Sulfur Nutrition of Canola

H. Janzen and J. R. Bettany

I. INTRODUCTION

For a number of years, sulfur deficiencies have been observed to limit crop production in many Saskatchewan soils. These deficiencies have been most evident in Grey-wooded soils but some sulfur deficiencies have been identified in the Black and Dark Brown soil zones.

Canola (rapeseed) production is particularly sensitive to sulfur deficiency because of the relatively high sulfur uptake requirements of Cruciferous species. Moreover, Canola is a predominant crop on the potentially sulfur deficient soils of Saskatchewan and consequently, the study of the sulfur nutrition of Canola deserves specific attention.

The present investigation addressed two primary objectives:

i) to study the interaction of nitrogen and sulfur supply in Canola nutrition.

ii) to assess the effectiveness of sulfur applied during the growing season in alleviating sulfur stress.

II. NITROGEN - SULFUR INTERACTION

Nitrogen and sulfur are both constituent elements of plant protein. Consequently, a deficiency of sulfur will limit protein synthesis and result in the accumulation of non-protein nitrogen (Stewart and Porter, 1969). Conversely, nitrogen deficiencies will restrict the incorporation of sulfur into plant protein. Thus, nitrogen and sulfur are closely linked in plant nutrition and the efficiency of the assimilation of one element is directly related to the comparative availability of the other element in the soil medium.

A. Methods and Materials

The interactive effects of nitrogen and sulfur were investigated in a growth chamber pot experiment using two soils (Table 1).

Table 1: Characteristics of the two soils used in growth chamber pot experiment.

Great Group	Soil Association	Texture	pH	Available Nutrient Concentration (ppm)			
				NO_3^--N	P	K	$SO_4^=$-S
Gray Luvisol	Waitville	loam	6.6	12	14	120	4
"	Sylvania	sandy loam	6.1	11	12	170	4

The pots each contained 1150 grams of soil and sulfur (Na_2SO_4) was applied at rates of 0, 5, 15, and 40 ppm S (designated S_0, S_5, S_{15}, and S_{40}, respectively). Nitrogen (NH_4NO_3) was applied at rates of 0, 50, 100, and 300 ppm N (designated N_0, N_{50}, N_{100}, and N_{300}, respectively). All possibly combinations of N and S levels were represented and replicated three times. Sufficient rates of other macro- and micronutrients were added to ensure that elements other than N and S were not limiting. All nutrients were added to the surface of the soil as solutions prior to seeding.

One Canola plant (*Brassica napus* var. Regent) was grown to maturity in each pot. Leaves which absized after approximately week five were collected and retained for analysis. At maturity (designated to be the stage at which a majority of the pods approached dehiscence), the Canola plant was harvested and separated into seed, pods, and straw prior to elemental analysis.

B. Results and Discussion

i) seed yields

The pattern of seed yield responses to the various N and S treatments was similar in both soils (Table 2). Maximum seed yields were obtained only with the application of both high N and high S rates. The yield advantage of the $N_{300}S_{40}$ treatment over other treatments was substantial in both soils. No appreciable yield responses to sulfur application were evident in the N_0 treatments. With increasing N levels, the yield responses to sulfur became progressively more pronounced.

Particularly noteworthy is the observed effect of nitrogen application on seed yield. In the S_0 treatments, addition of 50 ppm nitrogen had no significant effect on seed yield but further increases in N levels completely inhibited seed production. In the S_5 treatments, the initial increment of nitrogen appeared to increase seed yield but further increments produced sharp yield declines. In the S_{15} treatments, seed yield increased significantly with the 50 and 100 ppm nitrogen applications but fell to zero with the final increment of nitrogen. Only at the highest sulfur rate was there a progressive yield increase associated with each successive nitrogen increment. The inhibitory effect of high nitrogen levels, therefore, was most evident at the S_0 level and gradually subsided with increasing sulfur levels until, at the S_{40} level, the high N rate produced a very substantial yield response.

