CANOLA YIELD RESPONSES TO SEVERAL SULPHUR SOURCES - A ONE YEAR'S EXPERIENCE

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INTRODUCTION

Reports of sulphur deficiencies have become more common in recent years. Recent estimates suggest that S deficiencies affect in the order of 4 to 4.5 million hectares of land in the prairie provinces. With emphasis on intensified agriculture and depletion of soil S reserves due to long-term cultivation the number of sulphur-responsive soils will undoubtly increase in the future.

The numerous forms of commercial sulphur fertilizers currently available can be categorized into two groups, namely, fertilizers which contain S in the plant available form (sulphate fertilizers), and those which contain S in a form that requires oxidation before S becomes available for plant uptake. The results of limited number of studies conducted in the prairies suggest that oxidation of elemental S is often too slow to provide the short-term crop requirements for sulphate (Bettany et al., 1982). However, elemental S poducts in emulsion form with a very high specific surface area produced higher plant S uptake than other elemental forms in a growth chamber experiment (Janzen et al., 1982). Differences in effectiveness of various elemental S fertilizers in the year of application can be largely attributed to the effect of particle size (Janzen et al., 1982). The low oxidation rates of some of these products may actually offer an advantage as long-term sources of "available" S. However, in rotations where sulphur sensitive crops are introduced only every two to three years, use of slow-release products may result in considerable waste of fertilizer. Hence, there is a need for identifying the short- and long-term crop S requirements, and choosing the appropriate products to meet these requirements.

A 4-year program was established in 1986 to develop an appropriate sulphur fertilization program based either on single S sources or combinations of the same; to study the properties of these sources and the efficiency of S uptake from them by the plant; and, to attempt to establish criteria for diagnosis of S deficiencies. As part of this program a site was established in Wetaskiwin, Alberta to compare the short- and long-term benefits from the application of various rates of three elemental S sources and the need to supplement these sources with a readily "available" S form, i.e., ammonium sulphate. This is a report of the findings from the first year of experimentation on this site.

MATERIALS AND METHODS

A field study was carried out on a Transitional Grey Black soil in the Wetaskiwin region of North Central Alberta. The soil texture was variable from sandy load to loam and pH value of 5.3.

A composite sample was obtained from the experimental plot and assayed for $SO_4^{=}$-S prior to experimentation. The levels in the 0-15, 15-30 and 30-60 cm depths were 6.8, 4.8 and 5.6 kg ha^{-1}, respectively, with an overall total in the top 60 cm of 17.2 kg ha^{-1}.

A split-split plot design was adopted for the experiment with three elemental sulphur sources (two different mixtures of 90% elemental S and 10% bentonite in granular form and a 95% elemental S fine powder product applied in suspension) as main plots, four rates of elemental sulphur (0, 30, 60 and 120 kg ha^{-1}) as sub-plots and five rates (0, 5, 10, 20, and 40 kg ha^{-1}) of ammonium sulphate (21-0-0-24) as sub-sub-plots. The granular forms of elemental S were broadcasted and incorporated in the top 2-4 cm of the soil. The fine powdered product was suspended in water, according to manufacturer's specifications, and sprayed on the soil surface and subsequently incorporated in the top 2-4 cm of the soil. The various rates of ammonium sulphate were hand-broadcasted and subsequently incorporated. The balance of NH_4^{+}-N to match the nitrogen levels in the high ammonium sulphate treatment

was made up by blending urea with the lower rates rates of ammonium sulphate. In addition to the nitrogen received with the ammonium sulphate treatments 60 kg N ha^{-1} were deep banded prior to experimentation. Fifty kg ha^{-1} of phosphate as 12-51-0 were banded at approximately 8-10 cm prior to seeding in the seeding direction. Weststar canola, treated with Vitavax RS, was seeded on May 29, 1986 at a rate of 11 kg ha^{-1} at approximately 5 cm depth. The general layout of one block is illustrated in Fig. 1.

