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Canola Agronomic Research Program

Ag # 95-04

"Alternative Sulfur Fertilizer Sources for Canola"

FINAL REPORT

December 31, 1995

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Abstract:

Canola is a crop with a high demand for sulfur and without adequate available sulfur in the soil, severe yield losses can occur. A field study was conducted in 1995 near Star City, Saskatchewan which compared the effectiveness of different sulfur forms added as sources of fertilizer sulfur for canola. The sulfur forms compared were powdered elemental sulfur, powdered elemental sulfur combined with sewage sludge and lime, waste wallboard gypsum, waste gypsum from sodium sulfate mining, and fertilizer grade ammonium sulfate. In the year of application, elemental sulfur alone was least effective in increasing sulfur availability and yield of canola while ammonium sulfate was most effective. The observed lower sulfur availability and yield response from the elemental sulfur source is due to incomplete conversion of the elemental sulfur to the plant available sulfate form in the soil in the year of application. The waste gypsum sources performed nearly as well as the ammonium sulfate, pointing to the possibility of using such sources of sulfur as another means to increase soil sulfur availability in the Gray soil zone. Combinations of powdered elemental sulfur with lime and sewage sludge appear to result in a slight enhancement of sulfur oxidation and availability as well as offering a potential means of binding the elemental sulfur into a granule or prill which can be easily handled and applied.

Background and Objectives:

Canola is a crop with a high demand for sulfur as a plant nutrient. Canola sulfur requirements are about double that of cereals. Furthermore, the addition of high rates of nitrogen fertilizer to a sulfur - deficient soil can induce severe sulfur deficiency in the canola such that almost complete inhibition of seed yield may occur. Owing to the importance of sulfur nutrition in canola production, sulfur is routinely added to the fertilizer blend, even in soils that test relatively high in plant available sulfur. Goals in sulfur fertilization are to ensure that the canola crop has an adequate supply of sulfur in plant available form at the time of crop demand and that maximum efficiency is realized in terms of crop utilization and yield response relative to product cost.

The two main forms of sulfur fertilizers currently used in western Canada are elemental sulfur products and ammonium sulfate. The elemental sulfur products, usually characterized by a yellowish-brownish color and a high sulfur analysis, require a conversion in the soil (oxidation) in order to become plant available. For this reason it is usually recommended that for maximum benefit, elemental products be applied some time in advance of crop need in order to give it time to oxidize to the plant available sulfate form. Probably the most common sulfur source used by producers is ammonium sulfate (21-0-0-24). Ammonium sulfate is completely water soluble and the sulfur is in the sulfate form which plants can directly utilize. As such, ammonium sulfate is generally considered more effective as a sulfur source in the year of application.

Elemental sulfur is a by-product of the sour natural gas processing industry in Alberta, and is generally inexpensive and plentiful. In Saskatchewan soils, the plant availability of elemental sulfur fertilizers is often restricted by low oxidation rates. The low oxidation rates of elemental sulfur to sulfate are in large part due to cold, dry soil conditions which restrict the activity of the soil microorganisms responsible for the oxidation. Particle size of the elemental sulfur also affects oxidation rates, with large fragments oxidizing only very slowly. One way of increasing the oxidation rate is to finely grind the elemental sulfur into a powder. However, this causes considerable handling and application difficulties and safety concerns as elemental sulfur dust is explosive. Approaches which have been used to enhance oxidation rate include the combination of elemental sulfur with clays as a binding agent and to enhance dispersion of the elemental sulfur in the soil. Another possible approach to enhance the ease of handling and application of elemental sulfur while maintaining or increasing its oxidation rate is to combine the elemental sulfur with an organic binding agent like sewage sludge. The sludge will bind the small particles together in an easily decomposed matrix which may also enhance the activity of the sulfur oxidizing microorganisms.

Other sulfur sources exist in Western Canada that have not yet been explored for their potential value as sulfur fertilizers for canola production. One such source with potentially low cost and relatively high efficacy is waste gypsum (calcium sulfate). Waste gypsum is derived from wallboard manufacturing and is also a by-product of sodium sulfate mining. Such sources, with some small amount of processing, could represent cost-effective alternatives to traditional manufactured sulfur fertilizer products like ammonium sulfate.

The objective of this study, therefore, was to evaluate the effectiveness of two sulfur fertilizer product concepts: 1) powdered elemental sulfur mixed with sewage sludge and lime and 2) waste wallboard and mining gypsum in comparison with elemental sulfur powder alone and standard fertilizer grade ammonium sulfate. To achieve this objective, assessment was made of differences in plant sulfur concentration and uptake, residual soil sulfate and yield response in a replicated field experiment comparing the sources.