Table 2: Seed yields of Canola plants grown on Waitville and Sylvania soils at various nitrogen and sulfur levels.[1]

a. Waitville soil

	gms seed/pot			
	S_0	S_5	S_{15}	S_{40}
N_0	.91 bcd	.94 bcd	.92 bcd	.84 bc
N_{50}	.82 bc	1.06 cd	1.19 d	1.05 cd
N_{100}	0 a	.73 b	1.94 e	1.83 e
N_{300}	0 a	0 a	0 a	5.68 f

Table 2: continued

b. Sylvania soil

	gms seed/pot			
	S_0	S_5	S_{15}	S_{40}
N_0	.48 bc	.47 bc	.46 bc	.50 bc
N_{50}	.52 bc	.69 cd	.91 de	.84 d
N_{100}	0 a	.25 b	1.16 e	1.84 f
N_{300}	0 a	0 a	0 a	5.85 g

[1]All values succeeded by the same letter are not statistically different at $P \leq .050$.

It was observed in both soils that fertilizer N : fertilizer S ratios $\geq$ 20 resulted in significantly diminished seed yields. (This ratio, of course, is specific to the two soils under investigation as it is a function of initial levels of available nutrients and other soil properties).

The effects of sulfur deficiencies were much less evident in vegetative growth than in reproductive growth. For example, although the $N_{300}S15$ treatment produced no seed yield, its vegetative dry matter accumulation was not greatly different from that of the $N_{300}S_{50}$ treatment which produced substantial seed yields.

ii) deficiency symptoms

The treatments which exhibited definite sulfur deficiency symptoms were those which had excessive nitrogen levels relative to sulfur availability; namely: N_5S_0, $N_{100}S_0$, $N_{100}S_5$, $N_{300}S_0$, $N_{300}S_5$, and $N_{300}S_{15}$. Characteristic symptoms of sulfur stress observed under the growth chamber conditions are listed in Table 3.

Table 3: Sulfur stress symptoms observed in Canola (var. Regent) grown under growth chamber conditions.

plant component	symptoms
i) leaves	- interveinal chlorosis - cupping - purpling of ventral side and edges
(symptoms first appeared and remained most pronounced in younger leaves)	
ii) stems	- weak, elongated
iii) flowers	- petals - pale yellow, malformed, absize soon after opening - indeterminate flowering habit
iv) pods	- short, poorly filled - under moderate S stress, deficient pods tend to occur toward distal end of raceme

In addition to the morphological symptoms described, S deficiency also significantly delayed maturity.

iii) plant sulfur concentration[2]

Sulfur concentration in the seed was affected only marginally by the various rates of sulfur and nitrogen (Table 4). Sulfur concentrations tended to be positively correlated with sulfur rate and negatively correlated with nitrogen rate.

Table 4: Sulfur concentration of Canola seed as influenced by various levels of nitrogen and sulfur.

	% S			
	S_0	S_5	S_{15}	S_{40}
N_0	.25 ab	.28 cd	.30 de	.33 e
N_{50}	.23 a	.26 abc	.29 cd	.29 cde
N_{100}	---	.29 cd	.25 ab	.30 cde
N_{300}	---	---	---	.24 abc

[2]Plant composition data is presented for the Waitville soil only. Data obtained for the Sylvania soil was similar.

The sulfur concentration of the straw was generally markedly lower than that of the seed. A noteworthy exception is the high accumulation of sulfur in the low N/high S treatment. Analysis of these treatments revealed that a large proportion of this accumulated sulfur was reducible by hydriodic acid (HI), indicating the accumulation of sulfate and/or other non-protein sulfur forms. For example, in the N_0S_{40} treatment, 53% of the sulfur in the straw was HI - reducible as compared to 31%, 5%, and 14% in the N_0S_0, $S_{300}S_0$, and $N_{300}S_{40}$ treatments, respectively.

Table 5: Sulfur concentration of Canola straw[2,3] as influenced by various levels of nitrogen and sulfur.

	% S			
	S_0	S_5	S_{15}	S_{40}
N_0	.12 cd	.15 d	.28 f	.78 g
N_{50}	.07 ab	.11 bc	.15 d	.30 f
N_{100}	.10 abc	.07 a	.07 ab	.23 e
N_{300}	.08 ab	.09 abc	.09 abc	.07 a

[3]Plant material remaining at maturity after removal of pods and seed.