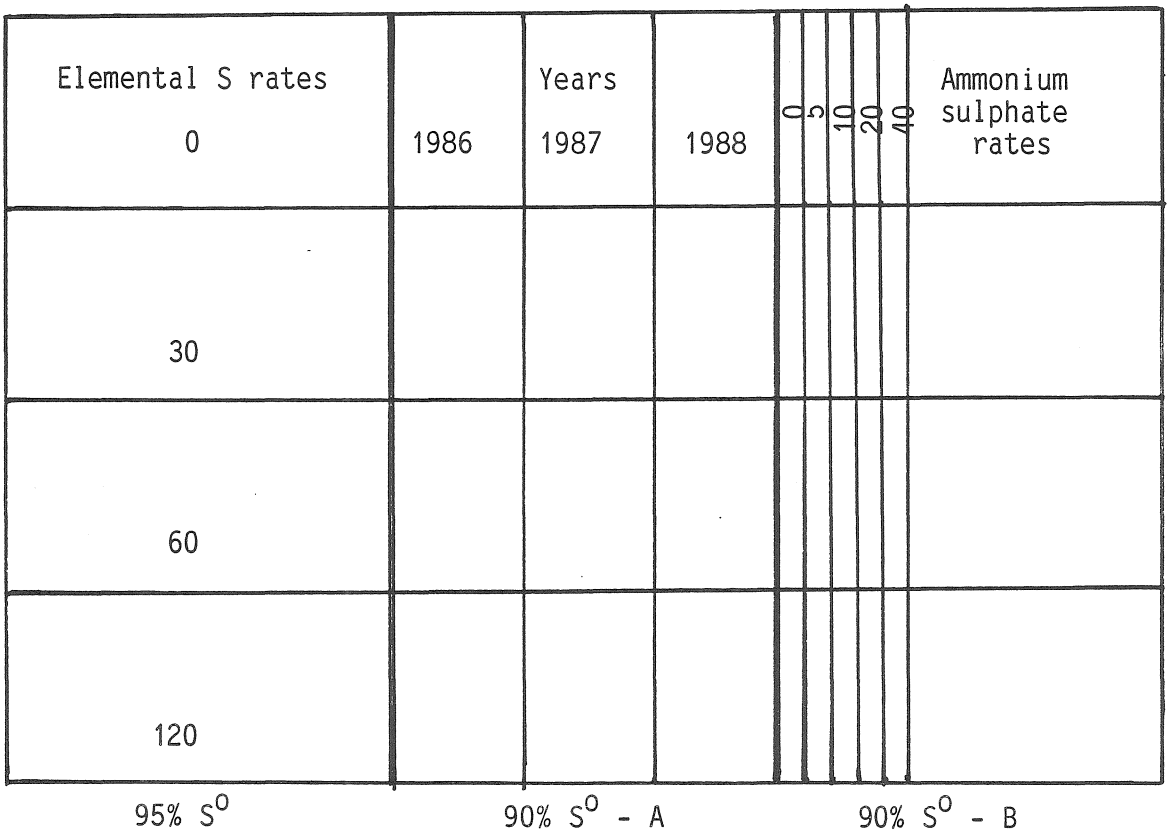


Fig. 1. Experimental layout of the treatments in a Block at the Wetaskiwin experiment (not randomized).

The size of a main plot was 22.5 m X 24 m and that of a sub-plot 22.5 m X 6 m. Each sub-plot was divided into three equal size portions (7.5 m X 6 m). Although the rates of elemental sulphur were applied to the whole of the

sub-plot, only one of the three portions was used in 1986 for ammonium sulphate application, thus utilizing 1/3 of the total area of the experimental site and allowing the remaining 2/3 for ammonium sulphate application in 1987 and 1988, respectively. The size of a sub-sub-plot was 1.5 m X 6 m. All treatments were replicated four times.

On June 18, 1986 the crop was sprayed by a BASF crew with Poast at a rate of 4.4 L ha^{-1}. The crop on the experimental site remained clean throughout the experiment.

The following sampling program was carried out throughout the growing season. On June 25, 1986 composite soil samples from each sub-sub-plot were obtained from the 0-15 and 15-30 cm depths (4 cores per depth per sub-sub-plot). Tissue samples of canola were also obtained from each sub-sub-plot and the four replicates were combined into one sample (60 plants per sample). The canola plants were at the rosette stage with 4-5 leaves expanded (stage 2.4 - 2.5). On July 14, 1986 plant sampling from each sub-sub-plot was again carried out in the same fashion. The canola plants were at late "bud" stage with 5-10 % early flowers (stage 3.3 - 4.1). Persistent rains at the time did not allow soil sampling. Thus, soil sampling was delayed till July 23, 1986 but again due to rain soil sampling was only completed from Block 3. At this time soil samples were taken from 0-15, 15-30 and 30-60 cm depths in the same fashion as before. Soil sampling of the remaining of the experimental site was cancelled. Visual symptoms of sulphur deficiency were observed and documented on July 23 as well as during a visit on August 6, 1986. Harvest of the plots was carried out on September 22-24, 1986. The middle three rows (3.04 m lengths) of each plot were hand-harvested, dried and the seed separated. On October 15 and 16, 1986, all sub-sub-plots were soil sampled for the final time. Soil sampling again consisted of 4 cores at 0-15, 15-30 and 30-60 cm depths per sub-sub-plot, which were subsequently composited into one sample per depth per sub-sub-plot.

Cumulative rain at the times of sampling was estimated from a rain gauge placed at the site and read six times over the growing season. This was 24 mm on June 25, 105 mm on July 23, and 207 mm at harvest.

Harvested plant material was dried in a forced-air oven at 60 C and ground to <40 mesh in a Wiley mill prior to chemical analysis. Total N and S analyses in plant material from all harvests were carried out by the Norwest Lab, Edmonton, Alberta. Total N was carried out in a digest from wet-ashing involving an acid mixture of H_2O_2 and H_2SO_4 described by Thomas et al. (1967), whereas total S was determined by combustion in a Leco analyzer.

Soil samples from all sampling dates were air-dried, ground and passed through a 2 mm sieve. Sulphates and nitrates were carried out in $CaCl_2$ extracts on all samples from the two samplings during the growing season and sulphates on all post harvest samples by Norwest Lab.

All data, except those from composite samples of all four reps, were subjected to analysis of variance for a split-split plot design with three main plots, four sub-plots, and five sub-sub-plots with four replicates (blocks). Response surfaces were estimated for all parameters using the following multiple regression model:

$$Y = b_y + b_1X_1 + b_2X_2 + b_3X_1^2 + b_4X_2^2 + b_5X_1X_2$$

where, Y = predicted value of the observed parameter, b_y = intercept, b_1, b_2, b_3, b_4, b_5 = calculated regression coefficients, X_1 = rate of elemental sulphur (kg ha^{-1}) and X_2 = rate of ammonium sulphate (kg ha^{-1}). R^2 values were calculated to determine the degree to which the response surface fit the observed data.