Experimental Method:

Experimental design

In April of 1995, a site on a farm field in the Gray soil zone was selected for the sulfur fertilizer comparison trial. The site (NW 13-44-17-W2), known to be responsive to addition of sulfur fertilizer, was located about two miles south of highway 41 near Star City, Saskatchewan on the Lyle Cowell farm. The surface soil is a Waitville loam of level to gently undulating topography, with a band of coarser - textured gravelly material at variable depth (0.3 to 1.5 m). Despite the wet soil conditions in early spring in this part of the province, soil samples were obtained from across the plot area. The samples revealed relatively low levels of plant available sulfate (16 to 20 lbs sulfate sulfur 0-15 cm depth) in the surface layer. At this level of soil test sulfate, a sulfur recommendation of 15 to 25 lb S / acre would be typical for canola.

Six different sulfur fertilizers were prepared for the experiment:

1) elemental sulfur powder alone (82 μm)
2) elemental sulfur powder + Saskatoon digested sewage sludge + lime (Mix)
3) elemental sulfur powder + lime
4) waste wallboard gypsum (coarse grind and sieving)
5) waste sodium sulfate mining gypsum (SOTEC, Cabri, Saskatchewan)
6) fertilizer grade ammonium sulfate

Each of the sulfur fertilizer products were applied at four different sulfur application rates: 0, 20, 40 and 80 kg S / ha. Pre-weighed amounts of the fertilizer mixtures were prepared beforehand to simplify application in the field. Each treatment was replicated three times with the experiment set up as a randomized complete block design, with check and control treatments included.

In the first week of May, prior to seeding, the plots were surveyed and marked out. Each plot, 8 meters x 8 meters, received the appropriate amount of each sulfur fertilizer product according to prescribed sulfur addition rate. Ammonium nitrate was added to each plot to ensure that nitrogen deficiency did not limit yield. The plot area had also received anhydrous ammonia at a rate of 100 lb N / acre the previous fall.

The sulfur fertilizers were applied in a broadcast and incorporate method of application on May 9, with the fertilizer spread across the plot area and then incorporated with a sweep-type cultivator. The problems in handling finely ground elemental sulfur powder immediately became evident to us in the difficulty we encountered getting a uniform distribution of elemental sulfur powder across the plot area even with only a slight wind.
One week following (May 16) the application of the fertilizer, the plots were seeded to Argentine canola (var. Garrison) using an International 7400 drill run across the plots.

Weed control on the plots was accomplished through the use of a pre-emergent granular herbicide which worked well. Although general conditions in the area during the summer of 1995 were drier than normal, the canola faired well due to rains later on in July and a good stand of canola was achieved.

Plant and soil measurements

On July 24, when the canola was in mid-flowering stage, square meter samples of the plants were taken from each of the plots. Typically, it is the supply of nutrient early on in the growth stage, usually up until the time of flowering, that has the greatest impact so it was felt that a mid-season sampling was important in the product comparison. The samples obtained were dried and weighed to provide a mid-season measurement of total plant dry matter production. The samples were then ground and analyzed for total sulfur and nitrogen concentration using a Leco model 2000 CNS analyzer. Using the plant sulfur and nitrogen concentrations along with dry matter yield, total nutrient uptake at the time of flowering was calculated for each of the treatments, and differences in uptake used as an indication of differences in plant availability and efficacy of the products.

Again in the first week of September (Sept. 1), when the canola seeds in the pod were beginning to change from green to brown, square meter samples were taken from each of the plots. The plant material obtained was dried and threshed to provide a seed yield and straw yield from each square meter sampling area. The seed and straw samples were then ground and run through the Leco C,N,S analyzer to provide sulfur and nitrogen concentrations in the seed and straw. These data were then used to calculate total sulfur and nitrogen uptakes for each of the treatments.

On September 16, the plots were sampled for residual soil sulfate levels. 0-30 cm samples of soil (4 cores per plot) were taken from each of the plots and analyzed for water soluble sulfate levels using extraction with 0.001M calcium chloride.

Statistical analyses

Statistical analyses of the data was performed using analysis of variance (ANOVA) in the SAS computer statistics program. Least significant difference (LSD) values are reported and used to test for significant differences among means.

