Grain Sorghum - a yield response to N or S?

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ABSTRACT

Sulfur (S) deficiencies have been recorded in cereal crops of the Darling Downs, since the early 1980s and symptoms are commonly mistaken as N deficiency. Few experiments have been successful in measuring soil parameters indicative of S responsive soils. A grain yield response in sorghum was recorded in a long-term S experiment during the 1998-99 season on the Darling Downs, Queensland. Soil was sampled to 90 cm in 4 increments with each increment analysed using both the KCl-40 and MCP (mono-calcium phosphate) extraction methods.

KEYWORDS

Soil sulfur, subsoil SO_4.

INTRODUCTION

Sulfur has been known for many years to be an essential plant nutrient. Reports of deficiencies have become more common in recent years in southeast Queensland and northwest NSW. Chisholm and Dowling (3) reported on soil S status of the Darling Downs after widespread S deficiencies were reported in winter cereals

Soil test S concentrations across the Darling Downs in the 0-60 cm layer are generally declining (3). This decline has been influenced by a number of changing soil management practices over the last 30 years, which have resulted in lower sulfur addition and increased S off-take from the soil. Factors associated with lower S availability include the change from superphosphate to ammonium phosphates (MAP and DAP), the reduction in gypsum (calcium sulfate) application and declining reserves of organic matter.

Sorghum is a widely grown summer cereal in Australia's north eastern grain belt. Production during 1999 was estimated at 560 000 hectares, with total yield of 1 360 000 tonnes. Average grain yield is roughly 2.3 t/ha (O'Connell 2000).

Little has been reported about the response of sorghum to S in Australia. This has resulted in limited information being available for prediction or diagnosis of likely S responses, either from use of soil, plant tissue or grain analysis. Peverill *et al.* (11) reports no data for sorghum from soil analysis, while Reuter and Robinson (14) provide limited data for use from various plant tissue samples.

Sulfur occurs in the soil in both organic and inorganic forms. Most of the S in soils that are likely to be S deficient is in organic combination. The organic S must undergo microbial decomposition to a soluble inorganic form before it is available to plants. This breakdown process is slow and usually does not supply enough S for plant growth during a growing season if available levels are low at seeding time. The rate of breakdown of organic matter and mineralisation of organic S is influenced by such factors as the S content of organic matter, moisture, temperature, soil pH and the presence of plants (7). The loss of organic matter under cropping systems also reduces the organic S content of soil (4).

Inorganic S occurs primarily as water-soluble sulfates of calcium, magnesium and sodium. Plant available S in the soil includes the soluble inorganic sulfate in the soil solution, the sulfate adsorbed to clay and that portion of the organic S that is mineralised and oxidised to the sulfate form during the growing season.

There are two commonly used soil S extractants used in Australian agriculture. Mono-calcium phosphate (MCP-S) extraction (13) determines the contribution of both non-adsorbed and adsorbed S (termed MCP-S). The second method involves 0.25 M KCl heated at 40 ^{o}C for 3 h (named the KCl-40 extract) which extracts some organic S and a lesser fraction of adsorbed S (1).

The use of soil-profile sampling for S has also come under closer examination, where the relative distribution of S through a profile is important in reliable response prediction. Soil profile samples are commonly analysed for nutrients (primarily nitrate-N), and crop restrictive conditions (salinity, sodicity, boron toxicity, etc). Hue and Cope (8) reported a weighted mean approach for sulfate distribution through a 0-60 cm sample depth in establishing a critical value for sorghum in the United States.

MATERIALS and METHODS

The S experiment is part of a larger long-term N x P study located at “Colonsay” Formartin, Qld and consists of 0, 10, 20, 30 kg S/ha/crop as ammonium sulfate (20.2% N, 24% S), band applied pre-plant. Nitrogen as urea (46% N) is applied to provide the equivalent total N rate of 80 kg N/ha/crop. Urea is band-applied 5 cm to the side of the seed row at sowing. Phosphorus is applied with seed at-sowing at 15 kg P/ha/crop as triple superphosphate (20.7% P, 1.0% S). There are 3 replicates in a randomised block design. Plots are 2.5 m wide and 50 m in length. The soil is a black vertosol, with pH (1:5 soil/0.01 M $CaCl_2$) 7.8, CEC ($cmol^+/kg^{-1}$) 57, Leco C 13.6 mg/g, Leco N 814 mg/kg. Residual soil N (as nitrate-N) was 160 kg/ha for 0-90 cm in August 1998. Colwell-P was 15 mg/kg and DTPA-Zn 0.9 mg/kg for 0-10 cm.

