THE EFFECT OF SULPHUR FERTILIZER ON THE AGRONOMIC TRAITS OF DRY PEA IN SASKATCHEWAN.

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INTRODUCTION

Dry pea (Pisum sativum L.) is an important pulse crop in Saskatchewan which benefits the producer by extending the crop rotation, diversifying crop production and fixing nitrogen (Slinkard and Drew 1986). Dry pea is best adapted to the cooler, more humid Black and Grey soil zones.

Sulphur (S) is an essential macronutrient for plants and is required for the synthesis of protein and S containing amino acids (Mengel and Kirkby 1987). S deficiency in the Black and Grey-Black soils has been noted in canola fields in the Northeastern area of the province for several years. This deficiency has been related to leaching losses and the low organic S reserves initially present in the soil. In the last 50 years, crop demand for S has increased as a consequence of higher yield, more extensive cultivation, and production of high S-demanding crops such as canola. In addition, modern nitrogen (N) fertilizers have minimal S impurities (Bettany et al. 1983).

The requirement and response of dry pea plants to S fertilization is not well understood. Accordingly, the objectives of this study were to determine the effect of 1) sulphate-sulphur (SO_4-S) fertilizer on agronomic traits of dry pea and 2) method of application (broadcast vs. band) and time of application (Fall vs. Spring) of SO_4-S on agronomic traits of dry pea.

MATERIALS AND METHODS

This study was initiated in 1988 within a 80 km radius of Nipawin, Saskatchewan, on Grey-Black and Grey-Wooded soils testing low in sulphur. The experimental design was a split plot with the main plots consisting of Fall band, Fall broadcast, Spring band, and Spring broadcast. The subplots were five sulphur fertilizer rates of 0, 10, 20, 30, and 40 kg SO_4-S ha^{-1}. Five replications were seeded for a total of 100 subplots per site. Eleven sites were used over the three year study. Aylsham (1988) had Spring treatments only, due

to a seeding error. The Fall treatments were eliminated in 1990 and the 1990 experiments consisted of a factorial arrangement of Spring band and Spring broadcast applications with 0, 10, 20, 30, and 40 kg SO_4-S ha^{-1} and were analyzed as a randomized complete block.

The source of sulphur was ammonium sulphate. The nitrogen source was ammonium nitrate that was applied at appropriate rates to balance nitrogen among all treatments at 30 kg N ha^{-1} (1988) and 60 kg N ha^{-1} in 1989 and 1990. Potassium chloride was broadcast at 30 kg K_2O ha^{-1} and ammonium phosphate was seed placed at 22 kg ha^{-1}.

Victoria pea was inoculated with Rhizobium leguminosarum "C" and sown at a rate of 160 kg ha^{-1} at 15 cm row spacings. The experimental areas received applications of trifluralin, sethoxydim and bentazon or MCPB + MCPA at recommended rates for weed control.

A 1.5 m high clearance hoe drill was calibrated to band and broadcast at 30 cm row spacings. Cultivation occurred on both band and broadcast treatments.

Soil Analysis

Low S sites were selected, based on soil test analysis of samples from the 0-15, 15-30, 30-60 cm soil depth. Soil test reports indicated that soil S levels ranged from 14 to 49 kg ha^{-1} and sulphur recommendations varied from 11 to 28 kg S ha^{-1}. Soil samples were analyzed by standard procedures used by the Saskatchewan Soil Testing Laboratory for N, P, K, S, and micronutrients. Sulphur and Nitrogen were determined by flow injection analysis of 0.001$CaCl_2$ soil extracts.

Plant Tissue Analysis

Plant tissue analysis for S was determined on the above ground parts of the pea plants at the 6, 11, 16, and 20 node stages for the 0 and 40 kg S ha^{-1} Spring band treatments. Total S was determined by the nitric-perchloric acid digestion method (Association of Official Analytical Chemists 1984).

Nitrogen concentration of the seed and straw was determined using the Udy colorimeter acid orange 12 reagent (Udy 1971) and Kjeldhal methods (Association of Official Analytical Chemists 1975), respectively. The S concentration of mature seed and straw was

determined by the nitric-perchloric acid digestion method (Saskatchewan Soil Testing Laboratory 1990).

RESULTS AND DISCUSSION

The effect of S fertilization on growth and yield of dry pea was determined in 11 experiments involving five rates of SO_4-S fertilizer applied broadcast or band in Fall or Spring. Grain yield, plant dry matter yield, and S and N concentration in the seed and straw were measured. Sulphur and N concentration of plant dry matter at the 6, 11, 16, and 20th node stage on the 0 and 40 kg S ha^{-1} Spring band treatment provided an indication of the fate of the added S during plant growth and development.

Time of S Application

Spring and Fall application of S were compared at seven locations in 1988 and 1989. The time of S fertilizer application had no effect on grain yield,or plant dry matter yield except at Codette (1988), which had significant time by method interaction (Table 1,2,3,4).

Plant dry matter yield at Codette (1988) had the spring band and broadcast treatments yielding approximately the same (822 and 827 g per plot), whereas Fall band outyielded Fall broadcast (877 vs. 787 g per plot).

White Fox (1989), plant dry matter also had a significant time by rate interaction with Spring application of 20 kg S ha^{-1} increasing plant dry matter yield and Fall application of 20 kg S ha^{-1} having no response.

The general lack of a significant effect of time and interactions involving time for grain yield and plant dry matter can be partially attributed to drought and heat stress during the growing season.

