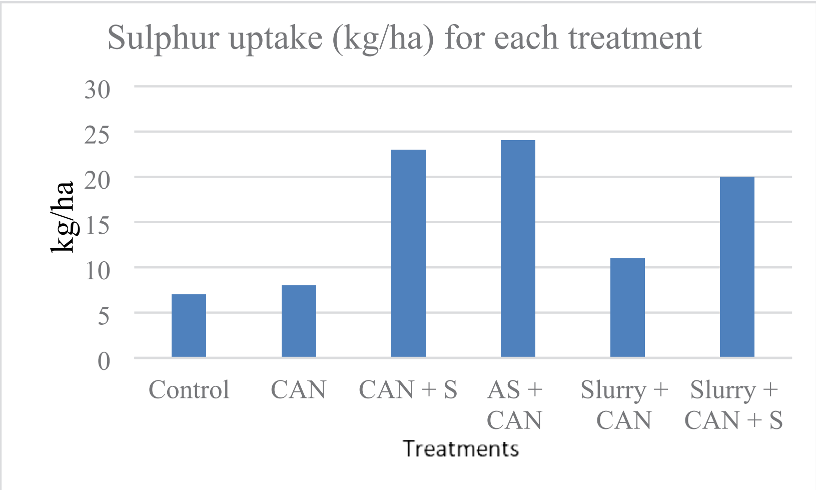

Figure 6. Sulphur uptake for fertilizer treatments *(Aspel et al, 2022)*.

Nitrogen (N) Uptake & S

Adequate S is essential for the uptake and efficient use of applied N. The N uptakes are shown in figure 7 below for the different treatments. The addition of S to CAN increased N uptake by 38 kg N/ha. This resulted in the apparent N recovery increasing from 39 to 49%. Applied S increased N uptake by 38kgN/ha over the CAN only treatment.

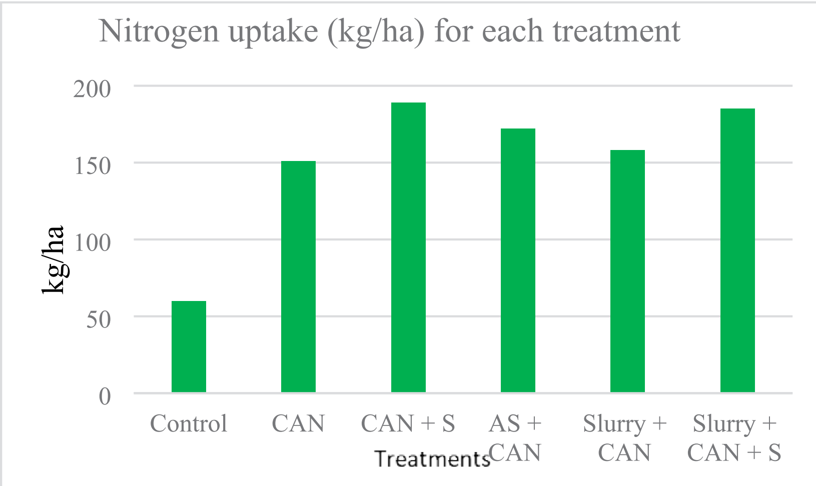

Figure 7. Nitrogen uptake for fertilizer treatments *(Aspel et al, 2022)*.

Nitrate N leaching & S

The addition of S reduced nitrate leaching significantly as shown in figure 8. The addition of S reduced nitrate leaching from 48 to 26 kg Nitrate–N/ha. The addition of S to the slurry treatment reduced N leaching from 83 to 33 kg Nitrate-N/ha. This clearly shows the important role that S has to play in reducing N losses from grassland systems. Where S was included in the fertilizer N programme nitrate-N concentration in water did not breach the EU drinking standard water maximum allowable concentration (MAC). Whereas, without S the MAC was breached for the CAN+slurry and the CAN treatments in October & November.

