Executive Summary

Project P07/13/145/11

S-fertiliser requirements of canola in the production areas of the Western Cape

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Low grain yields obtained with canola hampered the production of this crop in the Western Cape Province of South Africa. Nitrogen fertilisation has been reported to increase yield considerably in other canola growing regions of the world, but resulted in poor and variable responses in the Western Cape production area. Besides nitrogen as a major nutrient required in canola production, sulphur is also important for optimum growth, yield and quality of canola, but responses to sulphur applications are often influenced by soil properties and nitrogen application rates. Because the sulpur requirements of wheat, which is the major field crop in the Western Cape, are about four times less than that of canola, sulphur is not often included in fertilisation programs used in this area. The aim of this research was to determine the effect of sulphur (S) and nitrogen (N) application rates on plant nutrient content, yield and grain quality, as well as agronomic and water use efficiencies of canola as experienced at different localities in the Western Cape canola producing areas. The study was conducted at Elsenburg, Langgewens and Roodebloem (2009-2011) as well as at Welgevallen (2010) and Altona (2011) localities. Treatments consisted of five N (0, 30, 60, 90 and 120 kg N ha^{-1}) and three S (0, 15 and 30 kg S ha^{-1}) application rates laid out in a randomized block design with factorial split plot arrangement.

The following results were obtained:

1. The nutrient content of canola plants at 90 days after planting (early flowering) differed between localities due to differences in soil characteristics and climatic conditions. In this study, sulpur applied at planting as $CaSO_4$ had no significant on the S content of plants at flowering in spite of generally low S contents in the soil at all localities. The S content decreased due to the application of nitrogen and although significant differences were shown between localities, all localities showed values of less 0.5% which is the critical value needed at flowering. Lower S contents at higher N rates were most probably due to higher biomass produced at higher N rates. Nitrogen applications did increase the plant N content, but mean value for different localities after an application of 90 kg N ha^{-1} was still below the critical value of 3.5%.

2. In general, grain yield responses to increasing N application rates were higher if S was also applied, i.e the maximum response cannot be achived without the addition of S. In

contrast to treatments where no S was applied, grain yield did not tend to level off at application rates of 120 kg N ha^{-1} with applications of 15 and 30 kg S ha^{-1}, suggesting that even higher N rates may be needed to obtain maximum grain yield if S supply is sufficiently. Additional yield can be also be obtained by adding S in the absence of N, but as in the case of N fertilisation, maximum yield cannot be obtained with S on its own. The effect of S applications was however, less during high compared to low rainfall seasons, clearly illustrating the utmost importance of S applications in low rainfall areas to ensure maximum grain yields.

3. Sulphur applications did not have a significant effect on the grain proteïn content. Although the response differed between localities, oil content tended to increase due to applications of 15 and 30 kg S ha^{-1}. In general the grain oil content decreased and grain proteïn increased with increasing N application rates, but responses differed between localities due to soil and climatic differences.

4. Agronomic N and S use efficiencies (grain yield increase per kg N or S applied) were very variable between localities, years and even fertiliser (N and S) treatments. On average agronomic S use efficiencies varied between 10.96 and 14.58 kg increase in grain yield per kg of S applied, while agronomic N use efficiencies varied between 6.5 and 14.0 kg grain yield increase per kg N applied. These results indicated that S and N applications will improve profit margins as long as the application cost of S and N in kilograms per hectare is respectively less than 10.96 and 6.5 times the producer's price of canola (R per kg of grain).

5. Water use efficiency (WUE) differed between growing seasons and localities, most probably due to differences in total April to Oktober rainfall as well as rainfall distribution. Lowest WUE values of 4.0-5.0 kg grain per mm rainfall was obtained at Langgewens, while the highest values of 12.18 and 9.65 kg grain per mm of rainfall were obtain in 2011 at Roodebloem and Altona respectively. Water use efficiency increased as a result of nitrogen and sulphur applications in 2009 and 2011, but not in 2010. In 2011 (low rainfall year), mean WUE values of nearly 9 kg grain per mm of rain were obtained with high N and S application rates compared to about 6.5 kg grain per mm of rain where no N or S was applied. Sufficient N and S fertiliser can for this reason help to increase canola yields in low rainfall areas of the Western Cape.

This study clearly illustrated the importance of sulphur applications to canola grown in the Western Cape. The results, however also identify the need for some follow-up research to determine the effect of higher N and S application rates, optimum time of application as well as the efficiency of different S and N sources.

FINAL REPORT

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INTRODUCTION

Canola (*Brassica napus* L.), an oilseed crop, has become of major economic importance, with global production increasing to more than 60 million metric tonnes in recent years. Compared to the major global producers, production of canola in South Africa is still low with an annual production of 58 800 ton in 2011 on an area of 43 510 ha indicating a national average yield of 1.35 ton ha^{-1}. Profit margins of low yielding canola did not compete well with other winter crops (wheat, baley) grown in the area, making it difficult to convince producers to increase the land area used for canola production. For this reason it is important to focus on higher yields per hectare.

Fertilisation with nitrogen has been reported to increase yield considerably in other canola growing regions of the world, but has been shown to give poor and or variable responses in the Western Cape production area. Besides nitrogen as a major nutrient required in canola production, sulphur is one of the nutrients that plays a crucial role in canola, affecting growth and yield, with its requirements about four times higher than that of wheat or maize.

Sulphur forms an integral part of several amino acids, hence affecting seed protein content. Low sulphur supply suppresses the development of reproductive organs and may lead to silique abortion and decreases seed yield and oil content. From literature it became clear that in general, grain yield did not respond largely to S applications unless N is also applied. On average, applications of 15-20 kg S ha^{-1} are recommended per ton of grain yield potential, in a N: S ratio of 7:1. However, optimum application rates may be affected by soil properties and climatic conditions.

The aim of this research was to determine the effect of soil and climatic conditions, as experienced at different localities in the Western Cape canola producing areas on plant nutrient content, yield and grain quality, as well as agronomic and water use efficiencies of canola in response to N and S application rates.

MATERIAL and METHODS

Locality

Field experiments were conducted at Elsenburg, Langgewens, Roodebloem experimental stations in the Western Cape Province of South Africa during the winter growingseasons of canola during 2009, 2010 and 2011, as well as at Welgevallen (2010) and at Altona (2011). Originally the study was planned to be conducted at Elsenburg, Langgewens, Roodebloem and Welgevallen, but damage due to birds in 2009 and lesser extend also in 2010 at Welgevallen, necessitated the use of Altona in 2011 instead of Welgevallen.