In addition, time of S application had no effect on S concentration of the pea seed (Tables 5,6) and affected S concentration of the pea straw only at Nipawin (1989) where Fall application resulted in a significantly higher S concentration of the pea straw than Spring application (1.48 vs. 1.30g Kg^{-1} dry matter) (Table 7,8). Only two interactions involving time had a significant effect on S concentration of the pea straw, time by rate and time by method by rate interaction both at Pontrilas (1989) with Fall broadcast application of 40 kg S ha^{-1} resulting in a large increase in S concentration of the pea straw, relative to the other time by

method treatments.

Time of S application had no effect on N concentration of the seed and straw, except at White Fox (1989) where both the time by rate interaction and time by method by rate interaction were significant for N concentration of the straw (Table 9,10,11,12). The N concentration of the pea straw increased from the 20 to 40 kg S ha^{-1} rate when Fall applied whereas the reversal occurred when Spring applied with a decrease from 20 to 40 kg S ha^{-1} rate . Time by method by rate interaction was significant at White Fox (1989). N concentration of the pea straw decreased from all time by method treatments from 20 to 40 kg S ha^{-1} rate except the Spring band treatment. Again the lack of response by dry pea to time of S application reflects the general lack of growth during drought conditions which reduced response to S fertilization and uptake, and preventing expression of differences in efficiency between Spring and Fall application.

In 1988, severe drought conditions prevailed with low rainfall and above normal temperatures. The third location, Nipawin (1988), was removed from the study as a result of severe drought stress. The two remaining locations had a mean yield of 960 kg ha^{-1} compared to the provincial five year average of 1660 kg ha^{-1} (Saskatchewan Agriculture and Food 1990). In 1989, yield across the six locations ranged from 932 kg ha^{-1} at Sand Hill (1989) to 2034 kg ha^{-1} at White Fox (1989) (Table 2). Dry pea was placed under severe stress at flowering during July by high temperatures (30°C) and low rainfall. Hagstrom (1986) states that Fall application of sulphate fertilizer is typically less efficient than Spring application due to leaching. Results of the current study were contrary to Hagstrom's findings due to drought affecting the response to the time of application and general lack of leaching.

Method of S Application

Method of S application had no effect on grain yield at 10 of the 11 locations (Table 1). At Aylsham (1988), band application of S resulted in significantly higher seed yield than broadcast application (1046 vs. 923 kg ha^{-1}) (Table 2). In addition, the method by rate interaction was significant at Nipawin B (1990) due primarily to the extreme effect of method for the 20 kg ha^{-1} rate of S: the highest yield for band application of 3293 kg ha^{-1} and the lowest yield for broadcast application of 2802 kg ha^{-1} .

Plant dry matter yield was affected by method of S application only at Aylsham (1988) and Codette (1988) where band

application of SO_4-S resulted in a higher plant dry matter yield than broadcast application (906 vs 808 g $plot^{-1}$ at Aylsham (1988) and 849 vs. 810 g $plot^{-1}$ at Codette (1988)); (Table 3,4).

The method by rate interaction was significant only at White Fox (1989) with band application of 30 kg S ha^{-1} decreasing plant dry matter yield and broadcast application of 30 kg S ha^{-1} increasing plant dry matter yield. In 1988, the entire 5.0 m^2 plot was hand harvested which allowed smaller differences to be detected as significant (lower CV, Table 3) than when sample sizes of 0.10 m^2 and 0.30 m^2 were used in 1989 and 1990, respectively.

The lack of difference in grain and dry matter yield between the two methods of application is contrary to the findings of Hagstrom (1986). He found that Fall application of sulphate fertilizer was less efficient than Spring application due to leaching losses. All locations in 1988 and 1989 were affected by drought which reduced potential increases in grain and dry matter yield.

Method of S application had no effect on S concentration of the seed at nine of the 11 locations (Table 5). Broadcast application resulted in a significantly higher S concentration of the seed than band application 2.28 vs. 2.11 g kg^{-1} at Sand Hill (1989) and 2.17 vs. 2.08 g kg^{-1} at Nipawin A (1990)(Table 6). In addition, broadcast application of S resulted in a higher S concentration of the pea straw at Nipawin (1989), Nipawin B (1990) and Smeaton (1990) than band application (1.48 vs. 1.30), (2.16 vs. 1.84), (1.68 vs. 1.35), respectively (Tables 7,8). Sulphur concentration of the pea straw at Pontrilas (1989) had a method by rate interaction where broadcast application resulted in a positive linear response whereas band application had little effect.

Sulphur fertilizer application method had no effect on N concentration of pea seed or straw with the exception of White Fox (1989) where broadcast had a higher N concentration of the seed than Band (46.1 vs. 45.5 g kg^{-1})(Table 9,10,11,12). An explanation for the greater uptake of S with the broadcast treatment maybe due to a low pH in the vicinity of the ammonium sulphate band which reduced S uptake by the roots. Barrow (1975) indicated that the low pH from ammonium sulphate was mainly from nitrification of the ammonium ion.

Rate of S Application

Rate of S fertilizer had no effect on grain yield (Table 1), plant dry matter yield (Table 3), at any of the 11 locations. Research on

S fertilization has been limiting in legume crops for Saskatchewan. Rowles (1938) and Schalin (1947) reported increases in alfalfa seed yield and forage with the application of 26 and 22 kg ha^{-1} ammonium sulphate.

The general lack of S fertilizer rate response for seed yield and plant dry matter yield was the result of both environmental conditions and the degree of S deficiency. In 1988 and 1989, drought and heat stress, particularly during flowering and pod filling, had a detrimental effect on grain and plant dry matter yield. These drought conditions probably reduced the plant external requirement for S (Spencer 1975), minimized leaching (Freney and Williams 1983) and through warmer soil temperature possibly promoted S mineralization (Biederbeck 1978).