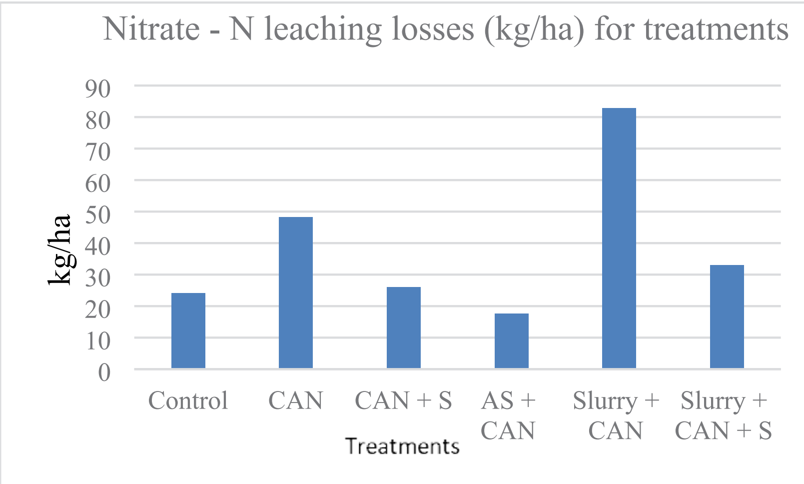

Figure 8. The effect of S on total annual nitrate-N leaching from the different N fertilizer treatments *(Aspel et al, 2022)*.

In summary the nitrogen by sulphur interaction resulted in;

1. Increased grass dry matter yield (+ 2.6t DM/ha)
2. Increased N uptake (+38kg N/ha)
3. Reduced N leaching (-22 kg N/ha)
4. Grass N recovery increased from 39 to 49%
5. Cattle slurry S not sufficient to meet grass S demand

Ongoing research at Johnstown Castle (Aspel et al *in prep.*) indicates that responses to S are heavily dependent on soil type with yield responses as low as 4% observed on a heavier soil type (Castlecomer), on a loam 15% (Elton) and as high as 50% on a lighter soil type (Oak Park). This highlights that S is not a one size fits all and S applications and needs to be tailored based on knowledge of sulphur responsiveness according to soil type.

Figure 9. Adequate sulphur on a sandy loam soil type improved N efficiency from 39 to 49% in a grassland sward, while reducing N leaching.

Cereal Crops – Winter & Spring

Recent research at Teagasc Oak Park Research Centre has demonstrated the importance of sulphur applications in preventing yield loss in cereals. On light sandy soils, where the risk of sulphur deficiency is higher and deficiency symptoms were clearly visible in the untreated crop, yield loss where no sulphur fertilizer was applied was in excess of 1 t/ha in winter barley. In terms of timing of the S application to minimise potential yield loss, no significant difference was observed between applying the S with the second split of N in comparison to applying it with the first split of N. In practice many growers will apply some sulphur at both N timings.

Research investigating the effect of fertilizer S rate on spring barley, on a light sandy soil where sulphur deficiency symptoms were clearly visible in the untreated crop, indicated that application of 8 kg S/ha gave a significant yield increase of about 0.7 t/ha compared to where no fertilizer S was applied. Increasing S rate from 8 kg S/ha to 16 kg S/ha gave no further increase in yield. This would indicate that the current recommendations of 15 kg S/ha for cereals is adequate even on soils with low sulphur supply. It should be remembered that lower response to S could be expected on heavier textured soils, soils with high organic matter and soils that have received repeated applications of organic manures as all these factors will increase the soils ability to supply the crop with sulphur *(Source: Communication with Dr. Richard Hackett, Teagasc)*.

6. Sulphur Advice

Table 1. Sulphur advice for a range of crops	
Crop Type	**Sulphur Rate (kg/ha)**
Grass – Grazing	20 kg/ha/year
Grass – Silage	20 kg/ha/cut
Cereal Crops	20 kg/ha
Oilseeds	30 kg/ha
Legumes / Brassicas	15 kg/ha
	Source: Teagasc, 2020

Sulphur & Timing of Application

On grassland apply S as part of a grazing fertilizer programme starting in spring and apply S in 2 to 3 applications between March and July. Recent grassland trials (Aspel et al, 2022) show up to 2.5t/ha DM yield response to application of S compared to no S during this period. The largest response to S occurred in the early part of the growing season in the months of March, April, May and June. For crops of grass silage apply recommended rates prior to closing for each cut. For cereals apply S requirements with main N splits during March and April.

7. Sulphur Containing Fertilizers

Sulphur is available in a range of fertilizers from straight N's to blends. For example, straight N's such as Protected urea, CAN, and Urea contain 4 to 7% S while ASN (26% N) contains 14% S and is very suitable for high S demanding crops such as oilseed rape in a single or split application. In addition, ammonium sulphate 21% N and 24% S is another option.

Sulphur can also be added to fertilizer blends such as 10-10-20 / 18-6-12 +S etc. and levels range from 2 to 8% S. These products are very suitable for grazing / silage / cereal production.

Figure 10. Fertilizer N, P & K blend containing S.
(Source: Kieran Holden, FAI).

