Soil and tissue tests to predict the sulfur requirements of canola in Western Australia

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ABSTRACT

The sulfur (S) requirement of canola (Brassica napus L.) grown in Western Australia (WA) are not known. This work was done to determine critical soil and tissue test for S values for canola. The KCl-40 soil test procedure was measured KCl-40 values for soil samples collected at 0-10, 10-20 and 20-30 cm and related the values to canola seed (grain) yields measured at the end of the growing season. Total S measured in dried shoots at about 90 days after sowing (DAS) was related to yields of dried shoots at the time of sampling (diagnostic test) and to grain yields at the end of the growing season (prognostic test). In addition, the concentration of oil in canola grain was measured to see if applications of S affected the oil concentrations.

Soil test S values were related to grain yields, the relationship was similar for the 0-10 and 10-20 cm soil sampling depths ($R^2 \approx 0.27$), and was best for the 20-30 cm depth ($R^2 = 0.48$). The critical soil test S value (mg S/kg) for the top 10 cm was ~6.3, decreased to ~5.0 for the 10-20 cm and was ~6.9 for the 20-30 cm. At 90 DAS when soil test S was <7 in the top 10 cm of soil, canola shoot yield responses to applied S occurred in about 70% of the harvests regardless whether soil test S below 10 cm was >7. By contrast, when roots accessed S deeper in soil, grain yield responses to applied S only occurred for about 30% of harvests and only when soil test S was <7 mg/kg to 30 cm depth. The top 10 cm soil therefore mostly overestimated the likelihood of S deficiency for canola grain production. Critical tissue test for S values for dried shoot yield at about 90 DAS was 3.8 g/kg. Tissue test values for dried shoots at 90 DAS poorly predicted S deficiency (prognostic) for grain production because in most cases the roots of S deficient plants at 90 DAS subsequently accessed adequate S deeper in soil for grain production. Applications of fertiliser S mostly had no effect on concentrations of oil in canola grain.

Additional keywords: critical sulfur concentrations in soil and dried shoots, prognostic sulfur concentration in dried shoots, extractable soil sulfur

INTRODUCTION

Canola (Brassica napus L.) has become a major crop grown in rotation with wheat and lupin in many of the south-western agricultural areas of WA. When first grown in the early 1990s on some sandy soils in the region, canola crops were identified as S deficient. Consequently, fertiliser S is now applied to most canola crops even though the S requirements of canola in the region are not known and most experiments since then only showed grain yield responses to applied S on some sandy soils.

The experiments were undertaken to determine critical soil and tissue test for S values for canola in WA. The KCl-40 soil test for S procedure has not been calibrated for canola crops and this paper calibrated the test for canola in WA.

Soil test values for soil samples collected the following 3 depths: 0-10, 10-20, 20-30 cm were measured. The soil test values for each of the 3 depths were related to grain yields. Total S concentration was measured in dried shoots of canola to determine critical tissue test for S values. The tissue test values of the dried shoots to grain yields measured at the end of the season to test the ability of the tissue test values to predict the final canola grain yields at the end of the growing season (prognostic test for S). Finally the concentration of oil in canola grain was determined to test if application of S affected the concentration of oil in the grain.

MATERIALS AND METHODS
A total of 59 experiments were undertaken from 1993-2003. The sites included a very wide range in soil S status in the top 30 cm of soil. The soil samples were separated into the following profile depths: 0-10, 10-20, 20-30 cm. The samples were extracted with 0.25 mol KCl/L heated at 40°C (Blair et al. 1991). The soils selected were segregated into 6 classes, depending on the soils test values obtained: (i) Low soil test S (<10 mg/kg) in the top 10 cm and values decreasing with depth (2) Low soil test S (<10 mg/kg) in the top 10 cm and values increasing with depth; (3) Low soil test S (<10 mg/kg) in the top 10 cm of soil and values about similar at all depths to 30 cm; (4) Low soil test S (<10 mg/kg) at all depths and grain yields <1000 kg/ha ; (5) High soil test S (≥10 mg/kg) in the top 10 cm of soil and values decreasing with depth, and (6) High soil test S (≥10 mg/kg) in the top 10 cm of soil and values increasing with soil depth.