The locations were selected as being low in SO_4-S, based on soil test levels. The 1988 and 1989 locations had between 14 and 35 kg SO_4-S ha^{-1} in the top 60 cm of soil and an application of 28 to 17 kg SO_4-S ha^{-1} was recommended. The 1990 locations had between 45 and 50 kg SO_4-S ha^{-1} in the top 60 cm of soil and an application of 11 kg SO_4-S ha^{-1} was recommended. The near adequate soil test levels according to Saskatchewan Soil Testing Laboratory (1990) in the top 60 cm of soil along with drought conditions in 1988 and heat stress in 1989 led to the lack of a yield response from S fertilization.

Application of S fertilizer had a significant linear effect on concentration of S of the seed in six of 11 experiments (Table 5). Application of S fertilizer had a significant linear effect on concentration of S in the straw at eight of 11 experiments (Table 7). The increased S concentration of the seed and straw in most experiments indicated that addition of ammonium sulphate fertilizer resulted in increased S uptake, even though seed or plant dry matter yields were unaffected.

Application of S fertilizer had no effect on N concentration of the seed and straw at 10 of 11 and 9 of 11 locations, respectively (Tables 9,11). The lack of any effect of S on seed or dry matter yield eliminated possible dilution effects on N concentration of the plant. In addition, effectively inoculated peas grow uniformly over a range of soil N levels since increases in soil N are balanced by a decrease in N_2 fixation.

Sulphur and N concentration in the Growing Pea Plant

Above ground plant matter samples were collected at the 6,

11, 16, and 20 node stage from the 0 and 40 kg SO_4-S ha^{-1} Spring band treatments and analyzed for S and N concentration. Sulphur concentration increased significantly from the 0 to 40 kg SO_4-S ha^{-1} treatment at six of the eleven locations at Aylsham (1988), Codette (1989), Garrick (1989), White Fox (1989), Sand Hill (1989) and Smeaton (1990) (Table 13), again confirming that S uptake occurred even though seed and plant dry matter yields were unaffected.

The interaction between rate of SO_4-S and node stage was not significant for S concentration in the top growth, except for Codette (1989) and Smeaton (1990) (Table 13). The significant node stage by rate interaction for Codette (1989) was due to the similarity in S concentration of the 0 and 40 kg SO_4-S ha^{-1} rate at the 6 and 11 node stage and the larger decrease in S concentration for the 0 kg SO_4-S ha^{-1} rate relative to the 40 kg SO_4-S ha^{-1} rate at the 16 and 20 node stages (Table 14). The significant node stage by rate interaction for Smeaton (1990) was due to the large response to added SO_4-S at the 16 node stage, i.e., at the 0 kg SO_4-S ha^{-1} rate the S concentration dropped markedly from the S concentration at the 11 node stage whereas at the 40 kg of SO_4-S ha^{-1} rate the S concentration remained about the same as at the 11 node stage (Table 13,14).

At 10 of the 11 locations S fertilization (rates) had no effect on N concentration of the plant tissue (Table 15). Nitrogen concentration in the top growth of the pea plant decreased significantly from node 6 to node 20 in all 11 experiments.

Application of 40 kg SO_4-S ha^{-1} had no effect on N concentration except for Nipawin A (1990) where the N concentration for the check plot was significantly higher than for the 40 kg SO_4-S ha^{-1} rate (43.05 vs 37.58 g kg^{-1}) (Table 16). The rate by node stage interaction was not significant except for Nipawin B (1990) due primarily to the erratic N concentration at node stage 16, i.e., it was high in the check plot (41.50 g N kg^{-1}) and low in the 40 kg SO_4-S ha^{-1} plot (34.45 g N kg^{-1}) (Table 16).

Node stage had a significant negative linear effect on S concentration of the plant tissue at 8 of 11 locations and a significant negative linear effect on N concentration in the plant tissue indicating a dilution effect for both S and N with growth and dry matter accumulation (Table 15).

Duke and Reisenauer (1986) previously reported that total S concentration is affected by growth stage and proposed that a

standard growth stage be used to determine plant requirement for S. Bettany et al. (1983) suggested that the total S/total N ratio can be used to determine the S status in plant tissue. Ratios of S to N on the 6th node stage of pea plant for the 0 and 40 kg SO_4-S ha^{-1} treatments were compared. The S/N ratio for 0 kg SO_4-S ha^{-1} treatment at the 6 node stage at the 11 locations ranged from 0.11 to 0.05. The S/N ratio from 40 kg SO_4-S ha^{-1} treatment at the 6 node stage at the 11 locations ranged from 0.11 to 0.06. Therefore, the range in S/N ratio did not relate S response to S concentration of the growing pea plant.

The soil samples from the 1989 and 1990 locations were analyzed for the micronutrients B, Fe, Zn, Mn and Cu. Critical levels of micronutrients established by the Saskatchewan Soil Testing Laboratory (1990) were present except for Cu at 0.4 ug g^{-1} and B at 0.35 ug g^{-1}. The Cu concentration of the soils at Pontrilas (1989) and Sand Hill (1989) were 0.28 and 0.32 ug g^{-1}, respectively. The critical level of Cu (0.4 ug g^{-1}) in the soil was established to supply plants during optimum growing conditions, although optimum growing conditions did not exist in 1989 due to heat stress. Copper may have been a limiting factor to growth in these two sandy soils.

The B concentration in the soil samples from Garrick (1989), Sand Hill (1989), Smeaton (1990) and Nipawin B (1990) were less than the critical level of 0.35 ug g^{-1}. However the B concentration of the seed from 40 kg S ha^{-1} treatments for Garrick (1989), Nipawin A (1990), Nipawin B (1990) and Smeaton (1990) ranged from 20 to 30 ug g^{-1}. According to Woodbridge (1969), a level of 11-13 ug g^{-1} of B was adequate dry matter concentration, thus these soils were able to supply adequate amounts of B to the pea plant.