Rainfall and temperature

In 2009, Elsenburg received the highest total rainfall (May to October) of 568.3 mm, whilst Roodebloem and Langgewens received a total of 339.4 and 285.2 mm rain, respectively. In 2010, Elsenburg received more rain (442.9 mm) than Welgevallen (426.6 mm), Langgewens (366 mm) and Roodebloem (320.9 mm). During 2011, rainfall was far below that of previous years at most localities except at Langgewens (308.6 mm) which was higher than in 2009, even though below that received in 2010 at the same locality. Elsenburg received a total rainfall of 325.8 mm, Altona a rainfall of 295.9 mm and Roodebloem 241.5 mm. Temperatures were generally favourable for canola production even though the 2010 season was considerably warmer at all localities with temperatures experienced being above those of 2009 and 2011.

Soil Characteristics

Soil samples were collected at planting from the plots receiving no N or S and analyzed for pH, acidity, resistance as well as macro and micronutrients at the laboratories of the Department of Agriculture in the Western Cape at Elsenburg using standard procedures. Soil nutrient content at the different localities did not vary much between years, therefore results for different years per locality were pooled (Table 1).

Soil at Altona, Elsenburg and Welgevallen showed pH with values of less than pH_{KCl} 5.0, while Roodebloem and Langgewens showed values within the optimal pH range (Ph_{KCl} 5.0 - 7.0) for growth and development of canola. Considering the mean values in the 0-45 cm soil profile, all micronutrients were above the critical levels required for canola production. The only exception was B (< 0.2 mg kg^{-1}) at all localities, but Roodebloem. Sulphur and total N levels at almost all localities were low with S, at all localities except at Elsenburg and Welgevallen, below the critical level of 6 mg kg^{-1} required for canola production (Table 1). The N-mineralisation potential in the 0-200 mm soil profile was calculated as: Altona 111.3 kg N ha^{-1} (2011 only), Elsenburg 92.0 kg N ha^{-1} (2009-2011), Langgewens 56.8 kg N ha^{-1} (2009-2011), Roodebloem 59.9 kg N ha^{-1} (2009-2011) and Welgevallen 93.5 kg N ha^{-1} (2010 only). These values were calculated from nitrate and ammonium-N contents (indophenol-blue and salicylic acid methods respectively) measured in the soil at planting, plus nitrate- and ammonium-N mineralized in incubation studies during a forty day period, to give an indication of the potential of the soil to supply nitrogen to the crop.

Table 1: Soil characteristics at Altona (Alton), Elsenburg (Els), Langgewens (Lgwens) , Roodebloem (Rbloem) and Welgevallen (Welg) measured in the 0-45cm profile at planting. Mean values 2009-2011.

Locality	Depth (cm)	pH (KCl)	Resis-tance (ohm)	Total N (%)	P citric acid (mg kg^{-1})	K (mg kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})	S (mg kg^{-1})	C (%)	Cu (mg kg^{-1})	B (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
Alton[1]	15	4.7	420	0.11	90	111	3.08	0.85	7	1.27	1.38	0.24	50.37	3.58
Alton[1]	30	4.3	1280	0.06	60	69	1.93	0.62	3.3	0.59	1.72	0.14	105.4	1.99
Alton[1]	45	4.7	1980	0.04	34	56	2.24	0.83	2.1	0.36	1.99	0.17	119.8	1.29
Els	15	5.4	760	0.06	67	117	3.25	0.33	8.7	0.79	1.94	0.22	44.2	1.53
Els	30	4.6	13467	0.05	46	102	1.61	0.27	5.89	0.66	1.57	0.18	43.74	1.01
Els	45	4.6	1503	0.05	30	93	1.45	0.28	3.97	0.51	1.52	0.19	28.92	0.74
Lgwens	15	5.6	783	0.05	83	142	2.92	0.58	6.63	0.48	1.15	0.12	109.07	1.69
Lgwens	30	5.4	1653	0.04	77	115	2.2	0.66	4.35	0.37	1.07	0.11	117.58	1.26
Lgwens	45	5.9	1890	0.03	65	98	2.45	0.74	4	0.31	1.11	0.12	112.91	0.86
Rbloem	15	5.4	763	0.17	72	107	5.42	1.3	4.01	1.99	0.84	0.3	16.87	1.62
Rbloem	30	5.1	1090	0.11	32	66	3.21	1.08	2.18	1.15	0.88	0.21	11.98	1.07
Rbloem	45	5.1	1403	0.1	24	65	2.81	1.01	2.07	0.98	0.84	0.21	10.66	0.91
Welg[2]	15	4.7	540	0.12	201	241	2.57	0.66	11	1.08	1.44	0.14	18.55	3.64
Welg[2]	30	4.4	840	0.09	189	184	2.29	0.53	6.2	0.99	1.38	0.14	18.43	
Welg[2]	45	4.5	710	0.09	209	187	2.63	0.67	7.2	0.82	1.55	0.18	13.62	
Critical content*		<5*[2]	-	-	<36*[2]	<60*[2]	<1.0*[1]	<0.4*[1]	<6.0*[1]	-	<0.3*[1]	<0.2*[1]	<5.0*[1]	

* shows the critical soil nutrient levels at which the nutrient became deficient*[1] or where the growth of canola plants will be negatively affected*[2] (Canola production manual, undated; Peverill, 1999)
[1]2011 only; [2]2010 only

Experimental procedure

The experiment was laid out as a randomized block design with a factorial split plot arrangement. Treatments consisted of five nitrogen rates (0, 30, 60, 90 and 120 kg N ha^{-1}) as main plots and three S rates (0, 15 and 30 kg S ha^{-1}) as sub-plots, replicated in four blocks. The sizes of the subplots were 5 x 3 m^2. The N source was Limestone Ammonium Nitrate (LAN) with 28 % N while S was applied in the form of gypsum ($CaSO_4.2H_2O$) with 16 % S. All S treatments were applied at planting whilst N was applied as:

- N 0=0 kg N ha^{-1} (No N applied)
- N 1=30 kg N ha^{-1} (30 kg N ha^{-1}applied at planting)
- N 2= 60kg N ha^{-1} (30 kg N ha^{-1}applied at planting and 30 kg N ha^{-1}at 30 DAP)
- N 3=90 kg N ha^{-1} (30 kg N ha^{-1} applied at planting plus 30 kg N ha^{-1} at 30 DAP and final 30 kg N ha^{-1} at 60 DAP)
- N 4= 120 kg N ha^{-1} (30 kg N ha^{-1} applied at planting plus 30 kg N ha^{-1}at 30 DAP plus 30 kg N ha^{-1} at 60 DAP and final 30 kg N ha^{-1} at 90 DAP)

The canola cultivar, Bravo TT, was sown at a density of 4 kg ha^{-1} between 22 April and 17 May in all seasons.