Table 2. Fertilizers Products containing Sulphur				
Product	**Nutrients%**			
Straight N + S	**N**	**P**	**K**	**S**
Sul of Ammonia	21			24
ASN	26			14
CAN + S	26			4 - 5
Urea + S 38N + 7.6S	38			7
Urea + S 40N +6S	40			6
N,P+S & N,K +S				
23-10-0 +S	23	10		3
13-0-25 + S	13		25	3
19-0-15 + SULP	19		15	3
Protected Urea PLUS K+S	29		14	3.8
Compounds / Blends	**N**	**P**	**K**	**S**
10-5-25+S	10	5	25	3
10-7-25+S	10	7	25	2
10-8-20 + S	10	8	20	2
12-4-24 + S	12	4	24	3
12-8-20 + S	12	8	20	2
13-6-20 + S	13	6	20	3-4
15-10-10 + S	15	10	10	2
18-6-12 + S	18	6	12	3
27-2.5-5 +S	27	2.5	5	2
26-2.5-5 + S	26	2.5	5	4
25-2.2-4.5 + S	25	2.2	4.5	4
24-2.5-10 + S	24	2.5	10	2
24-2.2-4.5 + S	24	2.2	4.5	3 -4
23-2.5-10 + S	23	2.5	10	4

8. Sulphur & Organic Manures

Organic fertilizers such as cattle / pig slurry contain low levels of total S (0.3 to 0.4 kg/m^3) while poultry manures contain relatively higher S levels (layer manure 2.5 kg/t). The most recent work from Johnstown Castle *(Aspel, et al, 2022)* shows that approximately 21% of the total sulphur is available in the year of application. For example, cattle slurry contains ~ 0.3kg / 1,000 gals of available S. Table 3 shows the S values (totals & available per tonne / 1,000gals) for a range of organic fertilizers.

Table 3. Sulphur Levels Organic Fertilizers			
Manure Type	**Dry Matter %**	**Total S (kg/m³ or ton)**	***Available S (units / 1,000gals or Tonne)**
Cattle Slurry	6.3	0.3	0.6 unit
Pig Slurry	3.2	0.4	0.7 unit
Farm yard manure	20	0.9	0.35 unit
Broiler Manure	60	3.2	1.3 units
Layer Manure	55	2.5	1 unit
Mushroom Compost	35	6.6	2.6units
*Assumes 20% S availability			

Figure 11. Organic fertilizers are a valuable source of organic matter & S.

9. Sulphur & Trace Elements

The absorption of some minerals can be reduced when other minerals or compounds are present in the diet. For copper and selenium, excess sulphur in the diet and in water sources can cause such problems. High concentrations of dietary sulphur or the intake of water that contains high levels of sulphate will greatly reduce the absorption of copper and selenium. Dietary sulphur concentrations of 0.20% are normal and will not cause absorption problems for other minerals. An increased level of consumption will reduce copper and selenium status, and if mineral supplementation is not adjusted, status of those two minerals for the animal will decline. Adjust sulphur application rates depending on N application rates and grass production levels to reduce trace element issues.

Sulphur effect on Copper availability

High dietary molybdenum in combination with moderate to high dietary sulphur results in formation of thiomolybdates in the rumen. Thiomolybdates greatly reduce copper absorption (Spears, J.W. 2003). The relationship between S, Mo, and Cu has been widely investigated in grazing ruminants. Although Mo is an essential component in this antagonism, it will seldom affect tissue Cu stores when S levels are limiting. Provided adequate dietary S, Mo combines with Cu to form an insoluble complex in the rumen, rendering Cu unavailable for absorption. Arlington, J., (2003) found that a dietary concentration of S of 0.35% (total S) is sufficient for this antagonism to become a concern. The current beef cattle NRC (1996) suggests a maximum tolerable concentration of dietary S of 0.40%. In addition, nutritionists should consider feeding at least some of the supplemental copper from commercial sources designed to have greater bioavailability than copper sulphate.

Sulphur effect on Selenium availability

Selenium bioavailability is reduced by high dietary sulphur and the presence of cyanogenetic glycosides in certain legumes. Feeding organic selenium from selenomethionine or selenized yeast results in much higher tissue and milk selenium concentrations than are obtained with selenite (Spears, J.W. 2003). Cows fed diets with a level of 0.40% sulphur can also have lower absorption of selenium than cows fed diets with 0.20% sulphur. Some feed ingredients that are grown in areas with high selenium soil are naturally high in selenium (e.g. brewer's grains or linseed meal) can increase selenium concentration of the diet. If cows are fed high sulphur diets, cows should be supplemented with the maximum amount of selenium permitted by law, and a substantial amount of the selenium should come from a high-quality selenium product (Spears, J.W. 2003).

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