Results and Discussion:

Overall, a significant increase in mid-season dry matter yield was observed in response to increasing rates of added sulfur fertilizer (Tables 1 and 2). Rates of added sulfur above 20 kg S / ha did not result in significant increases in final grain and straw yield. It therefore appears that a sulfur fertilization rate in the range of 15-25 kg S / ha would be satisfactory in ensuring adequate sulfur nutrition of the canola crop under the conditions present. Comparison of yield increases induced by the different sulfur sources revealed the elemental sulfur to be least effective and ammonium sulfate the most effective sources in terms of increased yield, but with the waste gypsum sources closely approaching the ammonium sulfate. These results agree with previous research work (Solberg, 1982, Karamanos and Janzen, 1991) which has shown elemental sulfur sources to give the lowest yield responses with highest yield gains from totally soluble sources such as ammonium sulfate. Fertilizer gypsum sources have typically come out somewhere intermediate in yield response in the year of application (Nuttall, 1979, Harapiak, 1980). The results of the current study suggest that the waste gypsum sources are equally effective in inducing yield responses in comparison to fertilizer grade gypsum and that their performance under the conditions present in this field study was nearly as good as for ammonium sulfate. While combination of elemental sulfur with sewage sludge and lime has previously shown some small yield advantages in the growth chamber over elemental sulfur alone (Sulewski and Schoenau, 1995), the trend was less clear in the current field study. A relatively small overall effect coupled with higher variability under field conditions likely contributes to the lack of a significant impact of the combinations on yield over elemental sulfur alone.

Table 1. Average values for mid-season biomass and final grain and straw yield as related to sulfur rate and source.

	Dry Matter Production		
Rate	Mid Season	Grain	Straw
		$T\ ha^{-1}$	
20	2.68	1.85	5.11
40	2.76	1.89	5.16
80	3.25	1.88	5.48
LSD (0.05)	0.36	NS†	NS†
S Source	Mid Season	Grain	Straw
		$T\ ha^{-1}$	
Control††	2.13	1.63	4.90
S°	2.79	1.78	4.85
S° Mixture	2.90	1.79	5.14
S°+ Lime	2.99	1.85	5.12
Wallboard Gypsum	3.09	2.02	5.60
Gypsum Ore	3.08	2.02	5.44
Ammonium Sulfate	3.28	2.03	5.72
LSD (0.05)	0.56	NS†	NS†

† F value for the model not significant.

†† Control treatments consists of ammonium nitrate application equilavent to N supplied by ammonium sulfate.

Table 2. Mid-season biomass and final grain and straw yield of canola.

	Sulfur Applied kg ha^{-1}								
	20			40			80		
	Mid-Season	Final Yield		Mid-Season	Final Yield		Mid-Season	Final Yield	
Rate x S Source	Biomass	Grain	Straw	Biomass	Grain	Straw	Biomass	Grain	Straw
	T ha^{-1}								
Control††	2.06	1.58	4.63	1.84	1.70	4.94	2.48	1.62	5.11
S°	2.55	1.80	4.70	2.70	1.89	4.54	3.14	1.66	5.32
S° Mixture	2.42	1.76	5.24	2.65	1.76	4.99	3.62	1.84	5.18
S°+ Lime	2.97	1.73	5.00	2.68	2.09	5.09	3.33	1.74	5.28
Wallboard Gypsum	3.02	1.93	5.39	3.48	1.94	5.31	2.76	2.19	6.09
Gypsum Ore	2.70	2.09	5.23	2.75	1.94	5.70	3.78	2.02	5.41
Ammonium Sulfate	2.95	2.07	5.59	3.23	1.95	5.58	3.66	2.06	5.98

Mid-Season Biomass
LSD (0.05) = 0.96
Grain
LSD (0.05) = NS†
Straw
LSD (0.05) = NS†

† F value for the model not significant.
†† Control treatments consists of ammonium nitrate application equilavent to N supplied by ammonium sulfate.

Plant sulfur uptake is probably the most useful indicator of relative efficacy of the different sulfur fertilizer forms. Overall, compared to the control, the addition of sulfur fertilizer resulted in increased sulfur uptake by the canola, with significant increases as a function of rate observed at both mid-season and harvest (Tables 3 and 4). Following the pattern observed in yields, the increase in sulfur uptake as a result of fertilizer sulfur addition was lowest in the elemental sulfur powder treatment alone, and highest in the ammonium sulfate, with intermediate values for the waste gypsum sources. Gypsum can be considered a slowly available sulfate source, owing to its low solubility compared to ammonium sulfate, which is completely water soluble. The fact that gypsum is not completely water soluble may have some advantage in reducing losses of sulfate by leaching before the period of maximum plant demand. This would be of greatest benefit in high leaching environments such as coarse textured soils in the Gray soil zone and where the application was made in the fall rather than the spring. Combination of the elemental sulfur with lime and sewage sludge appears to result in some enhancement in sulfur availability over elemental sulfur alone. The sewage sludge and lime may act to enhance oxidation by buffering the acidity produced during the oxidation of the elemental sulfur as well as perhaps promoting the activity of sulfur oxidizing heterotrophic bacteria.