RESULTS AND DISCUSSION

Yields

Seed and vegetative yields were significantly affected by the various S application sources and rates (Table 1). Seed yields ranged from 582 kg ha^{-1} (8 bu/ac) to 2060 kg ha^{-1} (28 bu/ac) and vegetative yields from 5858 to 10389 kg ha^{-1}. There was a statistically significant difference in canola

interpreted that ammonium sulphate was not necessary with this elemental S product since the latter was an efficient source of $SO_4^=$-S for plant use. In

Table 2. Mean effect of elemental S sources on canola yields.

Source	Yield, kg ha^{-1}	
	Grain	Straw
95% Elemental S fine powder	1500[a@]	8290[a]
90% Elem. S + 10% bentonite - A	1306[b]	7623[b]
90% Elem. S + 10% bentonite - B	1481[a]	8459[a]

@ means for the same variable followed by the same letter are not statistically different.

contrast, for any given level of ammonium sulphate, there was no significant seed response to either of the two 90% elemental S + 10% bentonite mixtures (Figs 2b,c). This was also verified by orthogonal contrasts derived from the elemental S source X ammonium sulphate rate interaction (Table 3).

The vegetative yields followed a similar trend for the two 90% elemental S + 10% bentonite mixtures (Figs 3b,c). In the 95% suspension treatment, however, elemental S significantly affected vegetative yields but ammonium sulphate had no effect (Fig. 3a).

Nutrient Uptake

Uptake of S into aboveground plant parts was significantly affected by elemental S source, rate and ammonium sulphate rates (Table 4). A significant interaction between elemental S sources and rates (Tables 4 and 5) and elemental S and ammonium sulphate rates (Tables 4 and 6) was also observed. The former interaction was primarily a result of the strong positive effect of the 95% elemental S suspension rates on both canola seed and vegetative yield. There was no effect of elemental S rates on either seed or vegetative yields with the 90% elemental S + 10% bentonite-B source and all rates of the

Table 3. Effect of elemental S sources and ammonium sulphate rates on the yield of canola.

Elemental S Source	Ammonium sulphate rate kg ha^{-1}	Yield kg ha^{-1}	
		Seed	Vegetative
95% S^{o}	0	1465	7952
	5	1418	8949
	10	1499	8398
	20	1610	8096
	40	1508	8055
90% S^{o} - A	0	764	6457
	5	1241	7483
	10	1465	8243
	20	1434	7618
	40	1629	8316
90% S^{o} - B	0	860	6583
	5	1492	7910
	10	1644	8605
	20	1684	8838
	40	1728	9686

Contrasts

Comparison	Elem. S	ASL	ASQ	ASC	ASR	S^{o}XASL	S^{o}XASQ	S^{o}XASC	S^{o}XASR
95% X 90%-A	.01[@]	.01	.01	.01	ns	.01	.01	.01	.01
95% X 90%-B	ns	.01	.01	.01	ns	.01	.01	.01	.01
90% A X B	.01	.01	.01	.01	.05	ns	.01	ns	.01

[@] .01, .05 and ns = significant at P<.01, P<.05 and not significant

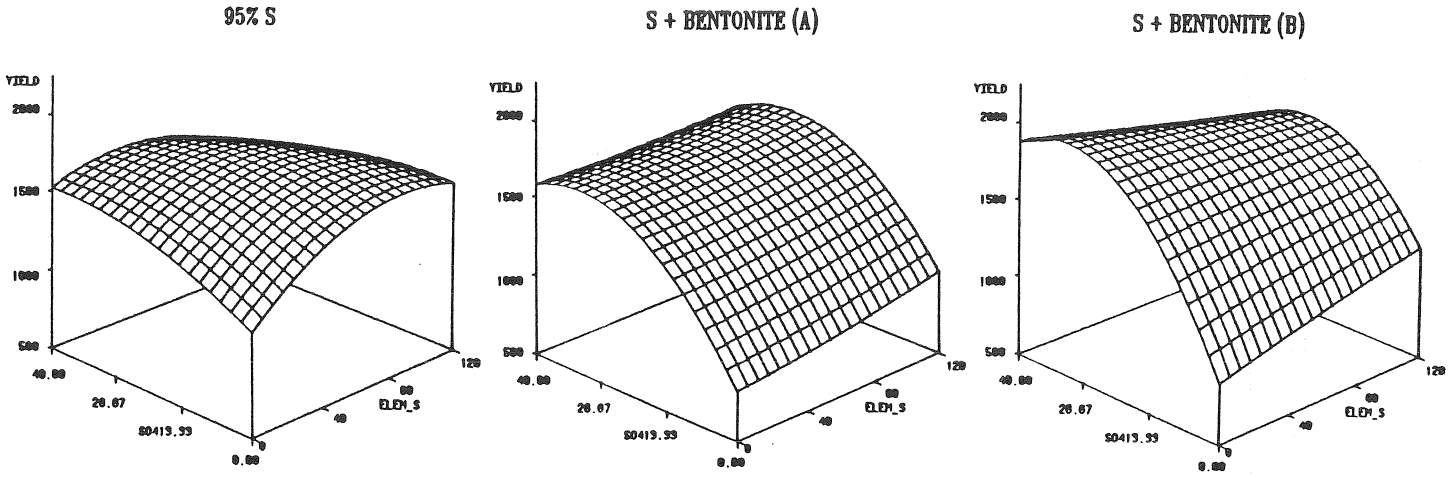


Fig. 2. Canola seed yields as influenced by elemental S sources, elemental S application rates and ammonium sulphate application rates.