CONCLUSIONS

In this three year study, the adverse growing conditions in 1988 and 1989 and the moderately S deficient soils in 1990 minimized the response of pea to SO_4-S fertilization.

1. Time of SO_4-S application (Fall vs. Spring) had little or no effect on grain yield, plant dry matter yield, S concentration of the seed and straw or N concentration of the seed and straw.
2. Method of SO_4-S application (band vs. broadcast) had little consistent effect on grain yield, plant dry matter yield, S concentration of the seed and straw or N concentration of the seed and straw.
3. Rate of SO_4-S application (up to 40 kg ha^{-1}) had little consistent effect on grain yield, plant dry matter yield, or N concentration of the seed and straw.

4. Rate of SO_4-S application (up to 40 kg ha^{-1}) increased S concentration of the seed and straw at more than half of the locations.

5. Sulphur and N concentration of the pea plant, decreased significantly with advancing node stage in all 11 experiments due to growth dilution effect.

6. The S requirement for pea may not be much different than for wheat and much less than for canola.

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Table 1. Mean squares from the analysis of variance for grain yield in 11 sulphur fertilization experiments on pea in 1988, 1989 and 1990.

		Year and location										
		1988		1989						1990		
Source	df	Ayl.+	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A+	Nip.B+	Smeat.+
		Mean square x 10^3										
Rep	4	68*	40	53	342	1078**	493**	964	131	2338**	50	3972**
Time (T)	1	---	5	43	239	29	1	131	1402	----	---	----
Method (M)	1	150**	35	80	108	1	45	9	298	696	81	238
T x M	1	---	65	47	73	8	0	188	594	----	---	----
Error a	12	---	23	27	155	75	38	384	419	----	---	----
Rate (R)	4	17	13	12	73	3	17	19	8	977	106	193
Linear	1	1	8	49	172**	6	3	1	2	429	406*	11
T x R	3	---	3	8	20	1	10	70	14	----	---	----
M x R	3	14	13	5	50	3	46	120	15	150	342*	197
T x M x R	3	---	9	35	11	8	6	32	17	----	---	----
Error b #	67	18	9	35	35	23	42	54	77	293	87	148

*, ** Significant at the 0.05 and 0.01 level, respectively.

+ These experiments had sulphur applied only in the Spring and were analyzed as a randomized complete block design with five replications, except for Nipawin B (1990) and Smeaton (1990) with six replications and 46 df for error.

Error b had only 37 df for Aylsham (1988), 65 df for Pontrilas (1989) and 66 df for Sand Hill (1989) due to calculation of missing plots. Nipawin A (1990) had 37 df with one replication lost due to flooding. The zero rate of S was excluded from the calculation of sums of squares for T, M, T x R, M x R, and T x M x R. Variation within the zero rate and 1 df each from T x R, M x R and T x M x R, as appropriate, were included in error b sums of squares and df, respectively.

Table 2. The effect of time, method and rate of sulphate-sulphur application on seed yield in 11 sulphur fertilization experiments on pea in 1988, 1989 and 1990.

	Year and location										
	1988		1989						1990		
Treatment	Ayl.	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A	Nip.B	Smeat.
	Seed yield (kg ha^{-1})										
Time											
Fall	---	961	1872	1260	2019	1898	1005	800	----	----	----
Spring	---	945	1826	1151	2057	1890	924	1067	----	----	----
Method											
Band	1046	974	1881	1242	2041	1870	975	869	3839	3064	3074
Broadcast	923	932	1817	1169	2035	1918	954	992	3575	2982	3215
Rate of SO_4-S (kg ha^{-1})											
0	922	926	1889	1287	2017	1851	1014	933	3990	3147	3110
10	1004	923	1869	1217	2032	1887	928	927	3796	3128	3359
20	1022	985	1860	1230	2043	1923	984	941	3711	3051	3202
30	971	951	1845	1252	2027	1902	968	956	3521	3012	3076
40	944	957	1823	1123	2047	1863	978	903	3800	2914	3203
CV (%)	13.4	10.5	10.0	14.1	5.9	8.6	19.9	24.2	14.8	10.7	15.5

Table 3. Mean squares from the analysis of variance for plant dry matter yield in 11 sulphur fertilization experiments on pea in 1988, 1989 and 1990.

		Year and location										
		1988		1989						1990		
Source	df	Ayl.+	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A+	Nip.B+	Smeat.+
		Mean square										
Rep	4	100022**	48555**	371	316	1158*	2960**	3049*	1204*	7760	4393	13629*
Time (T)	1	-----	202	274	18	162	34	211	106	-----	----	----
Method (M)	1	96138**	29838*	130	88	101	110	980	451	1	5896	1245
T x M	1	-----	28163*	520	320	266	22	832	6	----	----	----
Error a	12	-----	5806	263	150	261	63	728	329	----	----	----
Rate (R)	4	4194	2743	389	119	216	149	205	93	6773	1596	2335
Linear	1	1936	32	500	200	242	18	32	242	16384*	961	1985
T x R	3	-----	1088	70	259	272*	9	166	30	----	----	----
M x R	3	4684	5511	313	398	353*	157	67	122	5167	2790	3715
T x M x R	3	-----	1193	468	185	62	150	107	51	----	----	----
Error b#	67	15971	4315	3111	164	89	142	218	127	3422	2722	3202

*, ** Significant at the 0.05 and 0.01 level, respectively.

+ These experiments had sulphur applied only in the Spring and were analyzed as a randomized complete block design with five replications except for Nipawin B (1990) and Smeaton (1990) with six replications and 46 df for error.