Data collected

At 90 days after planting (DAP), a net plot of 0.5 m^2 per replication was sampled in each of the following six treatment combinations of S (0, 15 and 30 kg ha^{-1}) and N (0 and 120 kg ha^{-1}). It is however important to note that at the time of sampling only 90 kg N ha^{-1} was applied to the 120 N treatments as the last increment of 30 kg N ha^{-1} was applied at 90 DAP. Samples were air dried and thereafter milled and analysed to determine the nutrient concentrations (contents) of N, S, P, K, Ca, Mg, Na, Fe, Cu, Zn, Mn, B and Al.

At maturity, canola crop was harvested with a plot harvester on 5 x 3 meter plots and grain yields were converted to kg ha^{-1} (following cleaning and weighing). The grain protein and oil contents were determined, using NAR (Near- Infra-Red) technology.

Agronomic use efficiencies (AE) of N and S were calculated using the following equations for N and S respectively:

$$\text{NUE (kg seed kg N applied}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1}) - \text{Grain yield control (kg ha}^{-1})}{\text{N fertiliser applied (kg ha}^{-1})}$$

and

$$\text{SUE (kg seed kg S applied}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1}) - \text{Grain yield control (kg ha}^{-1})}{\text{S fertilise applied (kg ha}^{-1})}$$

Water use efficiency in form of grain yield per millimeter of rainfall received was calculated by using the following equation:

$$\text{WUE (kg grain mm water}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Water Use (mm)}}$$

Water use was calculated as follows:

Water use (mm) = 51.1+ 0.75 (May to October rainfall).

This equation was developed for Western Australian conditions, which are very similar to conditions in the Western Cape and most of the trials in this study were also planted during May. The equation was therefore considered to be relevant for this study.

Data analysis

Data was analyzed, using analysis of variance (ANOVA) (Statistica 11). Any treatment means found to be significantly different were separated using Fischer's protected $LSD_{0.05}$. Interaction effects were compared using least significant difference (LSD) test at 5 % level of probability. Because the results of the plant analysis did not show any differences due to the different years in 2009 and 2010, plant samples for different replications were pooled before analysis in 2011 and years were used as replications and locality was regarded as a factor. In order to obtain response curves for grain yield, means from the Statistica analyses were subjected to best fit regression curves plotted with the Microsoft Office Excel package, using polynomial equations. In this report only results showing statistically significant differences will be presented and discussed.

RESULTS and DISCUSSION

Nutrient contents (concentration) in plants at 90 days after planting (DAP)

Canola plants at Roodebloem (2.51 %) had a lower N content compared to those at Altona (2.84 %), Langgewens (2.92 %), Welgevallen (3.29 %) and Elsenburg (3.36 %) and all values were below the critical value of 3.5% (Table 2). A nitrogen application of 90 kg N ha^{-1} (120N treatment) did increase the plant N content, but mean value for different localities was still below the critical value of 3.5%. The S content was decreased due to the application of nitrogen and although significant differences were shown between localities, all localities showed values of less 0.5% which is the critical value needed. In this study, sulpur applied at planting as $CaSO_4$ had no significant on the S content of plants at flowering (data not shown).

The Na contents of plants at Elsenburg and Welgevallen were less than that at Altona and to a lesser extend also at Langgewens and Roodebloem, because the soil Elsenburg and Welgevallen showed lower Na contents.

Table 2: Canola nutrient contents at Altona (ALT), Elsenburg (ELS), Langgewens (LG), Roodebloem (RB) and Welgevallen (WLG) localities and plant response to N fertilisation rates of 0 and 120 kg ha^{-1} at 90 DAP.

	Locality					***N rate* (kg ha^{-1})**			**Critical[y]**
	ALT	ELS	LG	RB	WLG	0	120	Mean	
N (%)	2.84b	3.36a	2.92b	2.51c	3.29a	2.77b	3.20a	2.99	3.5
S (%)	0.28c	0.38a	0.34b	0.30c	0.35ab	0.35a	0.31b	0.33	0.5
P (%)	0.52	0.55	0.99	0.44	0.55	0.73	0.49	0.61	0.3-0.6
K (%)	4.62b	4.88b	3.43c	2.99c	6.02a	4.17b	4.61a	4.39	2.2
Ca (%)	1.24d	2.11a	2.12a	1.44c	1.79b	1.72	1.76	1.74	1.4-3.0
Mg (%)	0.54a	0.34c	0.39b	0.35c	0.31d	0.38	0.39	0.39	0.2-0.6
Na(mg kg^{-1})	10066.7a	2173.7c	6193.1b	7516.3b	1295.9c	4434.3b	6464.0a	5449.15	-
Fe (mg kg^{-1})	450.31	379.15	312.83	867.34	398.32	601.74a	361.44b	481.59	19
Cu (mg kg^{-1})	6.69ab	8.22a	5.07b	4.54b	5.88ab	5.40	6.76	6.08	3-5
Zn (mg kg^{-1})	39.12b	41.34b	24.65c	25.18c	60.17a	36.03	40.15	38.09	20
Mn (mg kg^{-1})	31.59c	40.0bc	43.35b	17.90d	54.75a	36.63	38.41	37.52	30-200
B (mg kg^{-1})	44.72a	32.09b	28.65c	29.61bc	25.40d	31.77	32.42	32.10	20-50
Al (mg kg^{-1})	483.33a	575.97a	267.07b	202.25b	520.0a	365.62b	453.83a	409.73	-

*, **, *** Significant at P<0.05, P<0.01, P<0.001 respectively, ns denotes non significance at P<0.05. Means in the same row for each one treatment with at least a common letter are not significantly different, LSD $_{0.05}$

[y] Critical nutrient level needed for optimal growth and development of canola at flowering (Canola Production Manual, undated), Fe critical level is obtained from the manual from Canola Council of Canada

High levels of Al measured in canola plants sampled at Welgevallen, Elsenburg and Altona may be ascribed to the lower soil pH and hence increased plant availability. Relatively low Al contents at Langgewens and Roodebloem may be due to the lower rainfall (assumed less soil moisture) and hence reduced uptake of nutrients.

Even though certain nutrients were lower at some localities, almost all micro-nutrients were above the critical levels for canola growth and development. Besides Mn at Roodebloem other exceptions were boron which was on the low side and especially at Welgevallen, Langgewens and Roodebloem because of insufficient levels in the soil.

In general, fertilisation with 120 kg N ha^{-1} significantly increased the content of N, K, Na and Al whilst S and Fe were reduced in canola plants sampled at 90 DAP (Table 3). Nitrogen fertilisation did not have a significant effect on P, Ca, Mg, Cu, Zn, Mn and B contents of canola plants in this trial, while S applications had no effect at all.