Table 3. Average values for plant sulfur uptake at flowering and maturity (grain + straw) as related to sulfur source and rate.

	Sulfur Uptake		
Rate	Mid Season	Grain	Straw
		kg ha^{-1}	
20	11.41	9.24	19.98
40	14.69	9.88	21.88
80	20.09	10.30	28.74
LSD (0.05)	2.88	NS†	3.06
S Source	Mid Season	Grain	Straw
		kg ha^{-1}	
Control††	8.51	8.03	16.96
S°	12.88	9.28	21.65
S° Mixture	15.11	9.06	21.96
S°+ Lime	13.20	9.18	20.47
Wallboard Gypsum	19.88	10.73	27.56
Gypsum Ore	15.30	10.93	24.38
Ammonium Sulfate	22.89	11.42	31.76
LSD (0.05)	4.40	NS†	4.68

† F value for the model not significant.

†† Control treatments consists of ammonium nitrate application equilavent to N supplied by ammonium sulfate.

Table 4. Sulfur uptake by canola at mid-season (flowering) and harvest.

Rate x S Source	Sulfur Applied $kg\ ha^{-1}$ 20 Mid-Season S Uptake	20 Final S Uptake Grain	20 Final S Uptake Straw	40 Mid-Season S Uptake	40 Final S Uptake Grain	40 Final S Uptake Straw	80 Mid-Season S Uptake	80 Final S Uptake Grain	80 Final S Uptake Straw
	$kg\ ha^{-1}$								
Control††	8.96	7.22	13.16	7.38	8.29	15.84	9.19	8.59	21.86
S°	9.40	8.73	19.02	11.23	9.83	20.62	18.01	9.28	25.31
S° Mixture	12.75	8.33	19.74	13.91	9.28	20.29	18.68	9.57	25.87
S°+ Lime	11.30	8.34	16.65	10.85	10.27	20.66	17.44	8.93	24.11
Wallboard Gypsum	11.77	9.72	23.13	26.19	10.47	22.93	21.69	12.01	36.61
Gypsum Ore	9.86	11.23	21.55	12.03	10.07	24.49	24.02	11.47	27.11
Ammonium Sulfate	15.85	11.08	26.60	21.24	10.91	28.33	31.59	12.28	40.36

Mid-Season S uptake
LSD (0.05) = 7.63
Grain S uptake
LSD (0.05) = NS†
Straw S uptake
LSD (0.05) = 8.11

† F value for the model not significant.
†† Control treatments consists of ammonium nitrate application equilavent to N supplied by ammonium sulfate.

The addition of sulfur increased the plant demand for nitrogen, with increased nitrogen uptake by canola plants as sulfur fertilization rate was increased. The residual levels of plant available sulfate in the soil (kg S/ ha 0-30cm) at the end of the growing season increased with the rate of sulfur fertilization (Table 5 and 6). The high levels of residual sulfate at the highest sulfur fertilization rate (80 kg S / ha) indicate that more sulfur fertilizer was applied that what the plant could assimilate at the highest rates. Correspondingly the sulfur fertilizer use efficiency by the canola crop decreased from about 50% at the 20 kg S / ha rate to 12% FUE at the 80 kg S / ha rate. Following the patterns in yield and sulfur uptake discussed previously, the residual levels of soluble sulfate were lowest in the elemental sulfur treatments and highest in the ammonium sulfate treatments, with intermediate levels found in the waste gypsum treatments. The low sulfur fertilizer use efficiency values observed in the elemental S treatments as indicated in Table 5 (15 - 20%) can be attributed to a low rate of oxidation of the elemental sulfur to soluble sulfate. Higher FUE values for waste gypsum (33-36%) reflect the fact that the sulfur is already in the plant available sulfate form, although the lower solubility contributes to lower fertilizer use efficiency compared to ammonium sulfate. Higher rates of sulfur fertilizer application result in greater residual levels of sulfate and this is particularly true for the ammonium sulfate forms. In the case of ammonium sulfate, the fact that what is not used by the plant remains as soluble sulfate increases the risk of sulfate losses by leaching before the period of plant demand the next year.

Table 5. Average residual soil sulfate levels (end of season) and sulfur fertilizer use efficiency (SUE) as related to sulfur rate and source.