Aylsham (1988) had five replications and 37 df for error, Nipawin B (1990) and Smeaton (1990) had six replications and 48 and 37 df for error, respectively. Nipawin A (1990) is a six replicate test with one replication removed due to flooding (38 df for error). Smeaton has 37 df for error due to lost samples. The zero rate of S was excluded from the calculation of sums of squares for T, M, T x R, M x R, and T x M x R. Variation within the zero rate and 1 df each from T x R, M x R and T x M x R, as appropriate, were included in error b sums of squares and df, respectively.

Table 4. The effect of time, method, and rate of sulphate-sulphur application on plant dry matter yield in 11 sulphur fertilization experiments on pea in 1988, 1989 and 1990.

	Year and location										
	1988+		1989						1990		
Treatment	Ayl.	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A	Nip.B	Smeat.
	Dry matter yield (g $plot^{-1}$)										
Time											
Fall	---	831	68	60	53	65	45	38	----	----	----
Spring	---	828	72	61	56	64	48	35	----	----	----
Method											
Band	906	849	71	59	56	63	50	34	273	303	294
Broadcast	808	810	68	61	54	66	43	39	273	325	282
Rate of SO_4-S (kg ha^{-1})											
0	875	824	72	56	51	65	46	34	314	330	356
10	867	824	75	59	51	65	47	34	304	318	297
20	864	849	66	61	58	60	42	35	249	303	285
30	853	822	73	61	56	65	51	39	256	327	286
40	842	823	65	60	54	68	46	37	274	310	290
CV (%)	10.2	7.2	21.9	21.1	18.0	17.9	34.2	28.9	22.0	15.7	19.4

+ Plant dry matter samples were collected from 5.0 m^2, 0.1 m^2, and 0.3 m^2 plots in 1988, 1989 and 1990, respectively.

Table 5. Mean squares from the analysis of variance for sulphur concentration of pea seed in 11 sulphur fertilization experiments on pea in 1988, 1989 and 1990.

		Year and location										
		1988		1989						1990		
Source	df	Ayl.	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A	Nip.B	Smeat.
		Mean square x 10^{-2}										
Rep	2	---	----	1.9	13.9	4.3	1.9	20.5	3.2	0.4	9.2**	1.3*
Time (T)	1	---	0.01	0.1	9.8	0.1	0.8	1.0	9.2	---	---	---
Method (M)	1	0.1	0.01	2.5	5.0	3.6	0.2	25.5	31.7*	6.1*	1.1	1.1
T x M	1	---	0.46	0.1	0.8	0.3	1.3	9.2	0.1	---	---	---
Error a	6	---	----	0.7	3.9	1.8	0.8	5.4	2.7	---	---	---
Rate (R)	4	7.2	8.60	2.2*	17.9*	0.1	13.7**	18.0**	16.6**	14.2**	2.7	3.3**
Linear	1	4.1	3.10	0.5	65.0**	0.1	31.2**	69.3**	65.7**	52.5**	2.0	11.6**
T x R	3	---	0.09	0.6	1.8	0.6	0.2	1.1	1.2	---	---	---
M x R	3	---	0.07	1.5	1.2	0.1	0.7	0.9	0.2	0.4	0.2	0.7
T x M x R	3	---	----	0.3	5.8	0.2	1.3	0.9	0.9	---	---	---
Error b #	35	16.0	57.00	0.7	2.3	0.5	0.6	1.4	1.3	1.0	1.4	0.5

*, ** Significant at the 0.05 and 0.01 level, respectively.

Error b at Alysham (1988) and Codette (1988) had 3 and 5 df for error, respectively due to reduced replications. Garrick (1989) and White Fox (1989) had 67 df for error as all five replicates were analyzed. The 1990 locations had sulphur applied only in the Spring and were analyzed as a randomized complete block design with 4 replications and 28 df for error. The zero rate of S was excluded from the calculation of sums of squares for T, M, T x R, M x R, and T x M x R. Variation within the zero rate and 1 df each from T x R, M x R and T x M x R, as appropriate, were included in error b sums of squares and df, respectively.

Table 6. The effect of time, method, and rate of sulphate-sulphur application on sulphur concentration of pea seed in 11 sulphur fertilization experiments in 1988, 1989 and 1990.

	Year and location										
	1988		1989						1990		
Treatment	Ayl.	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A	Nip.B	Smeat.
	Sulphur concentration (g kg^{-1} seed)										
Time											
Fall	---	1.92	2.19	2.05	2.05	2.23	2.23	2.15	----	----	----
Spring	---	1.91	2.19	2.12	2.05	2.08	2.25	2.24	----	----	----
Method											
Band	1.33	1.93	2.17	2.06	2.03	2.13	2.17	2.11	2.08	2.23	2.08
Broadcast	1.38	1.91	2.21	2.11	2.07	2.22	2.31	2.28	2.17	2.26	2.11
Rate of SO_4-S (kg ha^{-1})											
0	1.15	1.77	2.20	1.89	2.05	2.08	2.03	1.98	1.88	2.14	1.98
10	1.25	1.85	2.15	2.03	2.04	2.16	2.14	2.09	2.02	2.22	2.05
20	1.30	1.80	2.19	2.06	2.05	2.16	2.21	2.18	2.13	2.29	2.09
30	1.30	2.03	2.23	2.10	2.05	2.27	2.26	2.23	2.15	2.26	2.09
40	1.55	2.00	2.19	2.14	2.05	2.28	2.35	2.28	2.22	2.20	2.15
CV (%)	17.4	9.8	4.1	8.5	3.3	3.3	5.0	3.9	4.1	5.2	2.6

Table 7. Mean squares from the analysis of variance for sulphur concentration of pea straw in 11 sulphur fertilization experiments on pea in 1988, 1989 and 1990.