Grain yield

Grain yield differed between growing seasons and was significantly affected by N and S application rates. Although responses differed between localities, the trends were similar. To determine the effect of growing season on these responses, regression analyses were used to develop N x S response curves for each year (Figure 1). The mean total rainfall for the 2009, 2010 and 2011 growing season were 397 mm , 388 mm and 292 mm respectively and although grain yield responses to N and S showed similar trends, differences in rainfall did affect the response curwes. With no S applied, grain yields increased due to N applications and tend to level off at higher (90-120 kg) N rates during the high rainfall seasons (2009 and 2010), but show very little or even no yield increase due to N application rates in the season with lower rainfall (2011).

Grain yield responses to increasing N application rates were generally improved if S was applied (Figure 1). During the seasons with higher rainfall (2009 and 2010), differences in grain yield response to increasing N rates between the 15 and 30 kg S application rates were very small (response curwes were generally close together). During the lower rainfall season (2011) a larger response to N application rates was obtained with 30 kg S ha^{-1} compared to 15 kg S ha^{-1} at the higher N application rates. In general, grain yields did not tend to level off at the highest N application rates of 120 kg N ha^{-1} with applications of 15 and 30 kg S ha^{-1}, suggesting that higher N application rates may be needed to obtain maximum grain yield if S was applied sufficiently.

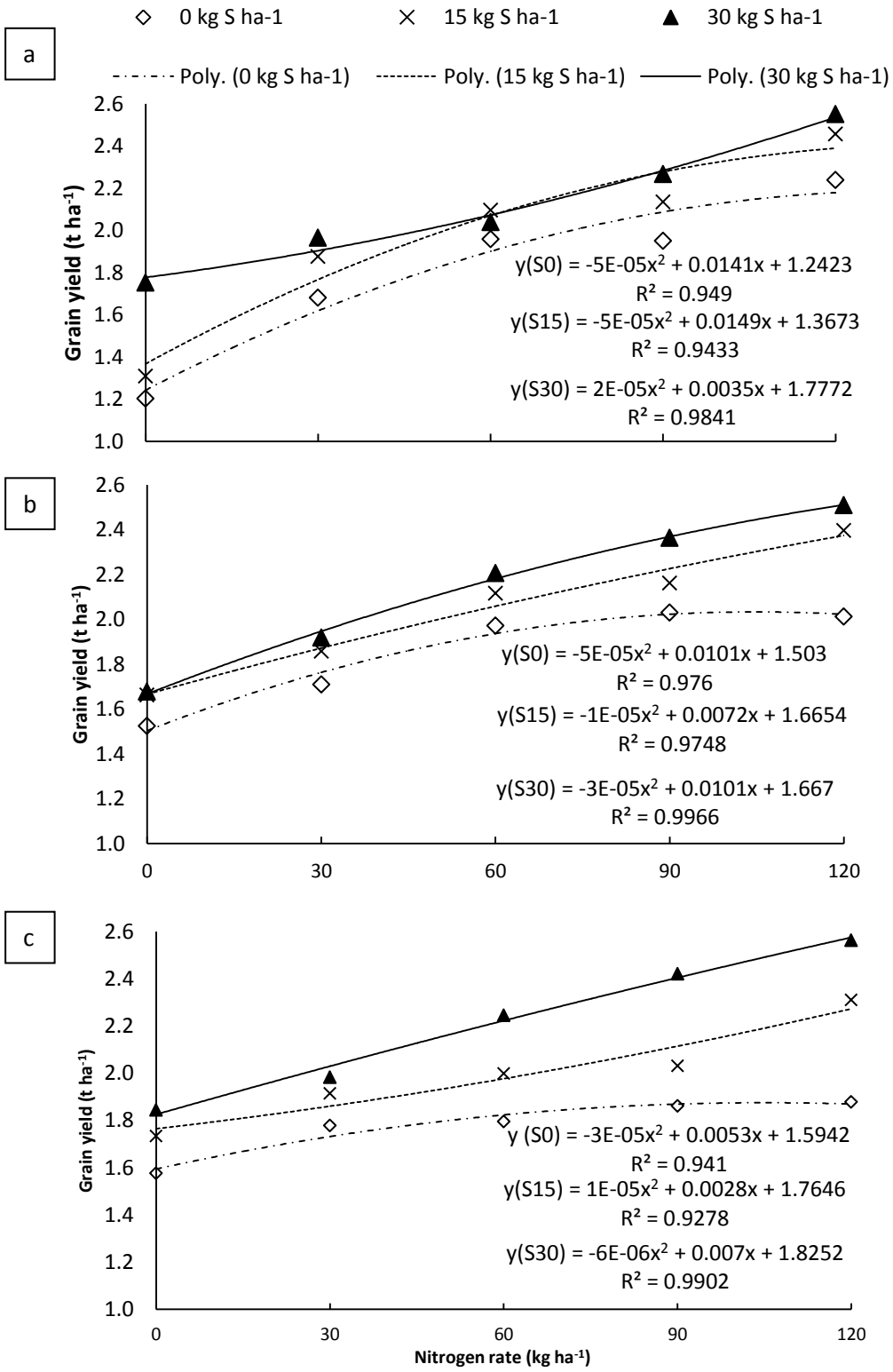


Figure 1: Effect of nitrogen and sulphur fertilisation rates on canola yields in (a) 2009, (b) 2010 and (c) 2011 seasons.

Grain oil and protein content

Grain oil content differed significantly as a result of the S rate, but responses differed between localities (Table 3). In contrast to Elsenburg and Roodebloem where no differences were recorded due to S application rate, the grain oil content at Langgewens increased from 36.2% to 36.6% and 36.7% with application rates of 15 and 30 kg S ha^{-1} repectively. No significant differences were however recorded between application rates of 15 and 30 kg S ha^{-1}. On average higher oil contents were measured at Roodebloem than at Langgewens. Sulphur application had no significant effect on the protein content at any of the localities (data not shown).

Table 3: Effect of S-fertiliser rates on grain oil content (%) of canola grown at different localities (Mean values for 2009-2011 period) .

S rate **(kg ha^{-1})**	**Elsenburg**	**Langgewens**	**Roodebloem**
0	39.1b	36.2d	41.3a
15	39.3b	36.6c	41.4a
30	39.3b	36.7c	41.5a
Mean	**39.2b**	**36.5c**	**41.4a**

High N application rates generally lowered the oil content whilst increasing the protein content of canola grain, but responses differed between localities (Table 4). At Elsenburg the oil content decreased from 40.9% where no N was applied to 36.7% due to the application of 120 kg N ha^{-1}, while the protein content increased from 20.5% to 23.7%. At Roodebloem these increases in N fertiliser rates resulted in a decrease in oil from 42.8% to 39.5% and an increase in protein from 18.5% to 22.5%, but no sigficant differences were recorded at Langgewens. Responses due to different N application rates were not significantly affected by S application rates.

Table 4: Effect of N and S-fertiliser rates on grain oil content (%) and grain protein content (%) of canola grown at different localities (Mean values for 2009-2011 period).