Rate	SO_4-S	SUE
	kg ha^{-1}	%
20	9.8	51.5
40	12.4	22.2
80	27.1	12.5
LSD (0.05)	2.12	9.49

S Source	SO_4-S	SUE
	kg ha^{-1}	%
Control††	8.2	-
S°	11.5	19.3
S° Mixture	12.0	19.4
S°+ Lime	12.7	14.4
Wallboard Gypsum	19.8	36.1
Gypsum Ore	21.1	32.8
Ammonium Sulfate	29.7	50.7
LSD (0.05)	3.24	13.42

†† Control treatments consists of ammonium nitrate application equilavent to N supplied by ammonium sulfate.

Table 6. Residual soil sulfate, nitrate, and sulfur fertilizer use efficiency.

	Sulfur Applied kg ha^{-1}								
	20			40			80		
Rate x S Source	Soil Nutrient SO_4-S	Soil Nutrient NO_3-N	S Fertilizer Use Efficiency	Soil Nutrient SO_4-S	Soil Nutrient NO_3-N	S Fertilizer Use Efficiency	Soil Nutrient SO_4-S	Soil Nutrient NO_3-N	S Fertilizer Use Efficiency
	kg ha^{-1}		%	kg ha^{-1}		%	kg ha^{-1}		%
Control††	10.06	5.96	-	7.71	7.28	-	6.97	9.89	-
S°	9.70	6.01	36.84	9.03	5.72	15.81	15.88	9.53	5.16
S° Mixture	7.05	5.39	38.48	8.56	6.51	13.60	20.31	9.07	6.23
S°+ Lime	7.17	4.91	23.02	11.98	7.73	17.00	18.88	6.76	3.22
Wallboard Gypsum	11.40	4.89	62.38	16.96	5.88	23.18	31.04	12.14	22.7
Gypsum Ore	9.65	6.73	62.03	10.95	6.49	26.11	42.63	9.02	10.15
Ammonium Sulfate	13.40	5.80	86.50	21.61	7.61	37.78	53.96	11.76	27.71

Residual soil SO_4-S
LSD (0.05) = 5.60
Residual soil NO_3-N
LSD (0.05) = NS†
SUE
LSD (0.05) = 23.24

† F value for the model not significant.
†† Control treatments consists of ammonium nitrate application equilavent to N supplied by ammonium sulfate.

Impact:

Powdered elemental sulfur alone was least effective, and ammonium sulfate the most effective sulfur fertilizer form in terms of increasing sulfur availability and increasing canola yield in the year of application. The waste gypsum sources were nearly as effective as ammonium sulfate in increasing sulfur availability and increasing yield. The elemental sulfur sources resulted in yield increases of approximately 0.2 T / ha compared with yield increases approaching 0.4 T / ha with the ammonium sulfate and gypsum sources. Application rates above 20 kg S / ha did not result in appreciable yield gains but did result in increased sulfur uptake and accumulation of residual sulfate in the soil. Lack of complete oxidation of the elemental sulfur to plant available sulfate during the growing season is the likely reason for the poorer performance of the elemental sulfur. As the elemental sulfur was finely ground to maximize the surface area and enhance oxidation, even lower oxidation rates and plant availability may be expected from coarsely ground elemental sulfur There was a small tendency for combinations of powdered elemental sulfur with sewage sludge and lime to enhance sulfur availability and increase yield. Perhaps most significant was the good performance of the waste gypsum forms in the field trial. Often on Gray Luvisolic soils, the top five to fifteen centimeters of topsoil is quite highly weathered and leached, with relatively low content of basic cations such as calcium. A low calcium saturation in the surface soil would enhance the solubilization of the gypsum and also minimize the potential reduction in phosphorus availability due to the addition of the calcium in the gypsum.

It appears that the waste gypsum sources evaluated in this project may be an effective means for canola producers to economically increase sulfur availability in sulfur deficient soils of the Gray soil zone. Other product possibilities include the combination of powdered elemental sulfur with sewage sludge and lime to produce a pellet or wafer of high sulfur analysis which is easy to handle and apply yet still oxidizes relatively rapidly. Such products might be worthwhile considering for producers who desire a slow release type of sulfur source which is applied once at a high rate and then slowly released into available form over a number of years. Factors which need to be addressed include considerations in how to best process the different alternative sulfur sources to make products which are easy to apply and handle, yet are still effective. Some consideration is also required of the effectiveness of the products in other soil types and under different growing season conditions. In this regard, a second field season is planned for 1996, supported by the Saskatchewan Agriculture Development Fund, which will examine product performance in a different soil type under different environmental conditions.

Acknowledgement

Thanks are owed to Mr. Gavin Sulewski who conducted the experiment as the final component of his MSc thesis, and to Catherine McCleod and Ken Greer who helped out with the field work, and to Lyle Cowell for looking after the plots.