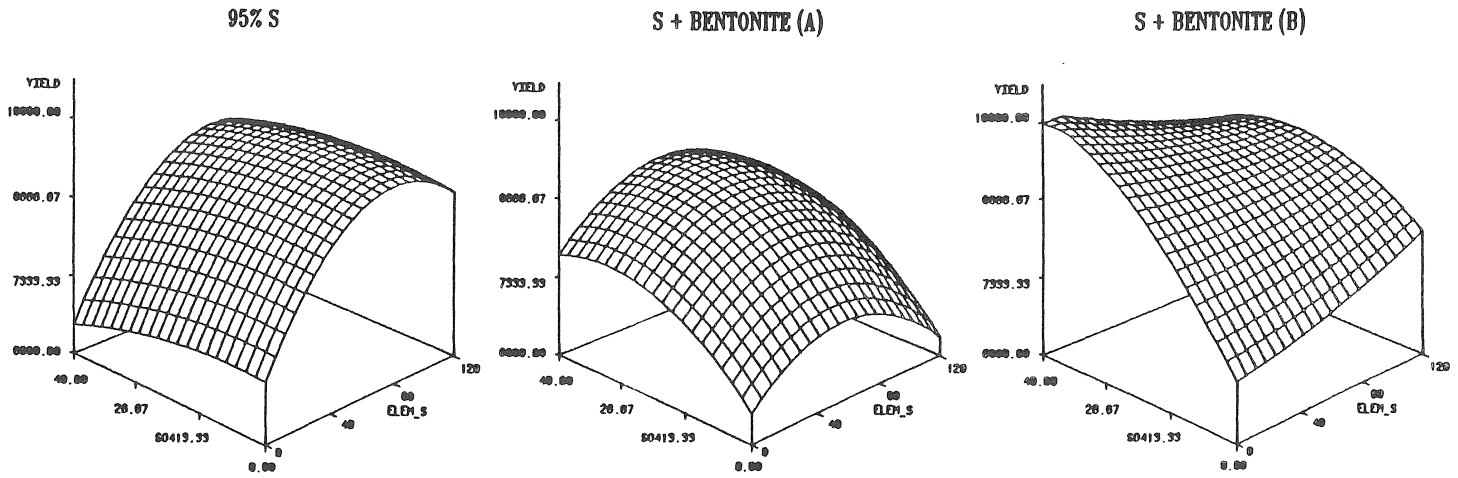


Fig. 3. Canola vegtative yields as influenced by elemental S source, elemental S application rate and ammonium sulphate rate.

Table 4. Significant effects of elemental S source and rate and ammonium sulphate rate on the uptake of S by aboveground canola plant parts.

Variable	Significance		
	Seed	Vegetative	Total
Elemental S source	.001***	.090ns	.062ns
Elemental S rate	.008**	.0001***	.0001***
Elem. S source X rate	.001***	.0001***	.0001***
Ammonium sulphate rate	.0001***	.0001***	.0001***
Elem. S source X AS rate	.0001***	.815ns	.418ns
Elem. S rate X AS rate	.174ns[@]	.683ns	.820ns
Elem. S source X rate X AS rate	.684ns	.423ns	.370ns

[@] ns = not significant

A-source had the same effect on both yield parameters (Table 5). The effect of ammonium sulphate on the uptake of S into the aboveground plant parts was stronger with the 90% elemental S + 10% bentonite mixture than with the 95% elemental S suspension, thus reflecting the superiority of the latter source in providing the plant with $SO_4^=$-S compared to the other sources. However, maximum S uptake in all cases was obtained with the addition of either 20 or 40 kg ammonium sulphate-$SO_4^=$-S ha^{-1} to these elemental S sources.

Nitrogen uptake was increased with S application rate (Tables 6 and 7). This is in agreement with the observation by Janzen and Bettany (1984) that S application significantly enhances N uptake at high N application rates in association with enhanced dry matter accumulation.

Nitrogen:sulphur ratios in the seed were two-fold those in the vegetative

Table 5. Effect of elemental S sources and ammonium sulphate rates on the uptake of S into canola abovegroud parts.

Elemental S Source	Ammonium sulphate rate	S Uptake, kg ha^{-1}	
		Seed	Vegetative
95% S^o	0	4.81	19.11
	5	4.86	22.99
	10	5.22	23.91
	20	6.00	23.70
	40	5.76	26.00
90% S^o - A	0	1.68	18.18
	5	3.01	13.14
	10	4.00	15.20
	20	4.44	15.64
	40	5.84	22.52
90% S^o - B	0	2.54	17.67
	5	4.78	21.18
	10	5.53	23.93
	20	5.80	23.06
	40	6.57	28.29

Contrasts

Comparison	Elem. S	ASL	ASQ	ASC	ASR	S^oXASL	S^oXASQ	S^oXASC	S^oXASR	
95% vs 90%-A	.01@	.01	.01	ns	ns	.01	.01	.01	.01	Seed
95% vs 90%-B	.01	.01	.01	.01	ns	.01	.01	.01	.01	
90% A vs B	.01	.01	.01	.01	ns	.01	.01	.01	.01	
95% vs 90%-A	.01	.01	.01	ns	.01	ns	.01	.01	.01	Veg.
95% vs 90%-B	ns	.01	.01	.01	ns	.01	.01	ns	ns	
90% A vs B	.01	.01	.01	ns	.01	.01	.01	.01	.01	

@ .01 and ns = significant at P<.01 and not significant, respectively.

Table 6. Significant effects of elemental S sources and rates and ammonium sulphate rates on the uptake of nitrogen into aboveground canola plant parts.