N rate **(kg ha^{-1})**	***S rate*** **(kg ha^{-1})**	**Elsenburg**		**Langgewens**		**Roodebloem**	
		Oil	**Protein**	**Oil**	**Protein**	**Oil**	**Protein**
0	0	40.9	20.4	37.7	23.5	42.8	18.6
	15	40.9	20.6	37.7	23.5	42.7	18.4
	30	41.0	20.4	37.8	23.4	42.9	18.6
	Mean	**40.9**	**20.5**	**37.7**	**23.5**	**42.8**	**18.5**
30	0	40.3	21.6	37.2	24.5	42.4	18.8
	15	40.2	21.5	37.4	24.6	42.4	19.0
	30	40.4	21.8	37.5	24.6	42.5	19.2
	Mean	**40.3**	**21.6**	**37.4**	**24.6**	**42.4**	**19.0**
60	0	39.7	22.2	36.1	24.9	41.6	20.1
	15	39.8	22.6	36.4	25.2	41.7	20.2

	30	39.9	22.9	36.6	25.4	41.8	20.3
	Mean	**39.8**	**22.6**	**36.4**	**25.2**	**41.7**	**20.2**
90	0	38.3	23.1	35.2	25.3	40.6	20.7
	15	38.4	23.1	35.9	25.2	40.7	20.7
	30	38.3	23.3	35.8	25.5	40.9	20.8
	Mean	**38.3**	**23.2**	**35.6**	**25.3**	**40.7**	**20.7**
120	0	36.5	23.8	35.0	25.3.	39.3	22.4
	15	36.9	23.7	35.6	25.6	39.6	22.6
	30	36.8	23.6	35.8	25.6	39.5	22.6
	Mean	**36.7**	**23.7**	**35.5**	**25.5**	**39.5**	**22.5**
Locality mean		**39.2**	**22.3**	**36.5**	**24.8**	**41.4**	**20.2**
Oil -$LSD_{0.05}$:	Locality: 2.3		Locality X N: 2.8		Locality X N X S: ns		
Protein- $LSD_{0.05}$:	Locality: 1.9		Locality X N: 3.2		Locality X N X S: ns		

Agronomic N use efficiency

Agronomic N use efficiency (NUE) differed between localities in 2009 with Elsenburg (14.03 kg yield increase per kg N applied) showing higher NUE values compared to Roodebloem (9.53 kg yield increase per kg N applied) and Langgewens (6.50 kg yield increase per kg N applied) (Figure 2), probably due to the higher rainfall at this locality. Differences in NUE at different localities were also recorded in 2010, but not so in 2011.

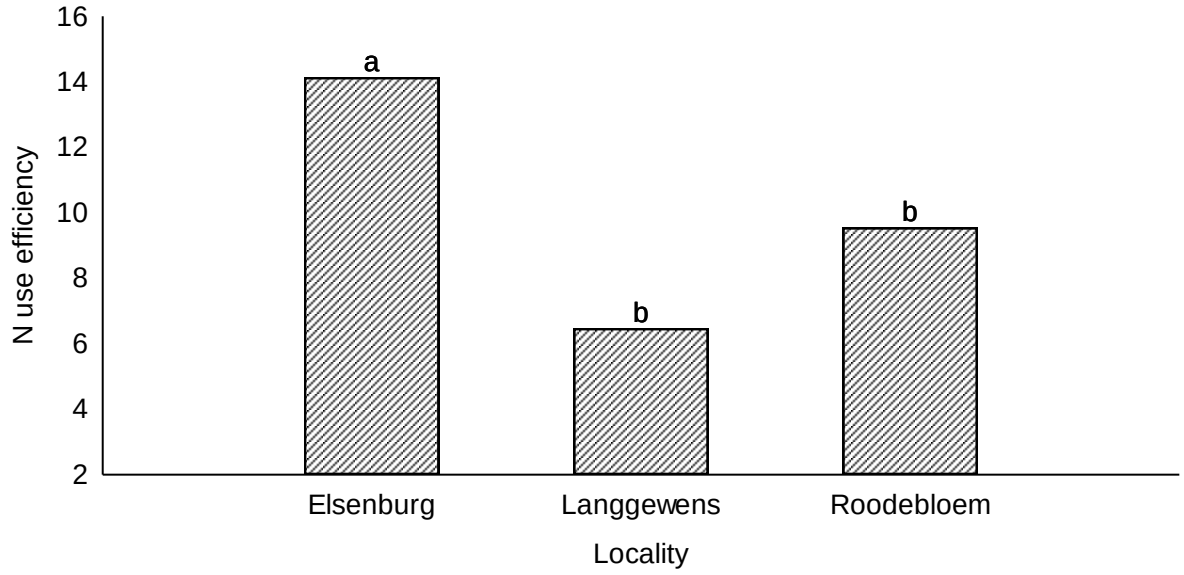


Figure 2: Agronomic N use efficiencies of canola at Elsenburg, Langgewens and Roodebloem localities during the 2009 season.

Agronomic N use efficiency decreased with an increase in N application rate from on average about 14 kg yield increase per kg N applied at a rate of 30 kg to less than 8 at N application

rates of more than 60 kg N ha^{-1} in 2009 (Figure 3). In 2010, NUE responses to N applications differed at different localities with low N application rates, but also showed a decrease in NUE with an increase in N application rate between 60 and 120 kg N ha^{-1} at all localities. No effect was recorded in 2011.

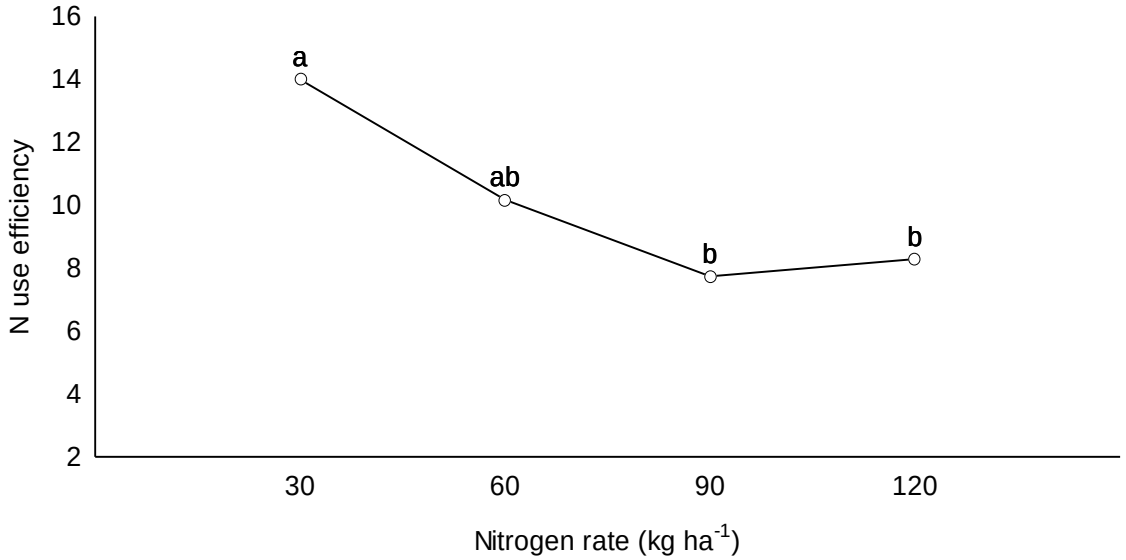


Figure 3: Agronomic N use efficiencies of canola with increasing N application rates during 2009 season