The nitrogen concentrations of the plant tissues responded in a converse manner to the various nitrogen and sulfur levels. Nitrogen concentrations of the seed were not appreciably affected by the various N/S regimes. In the straw, however, high nitrogen rates, in conjunction with low or moderate sulfur rates, produced accumulations of nitrogen. This observed effect may be attributable, in part, to the inhibition of seed production in these treatments and the conseqential absence of a sink for the absorbed nitrogen.

iv) sulfur uptake

Total sulfur present in the above ground plant tissues was strongly correlated to rate of sulfur application; an obvious reflection of the greater availability of sulfur associated with the higher rates of application. Total sulfur uptake appeared to be largely independent of nitrogen rates except in the S_{40} treatments where increasing nitrogen rates increased total sulfur uptake, especially in the Sylvania soil.

Calculation of the percent of the total plant sulfur present in the seed (Table 6) clearly demonstrates that maximum efficiency of the assimilation of applied fertilizer sulfur into the seed is attained only when it is applied in conjunction with a balanced application of nitrogen.

Table 6: Percent of total above ground plant sulfur present in the seed as influenced by various levels of nitrogen and sulfur.

% of Total Plant S in Seed

	S_0	S_5	S_{15}	S_{40}
N_0	36	31	19	10
N_{50}	40	44	27	16
N_{100}	0	34	40	17
N_{300}	0	0	0	42

C. Conclusions

From the preceding results it is evident that maximum Canola seed production is attainable only with sufficient and balanced levels of available nitrogen and sulfur. Applications of sulfur under conditions of restricted nitrogen availability produces no appreciable yield response and results in luxury sulfur uptake and the accumulation of non-protein sulfur in the vegetative plant components.

Applications of nitrogen to soils of limited sulfur supplying capacity result in inefficient plant utilization of fertilizer nitrogen. More importantly, such unbalanced nitrogen applications enhance the severity of the sulfur stress and result in large seed yield losses. Although the physiological basis of the observed inhibitory effect on seed production has not been elucidated, there may be a relationship between severe sulfur deficiency and disruption of hormonal activity (Singh and Singh, 1978).

The investigation clearly demonstrates that maximum Canola seed production in Saskatchewan demands consideration of both nitrogen and sulfur nutrition, and in particular, the interrelationship between these two nutrient elements.

III. TIMING OF SULFUR APPLICATION

Reasonably accurate assessment of Canola sulfur status can be made during the growing season using plant tissue analysis (Maynard and Stewart, 1980). Recognition of such a deficiency, however, is of immediate benefit only if the deficiency can be corrected during the same growing season.

Investigations using clover plants have suggested that plants have the physiological capacity to recover rapidly from sulfur stress if sulfur is made readily available (Bouma, 1967). The objective of the present investigation was to assess the effectiveness of sulfur applied at various stages of growth in correcting sulfur deficiency in Canola and averting the substantial seed yield losses demonstrated in the preceding experiment.

A. Methods and Materials

Soils and conditions of growth were the same as outlined for the preceding experiment. The same four rates of nitrogen were applied at seeding (N_0, N_{50}, N_{100}, N_{300}). Sulfur (Na_2SO_4) was applied in solution at a rate of 40 ppm S at four stages of growth as summarized in Table 7. One plant per pot was grown to maturity, harvested, and analyzed for yield, sulfur concentration, and nitrogen concentration.

Table 7: Time and stage of growth of sulfur applications on Waitville and Sylvania soils.