Variable	Significance		
	Seed	Vegetative	Total
Elemental S source	.001***	.073ns@	.017*
Elemental S rate	.008**	.110ns	.070ns
Elemental S source X rate	.278ns	.112ns	.052ns
Ammonium sulphate rate	.0001***	.019*	.0001***
Elem. S source X AS rate	.0001***	.123ns	.006**
Elem. S rate X AS rate	.254ns	.605ns	.667ns
S^{o} source X rate X AS rate	.917ns	.955ns	.967ns

@ ns = not significant

parts, indicating accumulation of N in the vegetative parts or proportionally reduced translocation of S into seeds. Janzen and Bettany (1984) offer an explanation for both mechanisms although they consider the latter as the most probable.

Soil sulphate and nitrate levels

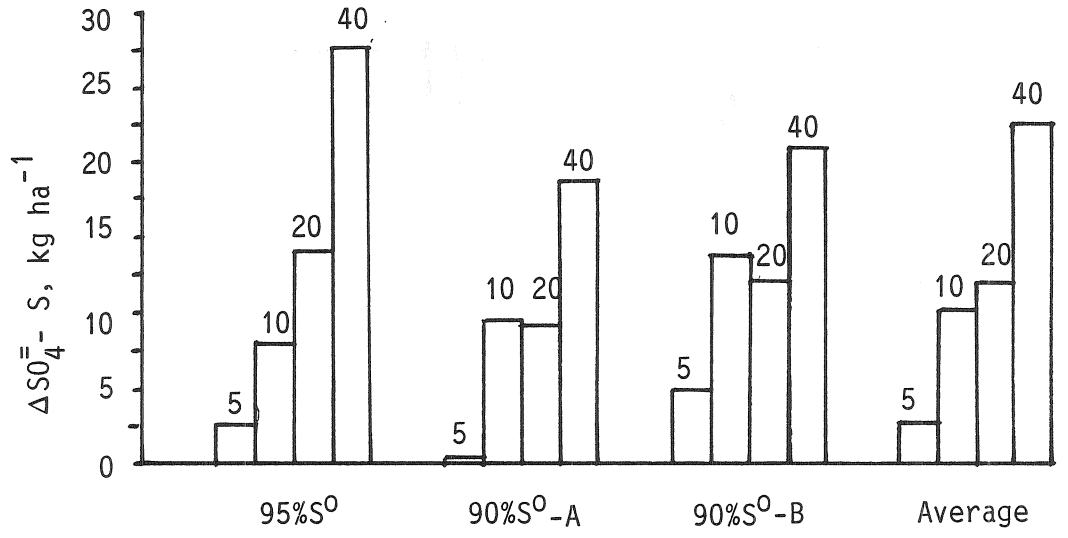
Elemental S source or rate and ammonium sulphate rates had no effect on nitrate N levels extracted from the 0-30 cm depth on June 25, 1986 (Table 8). The average NO_3^--N level in the whole experimental plot was 140 kg ha^{-1}. On the same sampling date (approximately 1 month after fertilizer application) sulphate S levels in the 0-30 cm depth were significantly affected only by ammonium sulphate rates (Table 8). Average residual soil $SO_4^=$-S levels on June 25, 1986 were calculated by subtracting the soil $SO_4^=$-S of the controls from those of the various sulphur treatments and are shown in Fig. 4.

Table 7. Effect of elemental S sources and ammonium sulphate rates on the Nitrogen uptake and N/S ratios of canola aboveground plant parts.

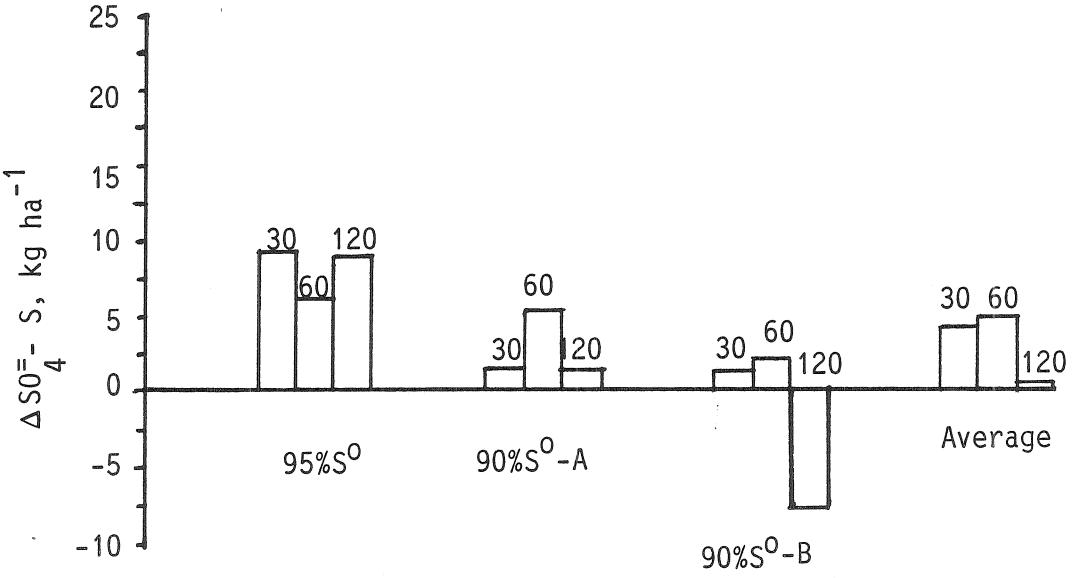
Elemental S source	Ammonium sulphate rate	Seed		Vegetative	
		Uptake	N/S	Uptake	N/S
	kg ha-1	kg ha^{-1}		kg ha^{-1}	
95% S^{o}	0	54.8	12.3	98.2	5.8
	5	54.1	11.9	107.4	5.4
	10	56.6	11.3	98.8	4.5
	20	61.2	10.1	91.7	4.1
	40	57.0	10.0	96.5	3.8
90% S^{o} - A	0	28.8	17.6	71.4	7.5
	5	47.3	16.3	82.7	6.6
	10	55.5	14.7	89.7	6.6
	20	54.9	12.8	88.2	6.2
	40	63.0	10.9	99.4	4.8
90% S^{o} - B	0	33.8	14.0	90.2	5.9
	5	61.1	13.0	91.5	5.1
	10	66.3	12.5	111.6	5.6
	20	68.0	11.8	108.6	5.1
	40	70.6	10.8	120.5	4.7