		Year and location										
		1988		1989						1990		
Source	df	Ayl.	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A	Nip.B	Smeat.
		Mean square x 10^{-1}										
Rep	3	----	----	0.61	6.88	0.55	0.53	1.06	12.09	0.65	0.99	4.22
Time (T)	1	----	0.40	1.52	1.13	0.02	4.03**	1.41	2.70	----	----	----
Method (M)	1	0.01	0.23	1.30	2.00	0.72	4.03**	12.68	1.68	5.48	7.33**	9.00*
T x M	1	----	0.03	0.46	3.38	0.05	1.20	6.53	1.88	----	----	----
Error a	6	----	----	0.42	1.41	0.43	0.36	2.55	3.86	----	----	----
Rate (R)	4	0.21	2.37	2.04**	12.01**	0.22	1.54**	5.44**	3.82	30.76**	2.70	4.97
Linear	1	0.17	1.34	7.49**	46.82**	0.07	0.94*	21.55**	13.74*	107.20**	5.64*	19.47*
T x R	3	----	0.52	0.34	0.77	0.54	0.28	1.23*	5.03	----	----	----
M x R	3	----	0.74	0.72	0.72	0.32	0.22	2.28**	4.08	1.92	1.17	2.53
T x M x R	3	----	----	0.02	0.12	0.08	0.19	1.85**	2.60	----	----	----
Error b #	35	0.25	0.63	0.28	0.43	0.36	0.27	0.33	3.91	1.51	0.82	1.48

*, ** Significant at the 0.05 and 0.01 level, respectively.

Error b at Alysham (1988) and Codette (1988) had 12 and 22 df for error, respectively due to reduced replications and missing plots. Garrick (1989) and White Fox (1989) had 67 df for error due to all replications were analyzed. The 1990 locations had sulphur applied only in the Spring and were analyzed as a randomized complete block design with 4 replications and 28 df for error. The zero rate of S was excluded from the calculation of sums of squares for T, M, T x R, M x R, and T x M x R. Variation within the zero rate and 1 df each from T x R, M x R and T x M x R, as appropriate, were included in error b sums of squares and df, respectively.

Table 8. The effect of time, method, and rate of sulphate-sulphur application on sulphur concentration of pea straw in 11 sulphur fertilization experiments on pea in 1988, 1989 and 1990.

	Year and location										
	1988		1989						1990		
Treatment	Ayl.	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A	Nip.B	Smeat.
	Sulphur concentration (g kg^{-1} straw)										
Time											
Fall	---	1.10	1.59	1.35	1.00	1.48	1.29	1.45	----	----	----
Spring	---	1.20	1.48	1.43	0.99	1.30	1.19	1.60	----	----	----
Method											
Band	0.65	1.20	1.48	1.34	1.03	1.30	1.08	1.31	1.30	1.84	1.35
Broadcast	0.63	1.10	1.58	1.44	0.97	1.48	1.40	1.74	1.56	2.16	1.68
Rate of SO_4-S (kg ha^{-1})											
0	0.58	0.84	1.33	1.01	0.97	1.34	0.91	1.34	0.82	1.64	1.06
10	0.60	1.13	1.40	1.14	1.02	1.48	1.08	1.31	0.79	1.90	1.28
20	0.55	1.15	1.52	1.32	1.04	1.53	1.13	1.48	1.04	2.11	1.48
30	0.65	1.23	1.55	1.51	0.98	1.26	1.28	1.56	1.65	1.98	1.64
40	0.75	1.08	1.65	1.59	0.96	1.31	1.48	1.75	2.22	2.02	1.66
CV (%)	11.1	11.5	9.0	15.4	18.2	11.6	15.3	26.6	29.3	15.4	24.7

Table 9. Mean squares from the analysis of variance for nitrogen concentration of pea seed in 11 sulphur fertilization experiments on pea in 1988, 1989 and 1990.

		Year and location										
		1988		1989						1990		
Source	df	Ayl.	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A	Nip.B	Smeat.
		Mean square										
Rep	2	----	----	1.77	57.64**	8.85*	64.49*	289.27*	15.98	3.80	4.49	1.98
Time (T)	1	0.01	0.01	4.32	3.44	1.27	2.85	0.33	11.51	----	----	----
Method (M)	1	----	2.03	5.47	5.72	7.30*	14.63	41.81	26.60	0.92	3.44	0.72
T x M	1	----	0.01	0.07	0.42	0.04	3.36	71.50	18.38	----	----	----
Error a	6	----	----	1.54	5.97	1.46	9.86	47.06	45.37	----	----	----
Rate (R)	4	0.21	0.52	0.88	3.02	6.47*	7.95	5.50	5.32	1.68	19.21	0.43
Linear	1	0.00	1.73	0.59	0.72	3.92	2.61	15.55	3.07	0.05	3.20	0.80
T x R	3	----	0.39	0.16	0.89	1.29	3.54	5.38	0.66	----	----	----
M x R	3	----	0.34	1.63	6.22	1.69	1.49	11.15	0.57	1.79	15.72	5.85
T x M x R	3	----	----	0.24	1.81	4.24	5.54	14.14	0.76	----	----	----
Error b#	35	0.35	0.75	2.90	2.65	1.73	7.42	8.16	3.52	1.37	14.91	4.66

*, ** Significant at the 0.05 and 0.01 level, respectively.

Alysham (1988) and Codette (1988) had 12 and 22 df for error, respectively due to reduced replications. Garrick (1989) and White Fox (1989) had 67 df for error since all five replications were analyzed. The 1990 locations had sulphur applied only in the Spring and were analyzed as a randomized complete block design with 4 replications and 28 df for error. The zero rate of S was excluded from the calculation of sums of squares for T, M, T x R, M x R, and T x M x R. Variation within the zero rate and 1 df each from T x R, M x R and T x M x R, as appropriate, were included in error b sums of squares and df, respectively.