	Waitville		Sylvania	
	Day	Approx. Growth Stage	Day	Approx. Growth Stage
T_0	0	seeding	0	seeding
T_1	17	rosette (4-5 leaf)	17	rosette (4 leaf)
T_2	32	bud	37	late rosette - early bud
T_3	43	late bud - flower	50	bud - early flower
S_0		no sulfur		no sulfur

(Low nitrogen treatments tended to be at later growth stages than high nitrogen treatments)

B. Results and Discussion

i) seed yields

The data for both soils reveal similar trends. In the Waitville soil, all times of sulfur application were equally effective in maintaining seed yields in the N_0, N_{50}, and N_{100} treatments. In the N_{300} treatments, a significant yield increase was observed with application of sulfur at the rosette stage (T_1) rather than at seeding (T_0). Application of sulfur at the bud stage (T_2) was equally effective in terms of yield response as application at seeding. A further delay in sulfur application, however, resulted in a significant yield decline.

In the Sylvania soil, similarly, time of sulfur application had no significant effect on yield in the N_0, N_{50}, and N_{100} treatments. In the N_{300} treatments, sulfur applications at seeding (T_0) and at the rosette stage (T_1) were equally effective, but later applications resulted in substantial yield declines.

Table 8: Seed yield of Canola as influenced by time of sulfur application and nitrogen levels.[4]

a. Waitville soil

	gms seed/pot				
	T_0	T_1	T_2	T_3	S_0
N_0	.82 b	.86 b	.90 b	.91 b	.91 b
N_{50}	1.25 b	1.08 b	1.04 b	1.19 b	1.06 b
N_{100}	1.83 c	2.29 c	2.16 c	2.09 c	0 a
N_{300}	5.68 e	6.86 f	5.80 e	3.77 d	0 a

b. Sylvania soil

	gms seed/pot				
	T_0	T_1	T_2	T_3	S_0
N_0	.50 a	.48 a	.35 a	.43 a	.48 a
N_{50}	.84 ab	.83 ab	.52 a	.52 a	.52 a
N_{100}	1.84 bc	2.08 c	1.94 bc	2.31 cd	0 a
N_{300}	5.85 e	4.92 e	2.29 cd	3.38 d	0 a

[4]Any values followed by the same letter are not significantly different at $P \leq .050$.

The $N_{300}T_3$ treatment in the Waitville soil and the $N_{300}T_2$ and $N_{300}T_3$ treatments in the Sylvania soil exhibited definite sulfur deficiency symptoms in the later pods, suggesting that sulfur uptake was not rapid enough to support the high sulfur demand during pod-filling.

In both soils, all times of sulfur application in the N_{100} and N_{300} treatment, including T_3, showed marked yield increases over the S_0 treatments. These substantial yield responses of Canola plants to late sulfur application can be attributed to two factors: i) very rapid uptake of applied sulfur. (Partial alleviation of sulfur stress symptoms was clearly visible two to three days after application) plants under severe stress virtually ceased growth in the early bud stage and resumed appreciable growth rates only after the application of sulfur. ii) time to maturity.

The effect of delayed sulfur application on maturation time is of considerable interest because Canola production in Saskatchewan is often restricted by limited growing season duration. In both soils, maturation time was not significantly affected by applying sulfur at the rosette stage rather than at seeding. Application of sulfur after the rosette stage, however, significantly prolonged ripening, particularly at the higher nitrogen rates. The delay in maturity, presumably, is the result of the virtual cessation of growth in the severely deficient plants prior to the application of sulfur. The more pronounced delays observed in the high nitrogen treatments are a reflection of the enhancement of sulfur stress by high nitrogen application.

Table 9: Maturation time (days)[5] of Canola plants supplied with sulfur at various growth stages.

a. Waitville soil

	T_0	T_1	T_2	T_3	S_0
N_0	95	95	95	95	91
N_{50}	85	91	85	91	86
N_{100}	83	85	95	102	---
N_{300}	91	91	106	113	---

b. Sylvania soil

	T_0	T_1	T_2	T_3	S_0
N_0	103	107	101	107	116
N_{50}	85	91	112	109	116
N_{100}	87	87	105	112	---
N_{300}	95	95	112	121	---

[5]The values presented are approximate because of the difficulty inherent in precise determination of maturity.

iii) sulfur concentration and uptake

No major trends were evident in the relationships between sulfur concentration in the seed and time of sulfur application (Table 10). In both soils, sulfur concentration decreased with delayed application in the N_{100} treatments. Slight increases in concentration were apparent with delayed application in the N_{50} treatments.