		Contrasts							
Comparison	Elem. S	ASL	ASQ	ASC	ASR	S^{o}XASL	S^{o}XASQ	S^{o}XASC	S^{o}XASR
Seed Uptake									
95% X 90%-A	.01[@]	.01	.01	.01	ns	.01	.01	.01	.01
95% X 90%-B	.01	.01	.01	.01	.05	.01	.01	.01	.01
90% A X B	.01	.01	.01	.01	.01	ns	.01	ns	ns
Seed N/S									
95% X 90%-A	.01	.01	.01	ns	.05	.05	.01	ns	ns
95% X 90%-B	.01	.01	ns	ns	ns	.01	.01	ns	ns
90% A X B	.01	.01	.01	ns	ns	.01	.01	ns	.05
Vegetative Uptake									
95% X 90%-A	.01	.01	ns	.01	ns	.01	.01	ns	.05
95% X 90%-B	.01	.01	ns	.01	ns	.01	.01	ns	ns
90% A X B	.01	.01	.01	.01	.01	ns	.01	ns	ns
Vegetative N/S									
95% X 90%-A	.01	.01	.01	.05	ns	.05	.01	ns	ns
95% X 90%-B	.01	.01	.01	ns	ns	.01	.01	ns	ns
90% A X B	.01	.01	ns	.01	.01	.01	.01	ns	ns

[@] .01, .05 and ns = significant at P<0.01, P<0.05 and not significant.



(a) AMMONIUM SULPHATE



(b) ELEMENTAL SULPHUR

Fig. 4. Average residual $SO_4^{=}$-S levels in the 0-30 cm depth on June 25, 1986 (approximately 1 month after fertilizer application).

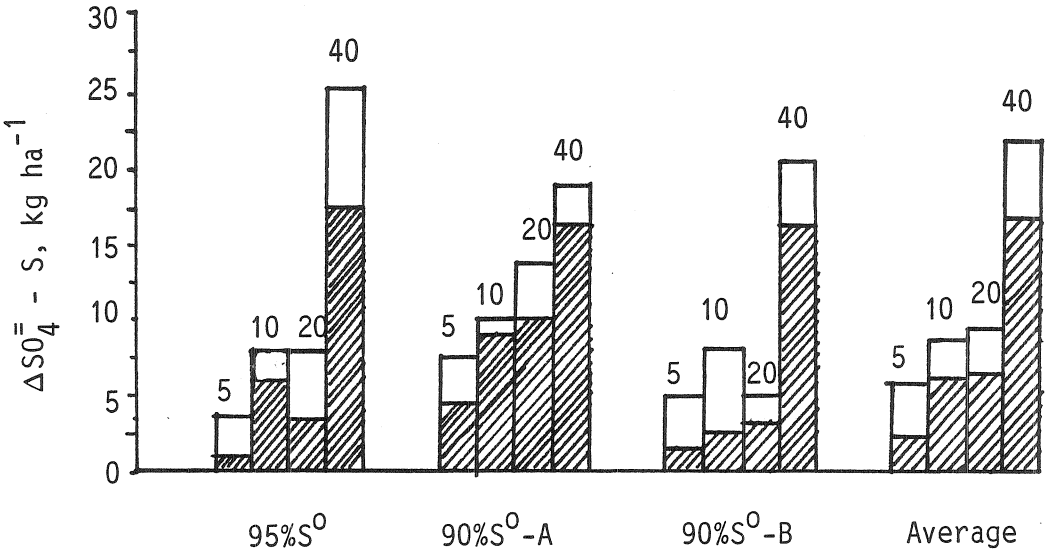
Table 8. Significant effects of elemental S sources and rates and ammonium sulphate rates on the sulphate and nitrate levels in the 0-30 cm depth one month after fertilizer application.

Variable	Significance	
	Sulphates	Nitrates
Elemental S source	.240ns[@]	.625ns
Elemental S rate	.369ns	.706ns
Elemental S source X rate	.563ns	.438ns
Ammonium sulphate rate	.0001***	.065ns
Elem. S source X AS rate	.819ns	.588ns
Elem. S rate X AS rate	.688ns	.535ns
Elem. S source X rate X AS rate	.995ns	.721ns

