Crop Response to Four Sulfur Products Applied in North-Central Saskatchewan

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Abstract

A field study was conducted based on previous laboratory, greenhouse and field trial evidence which suggest a potential use for two alternative sources of sulfur fertilizer. The efficacy of (1) crystalline gypsum and (2) a pelleted elemental sulfur plus sewage sludge combination (DDS°) was assessed with canola in the year of application. Comparisons were made with existing sulfate and pelleted S°-based products. The study was conducted in north-central Saskatchewan on a marginally sulfur deficient soil. Results suggest crystalline gypsum was capable of providing sufficient sulfate supplies early in the growth season and residual sulfate levels were maintained. Over the growing season DDS° provided sulfate supplies and residual sulfate quantities which were similar to an existing S° product. However, both S°-based products provided inferior sulfate quantities when plant demand was highest and negative sulfur balances at season’s end.

Key Words: elemental sulfur, gypsum, DDS°, fertilizer

1.0 Introduction

This study serves as an extension of previous work conducted on two potential sources of sulfur (S) fertilizer: (1) a combination of Saskatoon sewage sludge and elemental S (DDS°) and (2) crystalline by-product gypsum which originates from a sodium sulfate mine in south-west Saskatchewan.

Past research with DDS° based combinations in the greenhouse and laboratory has shown significant advantages over S° alone in both SO_4 recovery and yield (Cowell and Schoenau, 1995; Sulewski, 1997). The majority of this evidence was based on applying non-pelletized DDS° formulations. However, evidence of higher SO_4-S recoveries in the growth chamber were also apparent with pelletized formats of DDS° (Sulewski, 1997). Prior to this study, field testing of the DDS° product has been limited to non-pelletized formats (Sulewski, 1997). Indicators such as yield, plant uptake showed little advantage to DDS° use in the year of application. However, significant increases in post-harvest residual soil SO_4 were apparent at a moderate application rate (80 kg S ha”) and this effect was transferred to the nutrition of the subsequent wheat crop (Table 1).

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[1] Presented at Soils and Crops ‘97, Saskatoon, Saskatchewan, February 20-21, 1997

Table 1. Residual effect of sulfur sources added in spring 1995 on wheat S uptake in the 1996 crop year at Star City, Saskatchewan (Sulewski and Schoenau, unpublished data).

	Sulfur Application Rate (kg ha^{-1})			
	20		**80**	
Source	**Residual Soil S Fall 1995**	**Crop S Uptake 19%**	**Residual Soil S Fall 1995**	**Crop S Uptake 1996**
	kg ha-’			
OS	10.1	8.4	7.0	11.6
S$^{\circ}$	9.7	17.3	15.9	16.6
DDS”	7.1	12.9	20.3	21.2
Gypsum	9.6	15.6	42.7	20.0
Sulfate	13.4	13.6	54.0	19.9
LSD (0.10)	2.5	4.4	6.9	4.4

Both gypsum and sulfate provided high residual sulfate levels at 80 kg ha^{-1}; however, extra advantages to subsequent crop nutrition were not realized and suggest poor nutrient use efficiency. Large pools of soluble sulfate in soil are quite susceptible to loss through leaching and could be an explanation for the poor use efficiency observed with high rates of gypsum and sulfate.

The residual effect of the non-pelletized format of DDS$^{\circ}$ was likely a function of optimal S$^{\circ}$ oxidation rates (for Saskatchewan) due to good product distribution throughout the plow layer. Despite these observations, higher residual SO$_4$ in DDS$^{\circ}$ treated soils was achieved at the expense of any practical method of mechanical application. The loose forms were inherently dusty and largely unsuitable for large-scale use. Therefore, it is necessary to examine the effectiveness of DDS$^{\circ}$ in a format which could be easily applied with existing farm equipment. In the case of the pelletized DDS$^{\circ}$ formats, growth chamber evidence predicts a reduced effectiveness due to a reduction in product breakdown and subsequent dispersion within the soil.