Table 10. The effect of time, method and rate of sulphur application on nitrogen concentration of pea seed in 11 sulphur fertilization experiments on pea in 1988, 1989 and 1990.

	Year and location										
	1988		1989						1990		
Treatment	Ayl.	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A	Nip.B	Smeat.
	Nitrogen concentration (g kg^{-1} seed)										
Time											
Fall	---	32.4	44.6	43.7	45.6	41.3	37.2	27.5	----	----	----
Spring	---	32.3	45.2	43.3	45.9	40.8	37.0	28.5	----	----	----
Method											
Band	30.7	32.7	44.6	43.3	45.5	41.6	36.1	27.2	42.7	45.8	41.9
Broadcast	30.7	32.0	45.3	43.8	46.1	40.5	38.0	28.7	43.2	46.4	41.6
Rate of SO_4-S (kg ha^{-1})											
0	30.4	32.6	44.8	43.4	46.7	40.9	36.5	28.7	43.3	46.3	41.2
10	30.9	32.8	45.2	43.8	46.0	41.3	36.7	27.4	42.8	46.7	41.6
20	30.4	32.1	44.9	43.3	45.1	42.2	36.5	28.9	43.2	43.4	41.9
30	30.9	32.0	45.1	44.0	45.8	40.0	36.9	28.2	42.3	47.5	41.6
40	30.4	32.4	44.5	43.0	46.1	40.8	38.2	27.5	43.4	46.9	41.7
CV (%)	1.5	3.0	3.7	3.7	2.4	5.8	7.1	5.2	2.6	9.0	5.3

Table 11. Mean squares from the analysis of variance for nitrogen concentration of pea straw in 10 sulphur fertilization experiments on pea in 1988, 1989 and 1990.

		Year and location									
		1988		1989					1990		
Source	df	Ayl.	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	Nip.A	Nip.B	Smeat.
		Mean square									
Rep	2	----	----	0.23	28.13	0.61	1.54	4.33	1.05	5.11	1.43
Time (T)	1	----	0.08	0.33	5.23	0.10	2.04	1.00	----	----	----
Method (M)	1	0.01	0.18	0.27	1.60	4.77	0.04	10.01	0.75	2.17	0.11
T x M	1	----	0.01	0.05	19.44	3.92	9.63	0.40	----	----	----
Error a	6	----	----	1.17	17.18	1.84	6.05	2.33	----	----	----
Rate (R)	2	0.22	0.75	0.04	9.13	0.33	317.71**	0.80	3.95	0.77	1.33
Linear	1	0.09	1.28	0.06	8.64	0.24	541.50**	0.06	4.32	0.27	0.04
T x R	1	----	0.06	0.02	11.21	18.90*	1.31	0.22	----	----	----
M x R	1	----	0.13	0.06	0.48	0.03	2.41	1.00	0.56	2.34	11.39
T x M x R	1	----	----	0.21	8.20	14.88*	0.28	0.51	----	----	----
Error b#	25	3.07	1.45	2.90	11.31	2.55	8.20	2.85	2.04	1.17	5.65

*, ** Significant at the 0.05 and 0.01 level, respectively.

The Alysham (1988) df error = 3, Codette (1988) df error = 5 due to reduced replications. Nipawin A (1990) with 11 df for error, Nipawin B (1990) with 11 df for error had S applied only in the Spring and were analyzed as a randomized complete block design with three replications and three rates of sulphur. Smeaton (1990) had four replications with 18 df for error. The zero rate of S was excluded from the calculation of sums of squares for T, M, T x R, M x R, and T x M x R. Variation within the zero rate and 1 df each from T x R, M x R and T x M x R, as appropriate, were included in error b sums of squares and df, respectively.

Table 12. The effect of time, method, and rate of sulphate-sulphur application on nitrogen concentration of pea straw in 10 sulphur fertilization experiments on pea in 1988, 1989 and 1990.

	Year and location									
	1988		1989					1990		
Treatment	Ayl.	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	Nip.A	Nip.B	Smeat.
	Nitrogen concentration (g kg^{-1} straw)									
Time										
Fall	---	9.5	7.1	13.4	11.6	12.6	7.9	----	----	----
Spring	---	9.6	7.3	12.5	10.9	13.2	8.3	----	----	----
Method										
Band	9.1	9.7	7.2	13.2	11.4	12.9	7.5	6.4	8.9	9.5
Broadcast	9.1	9.4	7.2	12.7	10.5	12.8	8.8	6.9	9.7	9.3
Rate of SO_4-S (kg ha^{-1})										
0	8.7	9.0	7.3	11.5	11.0	18.3	8.4	6.2	8.8	8.7
20	9.1	9.4	7.1	13.2	11.1	17.0	7.9	5.8	9.5	9.4
40	9.0	9.8	7.3	12.7	10.8	8.8	8.3	7.4	9.1	9.4
CV (%)	13.8	1.4	10.3	15.5	9.9	12.5	13.5	23.3	12.5	21.9

Table 13. Mean squares from the analysis of variance for sulphur concentration of the top growth of pea plants at the 6, 11, 16 and 20 node stage for the 0 and 40 kg SO_4-S ha^{-1} Spring banded treatments in 11 sulphur fertilization experiments on pea in 1988, 1989 and 1990.