In 2009, agronomic efficiency of N fertiliser applications tend to increase with S applications from 11.37 where no S was applied, to 12.71 at rates of 15 kg S ha^{-1}, but showed a significant decrease when more than 15 kg S ha^{-1} was applied (Figure 4). This trend was however not repeated in 2010 and 2011.

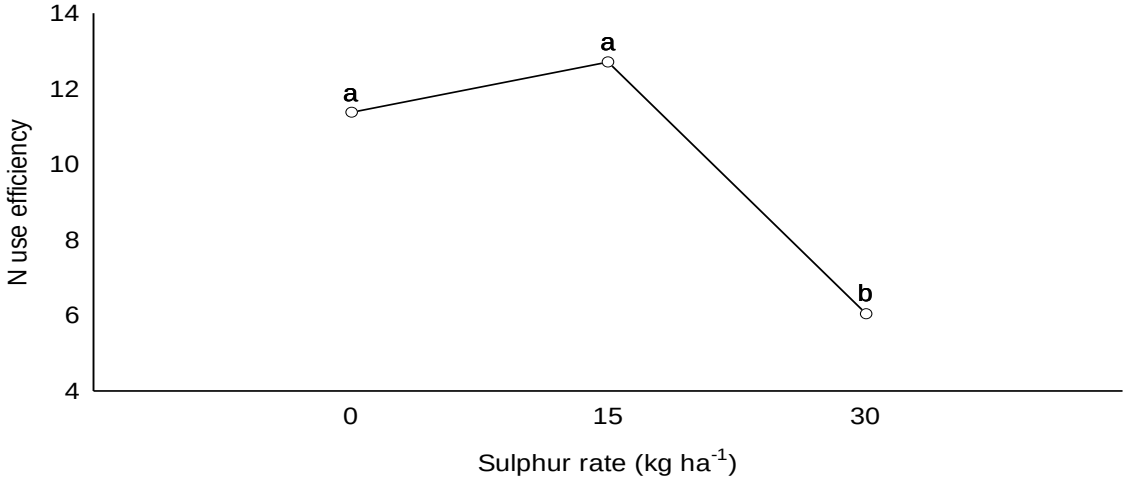


Figure 4: Agronomic N use efficiencies of canola with increase in sulphur rates during 2009 season

The generally low agronomic efficiencies reported (<15 kg seed yield kg^{-1} N added) in this study were within the range observed in earlier studies. These low values may be the result of climatic conditions (decreasing rainfall and increasing temperature) during the grain filling stages, but may also be the result of the high N-mineralization potential of the soil at experimental sites. According to the Canadian Canola Council, yield responses of rainfed canola to fertiliser N are unlikely to be profitable when the soil contains more than 34 to 45 kg nitrate-N ha^{-1} in the top 60 cm. In this study, mineral-N content in the top 30 cm soil was calculated and mean values for different localities were found to be 111.3 kg N ha^{-1}, 92.0 kg N ha^{-1}, 56.8 kg N ha^{-1}, 59.9 kg N ha^{-1} and 93.5 kg N ha^{-1} for Altona, Elsenburg, Langgewens, Roodebloem and Welgevallen experimental sites, respectively.

Agronomic S use efficiency

Agronomic use efficiency of applied sulphur (SUE) differ between localities in all years tested, with the highest values at Elsenburg in 2009 and 2010, but in 2011 the highest values were recorded Roodebloem (Table 5). The high SUE values at Elsenburg may be the result of the higher and extended rainfall period at this locality, because adequate availability of moisture and a lengthy grain filling phase ultimately lead to higher grain yield per kg S added. On average the lowest SUE values were recorded at Langgewens. However, agronomic use efficiencies of S (SUE) of 7.51 on average indicated that even on this locality, the application of S will be economically viable as long as the cost to apply a kilogram of S are less than 7.51 times the price of a kilogram of canola.

Table 5: Effect of N on agronomic S use efficiencies (kg ha^{-1} yield increase per kg S applied) of canola grown at different localities during 2010.

Locality (L)	2009	2010	2011	Mean
Elsenburg	23.05 a	16.55 a	12.11 b	**17.23**
Langgewens	3. 37 b	7.11 b	12.07 b	**7.51**
Roodebloem	6.46 b	7.19 b	19.48 a	**11.04**
Welgevallen	-	13.49 a	-	**13.49**
Altona	-	-	14.66 ab	**14.66**
Mean	**10.96**	**11.08**	**14.58**	**12.20**

In 2011, agronomic S use efficiencies of canola were significantly improved by N applications (Figure 5), with the highest value of 25.3 kg yield increase per kg S applied recorded with N applications of 120 kg N ha^{-1}.

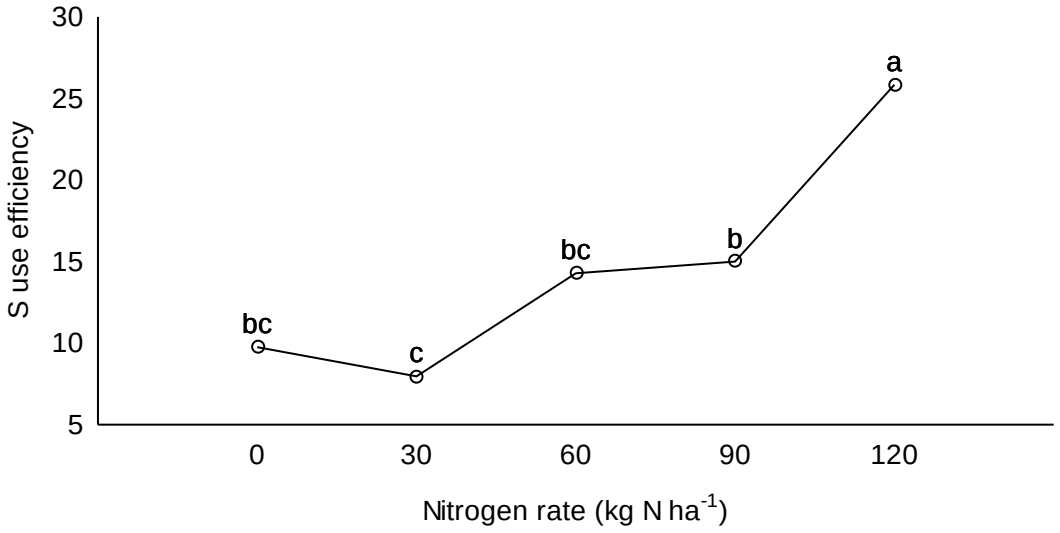


Figure 5: Agronomic S use efficiencies of canola at increasing N application rates during 2011.