Table 10: Concentrations of sulfur in Canola seed as affected by time of sulfur application.

a. Waitville soil

% S

	T_0	T_1	T_2	T_3	S_0
N_0	.33 bcd	.31 bc	.31 bcd	.31 bcd	.21 a
N_{50}	.29 bc	.30 bc	.34 d	.35 d	.23 a
N_{100}	.30 b	.23 a	.22 a	.23 a	---
N_{300}	.24 a	.23 a	.22 a	.23 a	---

Table 10: continued

b. Sylvania soil

	% S				
	T_0	T_1	T_2	T_3	S_0
N_0	.32 de	.32 de	.32 de	.31 cde	.30 bcd
N_{50}	.34 de	.30 cd	.32 de	.34 e	.24 a
N_{100}	.31 cde	.28 abc	.25 a	.26 a	---
N_{300}	.25 a	.27 abc	.26 ab	.25 a	---

In both soils, delayed applications of sulfur produced substantially higher total sulfur yields. In the Waitville soil, sulfur yields were highest in the T_2 treatments, whereas, in the Sylvania soil, sulfur yields were generally highest in the T_3 treatments. A very large proportion of this increased uptake, however, represents luxury uptake and accumulation of sulfur in the vegetative plant tissues, particularly in the leaves. In several treatments, concentration of sulfur in the leaves exceeded 3.0%. In most of the delayed sulfur application treatments, sulfur present in the leaves accounted for more than 40% of total plant sulfur. In general, time of sulfur application did not appreciably affect total uptake into the seed.

Table 11: Total sulfur uptake in above ground plant tissues as affected by time of sulfur application.

a. Waitville soil

	mg S/pot				
	T_0	T_1	T_2	T_3	S_0
N_0	27.7	34.6	43.2	40.4	6.4
N_{50}	23.2	31.9	44.0	38.8	6.0
N_{100}	28.9	36.5	50.6	43.5	7.4
N_{300}	31.8	36.2	44.1	44.1	3.8

b. Sylvania soil

	mg S/pot				
	T_0	T_1	T_2	T_3	S_0
N_0	16.5	19.0	17.1	17.9	3.5
N_{50}	23.7	29.0	27.3	30.7	3.9
N_{100}	25.1	32.3	37.8	43.1	2.8
N_{300}	37.3	41.8	44.3	50.5	2.1

C. Conclusions

Under conditions of moderate sulfur stress, the various times of sulfur application (from seeding to early flower) are equally effective in correcting sulfur deficiency. Under conditions of more severe sulfur stress, such as those induced by high nitrogen levels, sulfur applications after the rosette stage are clearly less effective than earlier applications.

Applications of sulfur after the rosette stage, particularly if the sulfur stress is severe, result in significant delays in maturity. These delays, obviously, restrict the usefulness of such applications in Saskatchewan Canola production.

Delayed sulfur application induces substantial increases in total sulfur uptake. Most of this additional absorbed sulfur, however, accumulates to excess in vegetative tissues.

It can be concluded that, given conditions conducive to the rapid uptake of fertilizer sulfur, application of sulfate during the rosette stage can successfully amend sulfur deficiencies in Canola and avert substantial yield losses.

LITERATURE CITED

Maynard, D. G. and Stewart, J. W. B. 1980. Sulfur deficiency in rapeseed - diagnostic plant analysis. In Proceedings of the 1980 Soils and Crops Workshop, Saskatoon, Saskatchewan, pp. 155-176.

Singh, N. and Singh, M. 1977. The effect of sulphur on the yield and chemical composition of rayo (Indian mustard) (*Brassica juncea* Coss.) grown on a sulphur deficient soil. Z. Pflanzenernaehr. Bodenk, 140:609-616.

Stewart, B. A. and Porter, L. K. 1969. Nitrogen - sulfur relationships in wheat (*Triticum aestivum* L.), corn (*Zea mays*), and beans (*Phaseolus vulgaris*). Agron. J. 61:267-271.