Grain sorghum (*Sorghum bicolor* cv. Pioneer Seeds “Magnum MR”) was sown in October 1998 using the Incitec Fertilizers cereal planter. The plant population was estimated at 75 000 plants/ha. In-crop rainfall from the period October 1998 to February 1999 was 193 mm. Growing conditions were favourable during most of the season.

Grain was harvested from whole plots in March 1999. Plot yields were recorded and grain samples were collected from each plot and analysed for grain N and S, and gravimetric moisture %. Grain N was converted to grain protein using a factor of 6.25. The grain yield and protein were adjusted to a constant 13% moisture prior to statistical analysis. ANOVA statistics and mean separation using least significant differences (l.s.d.) were calculated using Genstat V4.5 (Genstat Committee 1987).

RESULTS and DISCUSSION

Crop response to S at "Colonsay", 1998-99.

Visual responses to the S rates were observed during the 1998-99 season. This was the first observance of a visual response to S at this experimental site. The crop response was noted as broader leaves, a slightly darker green colouring and a slightly more vigorous plant compared to the 0 kg/ha S plots. In addition to the visual symptoms, a significant yield response for S fertiliser rate (Table 1) was recorded. Grain yield increased from 6150 kg/ha where no S had been applied to 6950 kg/ha where 30 kg S/ha had been applied to each crop. Mean grain yields from 20 or 30 kg/ha S rate yielded more than where 120 kg/ha N had been applied in the N x P experiment. Grain protein in the range 9 to 10 % indicates that the crop N supply was adequate for the yield increases measured (5). There were no significant grain protein, grain S% or grain N:S ratio effects from S application (Table 1).

Table 1. Effect of 4 S fertiliser rates on mean grain yield, grain protein, grain S%, and grain N:S ratio at "Colonsay", 1998-99.

S rate (kg S/ha)	Grain Yield (kg/ha)	Grain Protein (%)	Grain S%	Grain N:S
0	6150	10.1	0.093	17.2

10	6450	9.6	0.088	17.1
20	6850	9.8	0.092	16.9
30	6950	10.3	0.093	17.6
F prob.	0.02	0.32	0.59	0.70
l.s.d.	510			

It was speculated that the lack of response to soil S supply for grain S % and N:S ratio in sorghum may be related to its perennial habit compared to the known sensitivity of annual cereal species in these parameters (12). This result suggests it would be difficult to use S analysis of grain for prediction of S responses in this species. Alternatively the lack of response may have been relate to the timing of availability of S in the soil profile.

Analysis of the "Colonsay" Crop Response

Soil samples collected pre-sowing from the main N x P experiment that had received no S application were analysed for S to establish a baseline across the site. To further investigate the nature of the response, soil was sampled following grain harvest from the 0, 10 and 30 kg S/ha plots, to 90 cm depth in 4 increments, 0-10 cm, 10-30 cm, 30-60 cm, and 60-90 cm. For each depth increment, pre-sowing soil samples had higher MCP-S than KCl-40 S concentration (Table 2), suggesting that plant available S was dominated by adsorbed and non-adsorbed sulfates, rather than a contribution from organic S mineralisation during the growing season. The high S results at depths greater than 60 cm indicate the presence of gypsum.

Table 2. Soil Sulfur concentration for MCP-S and KCl-40 for 3 soil depth segments, pre-sowing.

Depth (cm)	MCP-S (mg/kg)	KCl-40 (mg/kg)
0-10 cm	5.4	3.5
10-60 cm	13.0	8.3
60-90 cm	51.8	38.2

The high S availability at depth provides another possible scenario for the lack of difference in grain S%, and N:S ratio. Access to the high S segment of the lower soil profile later in growth may have provided sufficient S for grain fill although, grain yield had been restricted by poor availability higher in the soil profile during earlier yield development stages.

The acidifying effect of ammonium sulfate on availability of other nutrients has been discounted as a contributor to the crop response. The combined effects of relatively low application rate, the time between product application and sowing (46 days), the rainfall received between application and sowing (160 mm), and the strong buffering capacity of vertosols make it unlikely that such zones of acidity would have persisted or have been a significantly large volume of soil to influence crop growth.

Currently available soil interpretation data suggests that in the 0-90cm soil segment there was adequate soil S (Incitec Fertilizers 1997). The yield response recorded suggests that partitioning of S by soil depth may be important because sufficient S must be available during early crop growth to avoid yield damage during panicle and grain initiation.