In the case of mine gypsum, previous tests in the growth chamber predict a readily to intermediately available SO$_4$ source if applied just prior to seeding (Sulewski, 1997). More realistic testing of the product in the field provided further evidence of gypsum SO$_4$ release rates which were inferior to ammonium sulfate, but superior to any S$^{\circ}$ based product. In addition, unlike the non-pelletized format of DDS$^{\circ}$ the crystalline properties and physical nature of the mine gypsum product is better suited for conventional methods of mechanized fertilizer application.

Objectives addressed in the current study were: (1) field testing of the efficacy of pelletized DDS$^{\circ}$ products compared to other commercially available S$^{\circ}$ based products in an aggregated format and (2) additional field evaluation of the mine gypsum source.

2.0 Materials and Methods

2.1 *Product Preparation*

Fertilizer products used in this study included two pelleted S$^{\circ}$-based products and two SO$_4$-based products. The S$^{\circ}$ products were (1) S$^{\circ}$ plus bentonite and (2) S$^{\circ}$ plus dried digested sewage sludge (DDS$^{\circ}$). The SO$_4$ products were (1) fertilizer grade ammonium sulfate and (2) crystalline gypsum ($CaSO_4$) originating from the tailings pile at the SOTEC sodium sulfate mine in Cabri, Saskatchewan. Product preparation for the DDS° product involved the creation of a 50:50 (sludge:S°) batch mixture, which was systematically pelletized and dried. The resulting product was manually crushed and sieved to remove all particles which were larger than 3.36 mm and smaller than 2.0 mm. The DDS° pellets (50% S) were analyzed for S concentration through combustion in a Leco CNS 2000 analyzer. Preparation for the mine gypsum product involved a two day air-drying process, which was followed by manual crushing and sieving. The resulting product (2 1% S) was comprised of those particles that could be collected on a 2 mm sieve. No preparation was involved for either the **S°-bentonite** or ammonium sulfate products.

2.2 Study *Description*

The field study was conducted in north-central Saskatchewan near Paddockwood. The soil was a degraded Black Chemozem mapped as a Paddockwood light-loam (Saskatchewan Soil Survey, 1995). Site selection was based on soil samples (0 - 60 cm) taken on May 2. Samples were subjected to a 0.01M $CaCl_2$ extraction for SO_4 and initial soil sulfate levels were found to be 9.6 kg ha^{-1}. The study area was previously sown to peas and had also received 56 kg N ha^{-1} the previous fall as anhydrous ammonia. The field plots were established on May 9 when fertilizer treatments were applied at three rates (10, 25 and 40 kg S ha^{-1}) with four replicates of each treatment. Elemental S-based and gypsum treatments had additional N applied as ammonium nitrate at rates equivalent to levels supplied by ammonium sulfate. An ammonium nitrate control (OS) and a unfertilized control treatment were included. The fertilizer was incorporated the same day by air-seeder during the application of a pre-plant herbicide. The plots were lightly harrowed four times over the following week to maximize the potential for product distribution throughout the plow layer. Canola *(Brassica napus) was* air-seeded on May 26 along with 56 kg 12-51-O ha".

2.3 *Parameters Measured*

Just prior to the bolting stage of canola soil sulfate supply rates for each plot were measured for a two week interval (June 13 - 27) 35 days after fertilizer application. Supply rates were obtained through the use of PRS anion exchange membrane probes (Greer and Schoenau, 1995). Mid-season whole plant biomass samples contained in a one sq. m quadrat were taken on July 29 when plants were in full flower. The samples were air-dried (40°C), weighed and finely ground for plant tissue analysis using combustion by a Leco CNS 2000 analyzer. Final yields and plant samples were obtained on September 9 using square meter samples from the plots. At harvest, seed weights were recorded and sub-samples of the seed and straw were respectively ground with a ball mill for subsequent S analysis through (CNS analyzer). Final soil samples were taken on October 5 from plots treated with S fertilizer at 10 and 40 kg ha^{-1} as well as the OSON and OS controls. Five samples per plot (0 - 30 cm) were bulked, air-dried and ground. Residual sulfate was determined through a 0.01M $CaCl_2$ extraction.