		Year and location										
		1988		1989						1990		
Source	df	Ayl.+	Cod.+	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A	Nip.B	Smeat.
		Mean square										
Rep	1	0.02	0.07	0.03	0.03	0.06	0.33	0.42	4.20**	0.53	0.01	0.53**
Node (N)	3	2.84**	2.84**	1.37**	0.63**	1.88**	1.41*	3.22**	2.00*	1.14	0.62**	2.15**
Linear	1	2.12**	5.28**	1.07**	0.04	3.46**	3.06*	8.57**	5.47**	0.47	0.19	6.23**
Rate (R)	1	0.14*	0.01	0.68**	1.50**	0.25*	0.14	1.56	7.02**	0.03	0.18	1.89**
R x N	3	0.03	0.02	0.24*	0.04	0.03	0.06	0.13	1.13	0.07	0.02	0.18*
Error	7	0.01	0.10	0.04	0.05	0.04	0.29	0.35	0.30	0.54	0.06	0.03

*, ** Significant at the 0.05 and 0.01 level, respectively.

Table 14. The effect of sulphate-sulphur on sulphur concentration of the top growth of pea plants at the 6, 11, 16, and 20 node stage for the 0 and 40 kg SO_4-S ha^{-1} Spring banded treatments in 11 sulphur fertilization experiments in 1988, 1989 and 1990.

	Year and location										
	1988		1989						1990		
Treatment	Ayl.	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A	Nip.B	Smeat.
	Sulphur concentration (g kg^{-1} dry matter)										
0 kg SO_4-S ha^{-1} at node stage											
6	3.25	3.55	2.80	2.45	2.45	2.75	3.50	3.95	3.35	3.75	3.40
11	2.90	3.25	3.50	2.65	3.20	3.20	2.55	2.90	2.85	2.75	2.55
16	1.70	2.05	2.40	2.70	2.15	2.65	1.70	1.90	3.90	3.35	1.85
20	----	----	2.15	1.85	1.60	1.85	1.65	2.00	2.35	3.05	1.80
Mean	2.62	2.95	2.71	2.41	2.35	2.61	2.35	2.69	3.11	3.23	2.40
40 kg SO_4-S ha^{-1} at node stage											
6	3.65	3.90	2.90	3.20	2.95	3.25	4.35	3.95	3.40	3.75	4.00
11	2.95	3.35	3.45	3.00	3.35	3.40	2.75	4.90	3.00	2.95	3.10
16	3.15	2.15	2.75	3.45	2.40	2.55	2.65	4.25	3.65	3.70	3.15
20	----	----	2.40	2.45	1.70	2.00	2.15	2.95	2.75	3.35	2.10
Mean	2.83	3.13	3.13	3.03	2.60	2.80	2.98	4.01	3.20	3.44	3.09
CV (%)	3.7	10.4	6.8	8.2	8.1	19.9	22.2	16.3	17.1	7.3	6.3

Table 15. Mean squares from the analysis of variance for nitrogen concentration of the top growth of pea plants at the 6, 11, 16 and 20 node stage for the 0 and 40 kg SO_4-S ha^{-1} Spring banded treatments in 11 sulphur fertilization experiments on pea in 1988, 1989 and 1990.

		Year and location										
		1988		1989						1990		
Source	df	Ayl.+	Cod.+	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A	Nip.B	Smeat.
		Mean square										
Rep	1	1.6	0.1	1.2	3.2	0.6	1.0	8.0	2.6	21.9	9.5	11.6
Node(N)	3	593.3**	542.1**	360.7**	254.5**	331.2**	436.4**	187.6**	256.5**	473.0**	440.8**	441.7**
Linear	1	1152.0**	961.0**	889.6**	607.0**	600.1**	826.4**	605.6**	109.1**	1409.2**	1239.5**	1067.3**
Rate(R)	1	1.1	11.0	0.3	3.9	26.5	0.1	0.1	8.6	119.4*	7.2	0.1
R x N	3	0.9	1.4	1.4	1.1	6.3	5.4	16.7	4.4	5.4	17.8*	14.5
Error	7	3.1	3.7	8.4	1.6	5.6	12.3	13.0	2.0	17.0	3.2	9.6

*, ** Significant at the 0.05 and 0.01 level, respectively.
+ error degrees of freedom = 5.

Table 16. The effect of sulphate-sulphur on nitrogen concentration of the top growth of pea plants at the 6, 11, 16 and 20 node stage for the 0 and 40 kg SO_4-S ha^{-1} Spring banded treatments in 11 sulphur fertilization experiments in 1988, 1989 and 1990.

	Year and location										
	1988		1989						1990		
Treatment	Ayl.	Cod.	Cod.	Gar.	W.Fox	Nip.	Pont.	S.Hill	Nip.A	Nip.B	Smeat.
	Nitrogen concentration (g kg^{-1} of dry matter)										
0 kg SO_4-S at node stage											
6	58.85	58.10	52.57	47.10	47.25	47.85	42.25	35.80	57.10	58.45	53.35
11	51.35	53.20	54.35	49.40	53.50	51.25	44.70	35.25	44.35	42.90	39.10
16	35.00	35.00	42.70	45.50	42.00	47.50	30.40	32.65	38.80	41.50	26.10
20	-----	-----	33.30	31.70	32.25	28.70	29.95	20.30	31.95	32.70	32.75
Mean	48.40	48.77	45.58	43.43	43.75	43.38	36.83	31.00	43.05	43.88	37.83
40 kg SO_4-S at node stage											
6	60.15	58.75	51.40	48.85	48.50	47.15	44.60	36.40	50.45	56.55	49.85
11	50.83	55.30	54.10	49.00	55.30	54.40	44.30	39.55	42.15	45.30	41.15
16	36.00	38.00	44.65	47.35	48.30	43.30	36.15	34.35	33.30	34.45	30.30
20	-----	-----	33.25	32.45	33.15	28.40	27.70	19.65	24.45	33.90	29.70
Mean	49.00	50.68	45.85	44.41	46.33	43.31	36.69	32.46	37.58	42.55	37.75
CV (%)	3.6	3.9	6.4	2.9	5.2	8.1	9.8	4.5	10.2	4.1	8.2