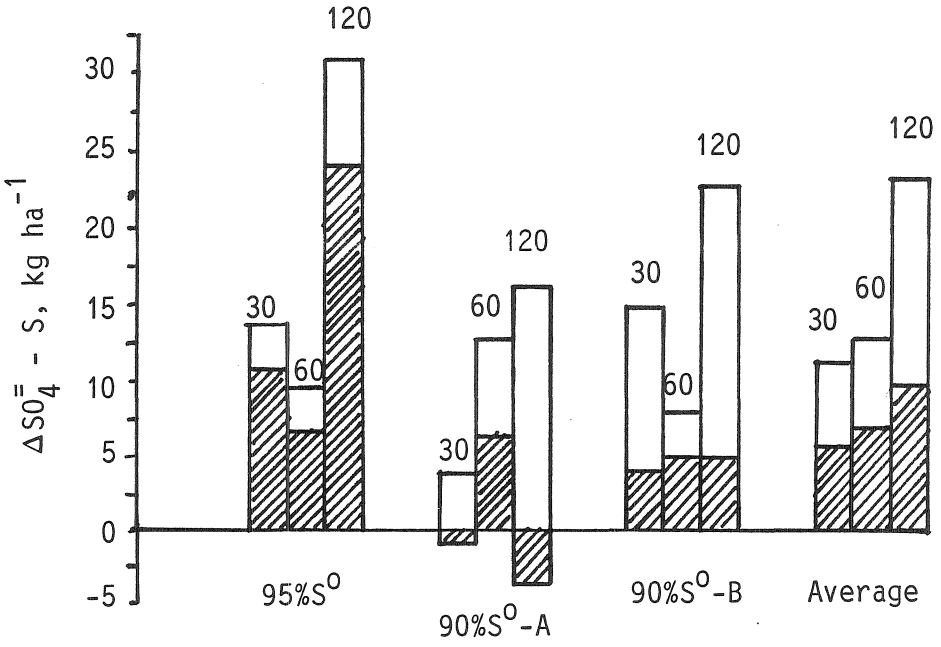
[@] ns = not significant

Approximately 50% of $SO_4^=$-S from ammonium sulphate could be recovered in the 0-30 cm depth on that date. Sulphate S levels in the top 30 cm of the 95% elemental S suspension were approximately 5-6 kg ha^{-1} (representing recoveries of 5 - 20 %), whereas those of the two 90% elemental S + 10% bentonite mixtures were considered to be at background levels.

There was no statistical evaluation of the soil $SO_4^=$-S and NO_3^--N data for July 23, 1986 since only one block was sampled. Qualitative evaluation of the data (Fig. 5) indicated that most of the $SO_4^=$-S from the fertilizer was removed from the top 30 cm of the soil either via uptake by the plant or leaching. Considerable amounts of residual fertilizer (approximately 20-30%) could be recovered in the 30-60 cm depth of the ammonium sulphate and 95% elemental S suspension treatments. However, for the same depth in the 90%



(a) AMMONIUM SULPHATE



(b) ELEMENTAL SUPLHUR

Fig. 5. Average residual ferilizer $SO_4^{=}$-S levels in the 0-60cm depth of block 3 on July 23, 1986 (approximately two months after fertilizer application). Levels in the 30-60 cm depth are represented by the hatched portion of the bar.

elemental S + 10% bentonite mixture treatments soil $SO_4^=$-S were at background levels.

There was a highly statistically significant relationship between the final seed yields and the $SO_4^=$-S extracted from the soil on June 25, 1986 (Table 9). Although this relationship has probably no value from a soil

Table 9. Relationship between canola seed yield and soil $SO_4^=$-S levels during the growing season for the 0 elemental S treatments.

Sampling date	Growth stage of canola	Sampling depth cm	df	Equation	r^2
June 25[@]	rosette	0-30	13	Y = 285.65 + 39.01 X	.75***
June 26[#]	bud	0-30	13	Y = 830.18 + 28.62 X	.14ns
		30-60	13	Y = 500.03 + 30.11 X	.23ns

[@] Average of 4 replicates, [#] for Block 3 only.

testing point of view, in combination with the absence of a relationship for July 23, it would indicate that yields are closely related to the "available" $SO_4^=$-S levels during the earlier part of the growing season. An empirical calculation in Table 10 suggests that the two 90% elemental S + 10% bentonite mixtures did not provide the necessary "available" $SO_4^=$-S for maximum growth. Though empirical, it is interested that the estimated yields for the 120 kg ha^{-1} rate were similar to the actual yields, whereas those of the 30 and 60 kg ha^{-1} treatments were greater than the actual. A completely reverse trend was observed with the 95% elemental S suspension, thus suggesting that this form of elemental S provided $SO_4^=$-S throughout the earlier part of the gowing season.

The residual fertilizer derived $SO_4^=$-S is shown in Fig. 6. The high average values for the 30 kg ha^{-1} treatment of the 90% emental S + 10% bentonite mixture-B are attributable to one block, where significant accumulation of $SO_4^=$-S occured and to the lower $SO_4^=$-S levels of the control treatments compared to other controls. It is, however, apparent that considerable amounts of $SO_4^=$-S accumulated in the soil of the 95% elemental S suspension and 90% elemental S + 10% bentonite mixture-B for use by the subsequent crop. This was not the case with the 90% elemental S + 10% bentonite mixture-A.

Table 10. Comparison between estimated and actual yields for the 0 ammonium sulphate treatment of the various elemental sulphur sources.

Elemental S source	Rate kg ha^{-1}	Yield, kg ha^{-1}	
		Estimated@	Actual
95% S^o	30	1133	752
	60	914	736
	120	975	985
90% S^o- A	30	1125	841
	60	1335	925
	120	917	1003
90% S^o- B	30	1361	1722
	60	1031	1705
	120	1189	1594

@ Estimated from $SO_4^=$-S levels in the 0-30 cm depth on June 25, 1986 and corresponding statistical equation in Table 8.