3.0 Results and Discussion

3. I *Sulfate Supply Rate*

The measurement of potential soil sulfate supply rate as influenced by sulfur amendment allows for the direct comparison of product plant availability. Measurement at the period just prior to bolting encompasses the period of high S demand by canola. Sulfate supply rates were significantly higher than soil alone ($P < 0.10$) only with the two highest rates of gypsum and all three ammonium sulfate rates (Table 2).

Table 2. Mid-season sulfate supply rate as measured using PRS anion exchange membrane probes at June 13-27 and mid-season canola S uptake at full flower (Paddockwood, Sask., 1996).

	Fertilizer Applied kg S ha^{-1}					
	10		25		40	
Source	Mid-Season S Supply rate ug 10cm^2 2wk^{-1}	Mid-seasonS Uptake kg ha^{-1}	M&l-Sawn S Supply rate ug 10cm^2 2wk^{-1}	Mid-season S Uptake kg ha^{-1}	Mid-Season S Supply rate ug 10cm^2 2wk^{-1}	Mid-S Uptake kg ha^{-1}
0S 0N[†]	27.7	14.9				
0S[††]	61.3	24.4	44.0	21.2	33.5	23.5
S°-bentonite	28.4	14.3	34.0	13.7	38.2	16.7
DDS’	39.6	14.8	47.8	14.4	57.6	12.1
Mime Gypsum	63.2	20.9	89.0	23.2	77.8	25.7
Sulfate	81.0	29.0	138.0	32.7	131.5	31.3

Mid-season S supply rate
LSD(0.10) = 49.2
Mid-season S uptake
LSD(0.10) = 11.1

[†] **Check treatment with no fertilizer amendments.**

[††] **Ammonium nitrate application equivalent to N supplied by ammonium sulfate.**

The supply rate for ammonium sulfate at 10 kg ha^{-1} was significantly lower than if applied at either 25 or 40 kg ha”. At equivalent doses, ammonium sulfate was superior to the 10 kg S° hi’ treatment and both S° and DDS° at 25 and 40 kg ha”. Differences in supply rate between ammonium sulfate and gypsum were only significant at 40 kg ha^{-1}. The supply rate comparison between the two S°-based products showed consistently higher values for DDS°; however, statistical differences between the S° sources were not apparent. Supply rate values for both S° sources suggest similar release characteristics over the initial **3** month period. Compared to soil alone, neither of the S°-based products could enhance sulfate supply rate at any application rate. The OS control treatments receiving compensatory ammonium nitrate showed relatively high sulfate supply rates compared to S°-based treatments, possibly reflecting enhancement of organic S mineralization by addition of N.

3.2 *Mid-Season Plant S Uptake*

Actual S uptake for the period from seeding to July 29 reflects the portion of canola growth wherein the majority of S uptake occurs. Mid-season plant uptake (Table

2) responded in a manner similar to the measured soil sulfate supply rates. Plant S uptakes were significantly higher than those achieved in unfertilized soil only with the highest rate of gypsum and all three rates of ammonium sulfate ($P < 0.10$).

Differences between gypsum and the S°-based products were not consistent. However, the highest rate of gypsum was superior to either S°-bentonite or DDS°. Ammonium sulfate was superior to both S°-based products at all application rates. Differences between the S°-based products were not apparent at any application rate. Both S° products were unable to significantly enhance mid-season S uptake beyond the level achieved in the unfertilized treatment.