Water Use Efficiency (WUE)

Water use efficiency (WUE) differed between growing seasons and localities (Figure 6), most probably due to differences in total April to Oktober rainfall as well as rainfall distribution. Lowest WUE values of 4.0-5.0 kg grain per mm rainfall was obtained at Langgewens,while the highest values of 12.18 and 9.65 kg grain per mm of rainfall were obtain in 2011 at Roodebloem and Altona respectively.

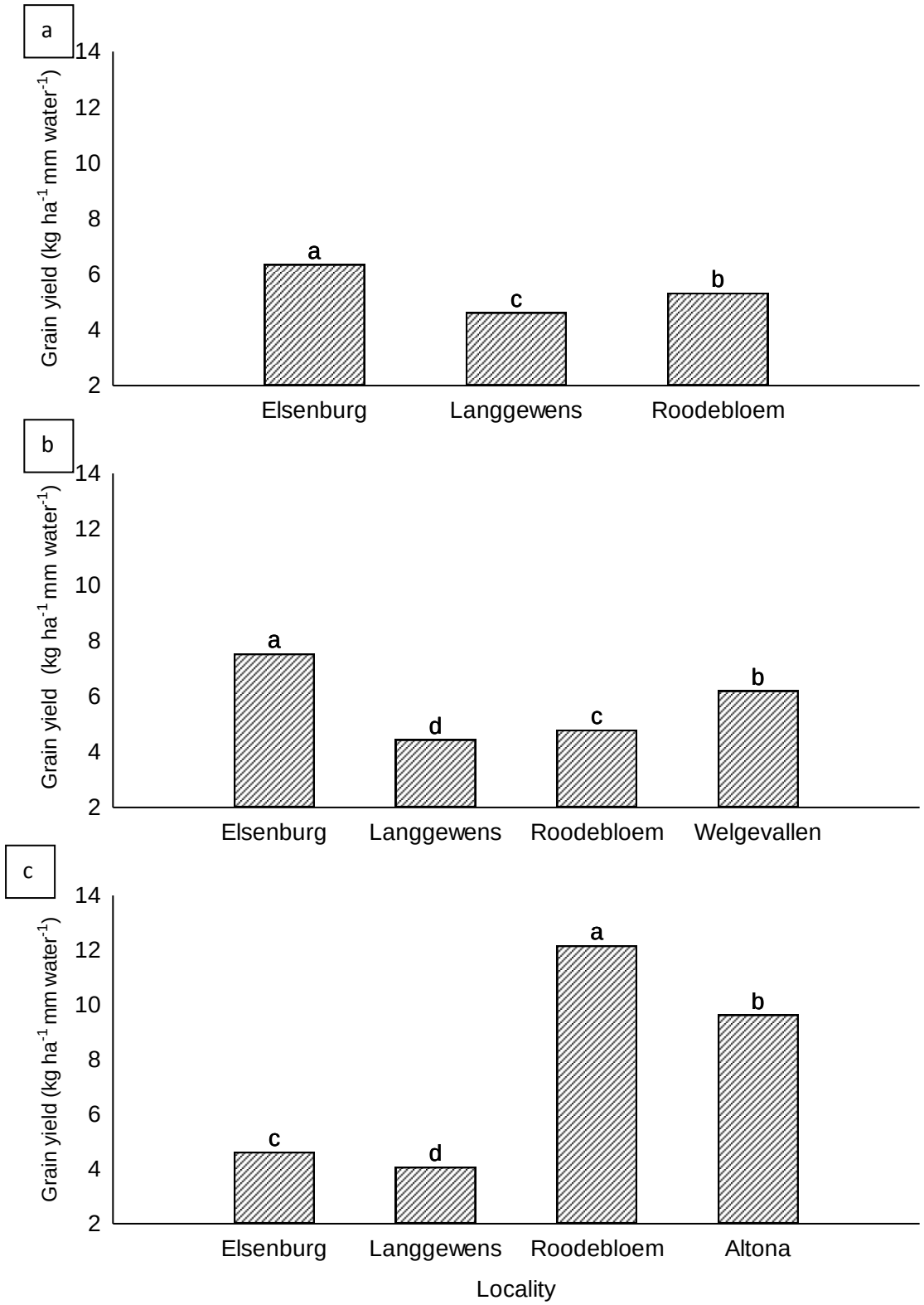


Figure 6: Canola yields per mm of water used at Altona, Elsenburg, Langgewens, Roodebloem and Welgevallen during (a) 2009, (b) 2010 and (c) 2011 seasons.

Water use efficiency increased as a result of nitrogen and sulphur applications in all growing seasons studied (Figure 7). Responses differed between growing seasons, but in 2011 WUE values of nearly 9 kg grain per mm of rain were obtained with high N application rates compared to about 6.5 kg grain per mm of rain where no N was applied. Similar differences were shown due to the application of 30 kg S ha^{-1} compared to no S at all.