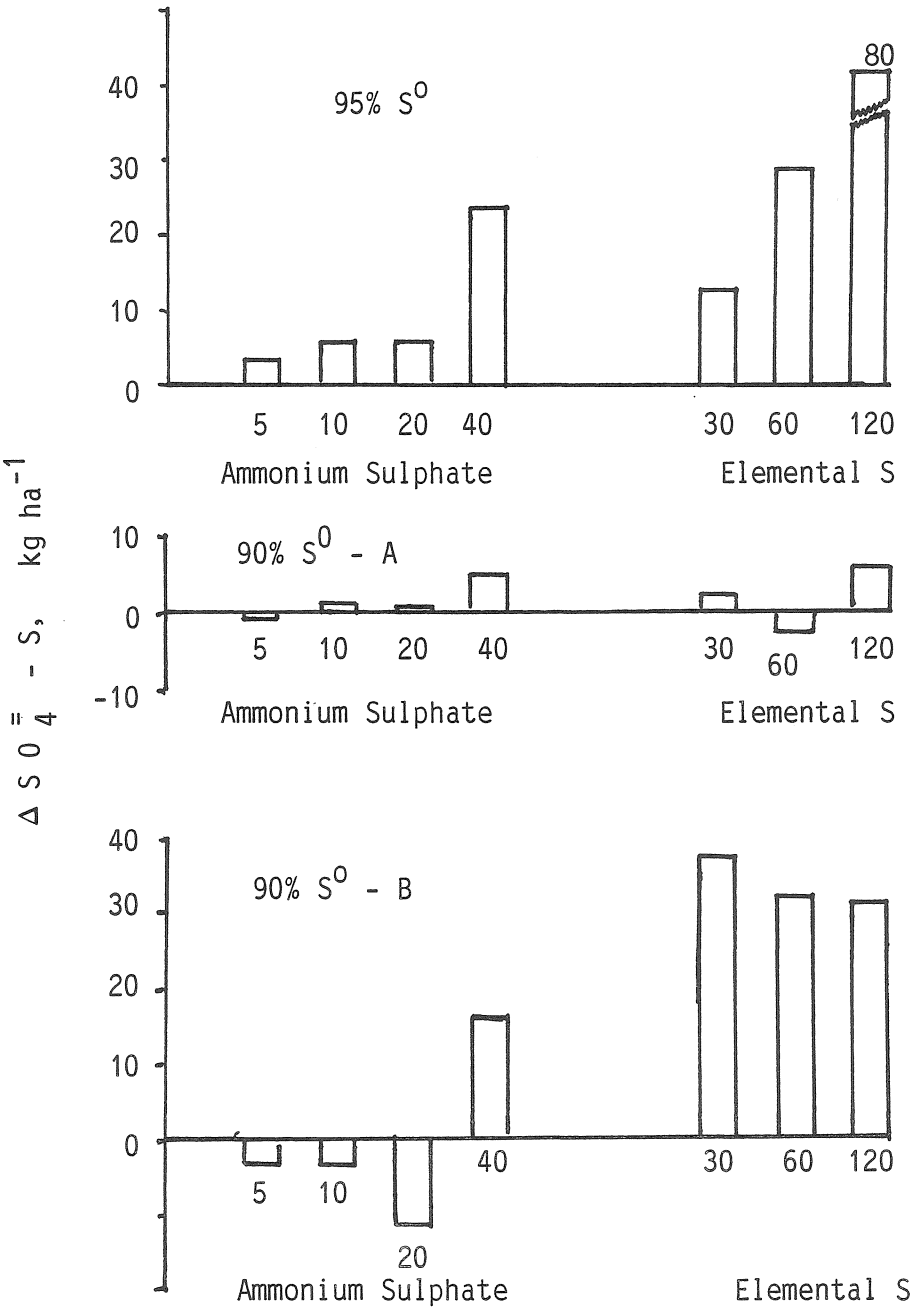


Fig. 6. Average residual $SO_4^{=}$-S levels in the 0-60 cm depth after harvest (October 12, 1986).

Plant tissue levels during the growing season

The relationship between final yields and total S in the plant tissue of all 0 kg ha^{-1} elemental S treatments and the corresponding N/S ratios at rosette and bud growth stages are shown in Table 11. The N/S ratios at bud stage provided the best fit with the obtained seed yield values.

Table 11. Relationship between canola seed yield and plant tissue total S content and N/S ratios during the growing season for the 0 elemental S treatments.

Growth stage	Parameter	df	Equation	r^2
Rosette@	Total S	13	Y = -612.34 + 3070.04X	.54*
	N/S	13	Y = 1623.25 - 31.27X	.05ns
Bud#	Total S	13	Y = 540.93 + 2395X	.47ns
	N/S	13	Y = 1928.04 - 42.48X	.67**

@ Average of four replicates, # values from Block 3 only.

CONCLUSIONS

The first year experience with one experiment on the comparison of three elemental S sources suggested that, under the experimental conditions of the experiment, 90% elemental S + 10% bentonite mixtures are not suitable for supplying the necessary "available" S for maximum canola yields. In contrast, a 95% elemental S suspension provided maximum yields with 30 kg ha^{-1} application rate. The effectiveness of this product at lower rates must be evaluated. Maximum yields with the 90% elemental S products were obtained only when 20 to 40 kg of ammonium sulphate ha^{-1} were supplied to the soil. The experimental design did not allow for the direct comparison of the various

elemental S sources with ammonium sulphate, although indirectly ammonium sulphate and the 95% elemental S supension performed equally. The question in choosing one of the two latter products for alleviation of S deficiency in the year of application remains with rates of application and cost of each product. The residual effect of all elemental S sources will be evaluated in the remaining three years of this experiment. Three other sites will be established to fulfill the multisite requirement and further afford a direct comparison of elemental S with ammonium sulphate.

LITERATURE

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