In some instances, mid-season S uptake for the OS treatments (i.e., receiving N) were significantly higher than through addition of S°-based fertilizer. These results correspond with the previously described trend of higher sulfate supply rates in OS treatments (Table 2). Suggesting a possible inhibitory effect of added S° on soil sulfate levels which may be related to reduced S mineralization rates. Heterotrophic soil organisms are the primary group responsible for S mineralization. Kuenan and Beudeker (1982) predicted the selection for heterotrophic populations in soils as carbon availability increased and the flux of reduced inorganic sulfur compounds decreased. Lawrence (1987) found direct evidence of S° (reduced inorganic sulfur) creating selection pressures which favored the establishment of mixotrophic and autotrophic species. This shift in population could be responsible for a temporary decline in mineralization rates. Sulewski (1997) found lower respiration rates in S° amended soils compared to unamended soils. Alternatively, the similarity between the two measures could simply be related to the common occurrence of areas in the landscape with high SO_4 due to natural gypsum deposition and/or nutrient accumulation by water redistribution.

3.3 *Total Plant S Uptake*

In contrast to mid-season values, statistical differences in total S uptake at maturity were not apparent (Table 3). This suggests the S deficit created by lower mid-season SO_4 supplies was compensated by plant uptake in the later stages of the growth period between late July to September. Janzen and Bettany (1984) have shown conditions wherein S deficient plants are capable of high absorption of SO_4 in later growth stages. They concluded that compensatory plant uptake mainly resulted in sulfur buildup in leaf tissue and was not readily redistributed within the plant to significantly benefit plant yield. Grain yields for the canola crop in the present study averaged 1.85 t ha^{-1} (33 bu ac^{-1}), which would require an average of 25 kg S ha^{-1} (Nuttall et al. 1992). Sulfur uptake values at mid-season (Table 2) suggest soil S deficiency for both the soil alone and S°-based products. Total S uptake (Table 3) values at maturity indicate the same trend but to a lesser extent and suggest an ability for S deficient plants to scavenge additional S later in the season at this site. At the end of the experiment, no statistical differences in grain yield could be found. Suggesting that the late season supply of available S, possibly from mineralization or deep subsoil reserves was an important source of available S at this site.

Table 3. Total plant S uptake at maturity (Paddockwood, Sask. 1996).

	Fertilizer Applied kg S ha^{-1}		
	10	2s	40
Source		Total S uptake kg ha”	
0S 0N†	17.4		
0S††	32.6	39.3	28.8
S°-bentonite	18.4	30.7	19.5
DDS”	21.0	24.5	17.1
Mine Gypsum	31.7	24.7	27.5
Sulfate	33.3	37.4	28.9
Total Uptake LSD(0.10) = NS			

† Check treatment with no amendments.

†† Ammonium nitrate application equivalent to N supplied by ammoniwn sulfate.

3.4 *Residual Soil Sulfate*

Plot research dealing with S is often problematic due to inherently high variability in soil SO_4 levels across short distances in a field. Residual soil sulfate in fall after harvest was low and quite similar among the diierent S sources at the 10 kg S ha^{-1} rate (Table 4).

Table 4. Residual soil sulfate (O-30 cm) after harvest on October 5 (Paddockwood, 1996).

	Fertilizer Applied kg S ha-’	
	10	40
Swrce	Residual Soil Sulfate kg ha-’	
0S 0N†	0.4	
0S††	0.3	0.4
S°-bentonite	1.2	2.8
DDS’	1.6	3.3
Mine Gypsum	1.9	11.1
Sulfate	3.0	16.1
Residual Soil Sulfate LSD(0.10) = 0.9		

† Check treatment with no amendments.

†† Ammonium nitrate application equivalent to N supplied by ammonium sulfate.