There were 2 types of experiments: 48 experiments from 1993 to 1996 comprised completely randomised block of 3 S treatments (0, 15 and 30 kg S/ha as gypsum) replicated 4 times. And the 11 experiments done from 1997 to 2003 comprised completely randomised blocks of 4 amounts of S (0, 7.5, 15 and 30 kg S/ha as gypsum) replicated 3 times. Plots for all experiments were 1.4 m wide and 30-40 m long. Canola seed was sown at 4-5 kg/ha 2 cm deep. The following basal fertilisers were applied: 150 kg/ha triple superphosphate 3.6 kg/ha copper oxychloride, 2 kg/ha zinc oxide and 0.25 kg/ha sodium molybdate. Applied 4-6 weeks after sowing, 70 kg N/ha as urea (46% N) and 50 kg K/ha as potassium chloride (50% K).

The S treatments, as gypsum (17% S), were applied 4-6 weeks after sowing (sown mid-late May and S applied mid-June to early-July). Narendra was the cultivar used from 1993-1995. Triazine tolerant canola cultivars were used thereafter: Karoo in 1996 and 1997, Pinnacle in 1998-2001, and Surpass 501 in 2001 - 2003.

Yields of dried shoots were measured about 90 days after sowing (90DAS) by cutting plants at ground level within 5 random 40 cm by 100 cm quadrats per plot. The material was dried for 3 days in a 70°C forced-draught oven before weighing. Subsamples of the dried shoots were used to measure concentration of S in dried tissue. Canola grain yields were measured and subsamples of the harvested grain were used to measure concentration of oil in grain corrected to 8.5% moisture content.

Analysis of data

Analysis of variance was used to compare means of treatments.

Estimating yield response to applied S. For the experiments, when >15 kg S/ha was applied, yields of shoots or grain were similar and so on the maximum yield plateau of the relationship between shoot or grain yield and the amount of S applied. In S deficient soils when yield responses to applied S were obtained, the percentage yield increases to applications of S (relative shoot or grain yield responses to applied S) was determined by:

\[
\text{% yield increase (Y\text{_{response}})} = \frac{(Y_{15} - Y_0)}{Y_{15}} * 100
\]

where \(Y_{\text{response}}\) was the percentage yield increase to added S, \(Y_0\) was the yield produced when no fertiliser S was applied (kg/ha), and \(Y_{15}\) is the yield produced when 15 kg S/ha was applied.

Relating yield response to soil test S. Data for the relationship between relative yield response and soil test S were fitted to the following exponential equation:

\[
y = a + b \exp(-cx)
\]

where \(y\) was the relative yield response (%), \(x\) was the soil test S value (mg S/kg soil), and \(a\), \(b\) and \(c\) were coefficients.

Estimating critical S concentrations in dried shoots. The concentration of S in dried shoots sampled at 90 DAS was related to the relative yield response of the 90-day old dried shoots to applied S. The fitted equation (Eqn 2) was then used to calculate the concentration of S in the shoots that was related to a relative shoot yield response of 10%, defined as the critical diagnostic tissue test value.

Relating S concentrations in dried shoots to grain yield. The S concentrations measured in dried shoots collected 90 DAS were related to the relative grain yield response measured at the end of the growing season. The fitted equation (Eqn 2) was used to calculate the S concentration in the shoots that was related to a relative grain yield response of 10%. This was defined as the critical prognostic tissue test value above which S deficiency in soil is unlikely to reduce grain yields.
RESULTS

Shoot yields at 90 DAS were measured and significant responses of shoots to applied S were obtained in 26 of the 36 experiments (72% of the experiments). By contrast, significant grain yield responses to applied S were only obtained in 16 of the 59 experiments (~30% of the experiments).

Soil test values were similar at all 3 depths in 9 (15%) of the experiments. Values were highest in the top 10 cm of soil for 21 (35%) of the experiments, and were highest in the 20-30 cm zone in 29 (50%) of the sites. These results indicate that soil test S was higher in the subsoil than the topsoil.

Soil test S values were related to relative grain yield responses for soil test values measured in the 0-10, 10-20 and 20-30 cm zones. Only about 27% of the variation was accounted for in the 0-10 and 10-20 cm zones, but 48% of the variation was accounted for in the 20-30 cm zone (Fig. 1).

Critical soil test S value (soil test for 10% grain yield response) was ~6.3 mg/kg in the top 10 cm. However, no increases in canola grain yields were achieved for soil test S values >7 mg/kg for the top 10 cm of soil (Fig. 1a). For S deficient sandy soils, the soil test procedure was not reliable at predicting grain yield responses to S already present in the soil in the range from about 3-7 mg/kg. In this range there were sites showing from 0 to 33% relative grain yield responses to applied S (Fig. 1a).