For annual cropping systems, were there may be insufficient time or unfavourable climatic conditions for significant organic S mineralisation back into the available sulfate pool, the levels of adsorbed and non-adsorbed S are likely to become more critical in predication of a response to S (2).

Post-harvest soil S concentrations were significantly different between depth increments ($P < 0.001$) for both extractant methods (Table 3). Significance for S rate was $P < 0.05$ for MCP-S and $P < 0.02$ for KCl-40. The KCl-40 S has a higher significance than the MCP-S, but has a larger standard error at a lower S extract concentration, indicating that this extraction method may be less robust than the MCP-S.

Table 3. Effect of S Fertiliser rate on soil sulfur concentration MCP-S and KCl-40 for 3 soil depth segments, post-harvest.

	MCP-S (mg/kg)			KCl-40 (mg/kg)		
Depth (cm)	0 kg S/ha	10 kg S/ha	30 kg S/ha	0 kg S/ha	10 kg S/ha	30 kg S/ha
0-10 cm	3.3	4.3	6.7	1.0	1.3	2.3
10-30 cm	2.0	5.3	11.0	1.0	2.3	6.7
30-60 cm	8.7	10.3	16.0	4.3	6.3	10.0
60-90 cm	66.3	54.7	80.3	58.3	47.3	70.0
l.s.d.	depth	2.7		depth	7.5	
	S rate	2.4		S rate	6.5	

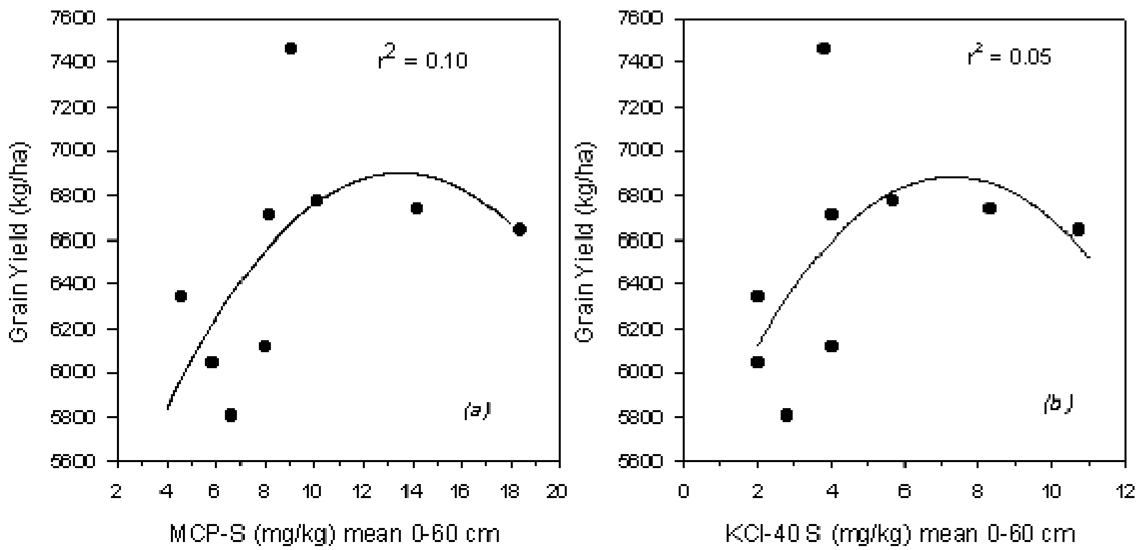

Figure 1. Grain Sorghum Yield as function of mean 0-60 cm MCP-S (a) and KCl-40 S (b) result

To determine the most appropriate sampling depth the calculated profile mean S concentration for both extractants over 3 depths, 0-30, 0-60 and 0-90 cm, were correlated with yield. The relationship for the 0-60 cm depth was stronger than for either the 0-30 or 0-90 cm depths (data not shown).

Mean grain yields were regressed against post-harvest 0-60 cm mean MCP-S (Fig 1a) and KCl-40 S (Fig1b). Neither extractant shows a strong correlation with grain yield for the post-harvest sampling.

CONCLUSIONS

In annual cropping systems where soil organic matter has declined, the use of the MCP-S extractant appears to provide a more robust basis for identification of S responsive situations than the KCl-40 S method. Cumulative application of S fertilisers increased grain yield in sorghum grown during 1998/99, however no strong relationship has been established between profile soil S for either extractant and grain yield. The selection of the most appropriate sampling depth for sulfate –S must be done with an understanding of the crop nutrient requirement at early growth stages to avoid masking of responsive soil by mixing low S surface soil with S rich layers deeper in the profile.

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