For the S°-based products, residual profile sulfate was also low at the 40 kg S ha” application rate. However, gypsum and ammonium sulfate gave rise to significantly higher residual soil sulfate levels at the 40 kg S ha” rate. Initial soil tests (0 - 60 cm) taken in May indicated an average profile sulfate at the start of the growing season of 10 kg ha” across the plot. Ammonium sulfate and gypsum at 40 kg ha” were the only sources capable of maintaining soil SO_4 levels above the levels measured in May. The S°-based products produced low final sulfate values at both 10 and 40 kg ha”. In comparison to the unfertilized treatment, slightly higher final SO_4 values were obtained with both S°-based products when applied at 40 kg ha^{-1}. It is unlikely that residual advantages similar to those achieved at Star City with non-pelletized **S°-based** products (Table 1) would be achieved with pelletized **DDS°** or **S°-bentonite**. However, additional weathering of the aggregated fertilizers in the subsequent year could potentially release additional sulfate.

4.0 Summary and Conclusions

The two indicators of S fertilizer efficacy in supplying available S (mid-season supply rate and plant S uptake) revealed significant benefits in S availability with gypsum applied at 25 and 40 kg ha^{-1} and ammonium sulfate applied at 10, 25 and 40 kg ha^{-1}. Both **S°-based** sources did not result in significantly higher release in the short-term and some short-term suppression of S mineralization may be associated with **S°** amendment to soil. Results suggest similar release characteristics for **DDS°** and **S°-bentonite** in both the initial 3 months and the remaining portion of the field season. Plants subjected to restricted S supplies early in the season appear to have scavenged for S in the later stages of growth (i.e., July - September) since no differences in total S uptake could be discerned. Yield differences were also not apparent. Application of ammonium sulfate and gypsum at 40 kg ha^{-1} maintained end-of-season soil sulfate above levels measured in the spring at the start of the experiment. This result supports previous field testing of the gypsum source, which found it a sufficient annual S source for canola. The use of pelletized **DDS°** and **S°**-bentonite in this study suggests low S availability in the year of application. However, unlike the more effective non-pelletized formats of **DDS°** and **S°** described in Table 1, the pelletized products are 'field ready' for large-scale mechanical application. Dispersion and release of the remaining S may be accelerated in subsequent years through additional weathering and breakdown of the **S°** aggregates.

Acknowledgments

The authors wish to express their appreciation to the Canola Council of Canada, Agricultural Development Fund and University of Saskatchewan for their support of this project.

References

Cowell, L.E. and J.J. Schoenau (1995). Stimulation of elemental sulfur oxidation by sewage sludge. Canadian Journal of Soil Science 75: 247-249.

Greer, K. J. and J.J. Schoenau (1995). Plant root simulators: an efficient tool for a in-field nutrient mapping. pp. 102-105. In_ Proceedings 1995 Soils and Crops Workshop, University of Saskatchewan Sasktaoon, Saskatchewan.

Janzen, H.H. and J.R Bettany (1984). Sulfur nutrition of rapeseed: I. Influence of fertilizer nitrogen and sulfur rates. Soil Science Society of America Journal 48: 107-112.

Kuenan, J.G. and RF. Beudeker (1982). Microbiology of Thiobacilli. pp. 473-497. In_ J.R Postgate and D.P. Kelly (eds.) Sulfur Bacteria, Proceedings of a Royal Society Discussion Meeting, Feb. 17-18, 1982. Philosophical Transactions Royal Society of London B.298.

Lawrence, J.R (1987). Microbial oxidation of elemental sulfur in agricultural soils. Ph.D. Thesis, Department of Soil Science, University of Saskatchewan, Saskatoon, Saskatchewan.

Nuttall, W.F., A.S. Leyson, D. Flaten and D.J. Tomasiewicz (1992). Saskatchewan fertilizer practices, Saskatchewan Advisory Council on Soils and Agronomy, Saskatchewan Agriculture, Agdex 541, pp. 1-12.

Saskatchewan Soil Survey (1995). Preliminary soil map and report, Rural Municipality of Paddockwood Saskatchewan Institute of Pedology, University of Saskatchewan, Saskatoon, Saskatchewan.

Sulewski, G.D. (1997). An evaluation of elemental sulfur-sewage sludge combinations and waste gypsum as sulfur sources. Thesis, Department of Soil Science, University of Saskatchewan, Saskatoon, Saskatchewan.