There were a total of 26 yield assessments that had soil test values <7.0 mg/kg in the top 10 cm of soil and of these only 7 (27%) showed a significant ($P<0.05$) grain yield response to
added S (Fig. 1a). For the 19 of the 26 yield assessments (73%) that showed no significant grain yield response to applied S, 15 (58%) were from sites where, relative to the top 10 cm, the soil test values increased in the 20-30 cm depth of the soil and were >7 mg/kg. Therefore S deficiency is most likely in sandy soils for canola grain production. For sandy soils, soils test values >7 mg/kg in the top 10 cm of soil indicate no need for fertiliser S because it is likely there is already enough S to ensure S deficiency does not limit canola grain production. However, the situation is less clear for soil test values in the top 10 cm of between 3-8 mg/kg. Without knowledge of soil test S values in the subsoil, the only option is to apply S to canola crops if soil test S for the top 10 cm of soil is ≤7 mg/kg. This means S is often applied when there is adequate S already present at depths in the soil eventually accessed by plant roots so that S fertiliser is not required for grain production. For soil samples collected at 10-20 cm, the critical soil test S value was 5.0 mg/kg. However, there was no grain yield response to applied S for soil test S values >8.0 mg/kg (see Fig. 1b). Similarly the critical soil test value for the 20-30 cm depth was ~6.9 mg/kg (Fig. 1c). Hence there was good agreement with our critical soil test S value and observed grain yield responses. That is, sites responsive to S fertilizer for grain yield are all less than the determined critical soil test S value to the 20-30 cm.

Fig. 2. Relationship for 36 experiments between S concentration in dried canola shoots at 90DAS and (a) relative yield response of dried shoots at 90 DAS (diagnostic tissue test) and (b) relative grain yield response (prognostic tissue test).

Relating tissue test values in shoots to relative yield responses to applied S
At about 90 DAS, applications of S increased concentrations of S in dried canola shoots. The concentration of S in dried shoots tended to decrease as the growing season progressed (data not shown) supporting results of previous research (Pinkerton et al. 1993).

For S deficient sites when it was possible to determine critical S in shoots, the critical S for dried canola shoots at about 90 DAS was about 3.8 g S/kg dried shoots (Fig. 2a).

Compared to the diagnostic test (Fig 2a), there was a poorer relationship for the prognostic test when tissue test for S values for shoots at 90 DAS were related to grain yields.
This was because some of the S deficient plants at 90 DAS eventually accessed adequate S when roots grew deeper in soil for grain production at the end of the growing season. The critical prognostic value was about 3 g S/kg (Fig. 2b).

Applications of S in 41 of the 46 experiments had no effect on the concentration of oil in canola grain. In 5 experiments applications of S did increase oil concentrations in grain. Percentage increases were small, about 4% (range 2.5-7%).

**DUSCUSSION**

The data therefore indicated there were far fewer plant yield responses to applied S at maturity than at 90 DAS, suggesting that yield responses to applied S decreased as plant roots grow deeper into soil and accessed adequate S in the subsoil for grain production. Probert and Jones (1977) found similar results for tropical legumes in Australia, as did Thomas et al. (2003) for sugar beet production in the UK.

N as a basal in our experiments to ensure N did not limit canola grain production. In a glasshouse study Pinkerton (1998) showed that oil concentrations in canola grain was lower in S deficient plants, particularly when large amounts of N were applied. However, in 3 field experiments, Pinkerton et al. (1993) showed that applications of S had no effect on concentrations of oil in canola grain, but in 1 experiment S deficient plants had lower oil concentrations when >40 kg N/ha was applied.

Diagnostic tests for S in dried canola whole shoots are 5.0-6.0 g/kg at stem elongation, 4.4-5.0 g/kg at the buds visible growth stage (Pinkerton et al. 1993), and 2.0-2.5 g/kg near or at flowering (Pinkerton et al. 1993; Pinkerton 1998). In our study only had 3 sites where the S concentration in dried shoots at 90 DAS was > 3 g/kg yet these plants eventually produced a significant grain yield response to applied S. At these 3 sites soil test S was low in the topsoil and decreased with soil depth. At 6 of the 36 sites (about 16% of the sites) the S concentration in dried shoots at 90DAS was below the critical prognostic value of 3.0 g S/kg yet there was no grain yield responses to applied S at the end of the growing season (Fig. 2b) because plant roots eventually access adequate S in the subsoil for grain production. Consequently the critical prognostic value of 3.0 g/kg was not of much value for predicting likely S deficiency for grain production. Similarly, Thomas et al. (2003) with sugar beet showed the use of plant analysis to predict S deficiency later in the growing season was limited because of the ability of plants to access S in the subsoil.

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