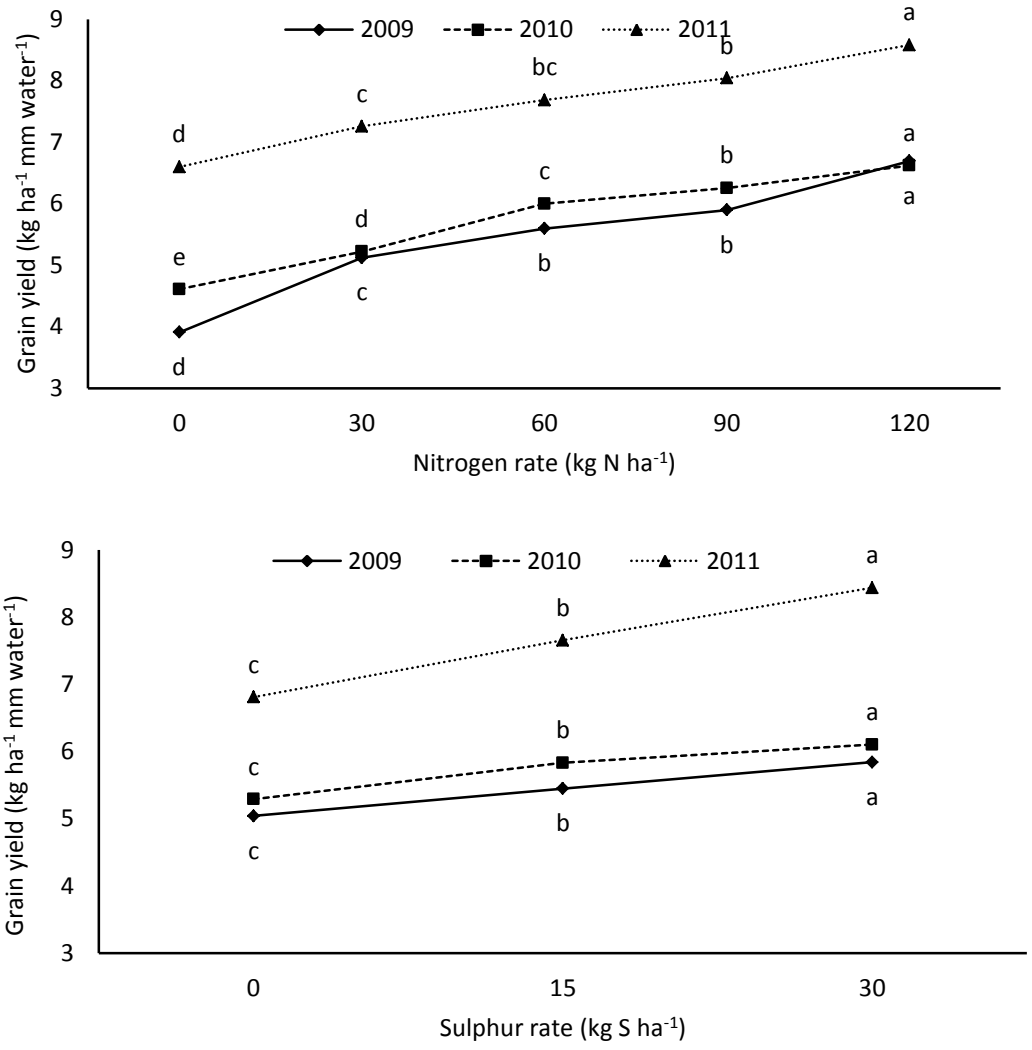
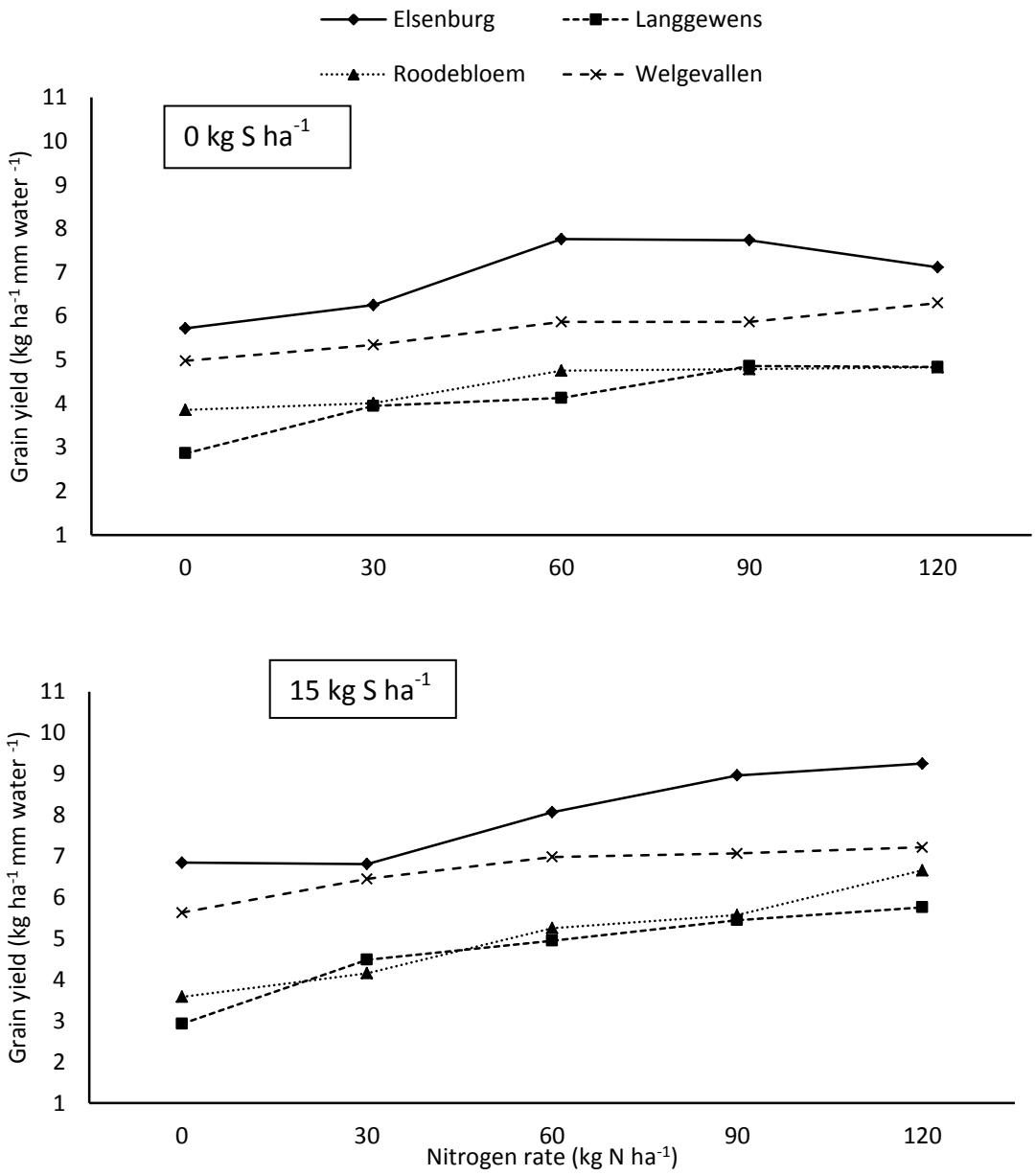


Figure 7: Canola yields per mm of water received in 2009, 2010 and 2011 seasons at different nitrogen (*top*) and sulphur (*bottom*) fertilisation rates.

Means for individual seasons with a common letter are not significantly different, $LSD_{0.05}$

In 2010 a significant interaction with regard to WUE was shown between locality and N and S application rates, suggesting different responses at different localities. From Figure 8 it is however clear although the degree of response did differ, WUE expressed as kg grain produced per mm of rainfall, increased at all localities with an increase in N application rate. Responses with increasing N rates also tend to be larger at 15 and 30 kg S application rates compared to where no S was applied, because without S added WUE tend to level off at N rates of 60-90 kg ha^{-1} at almost all the localities. With the addition of 30 kg S ha^{-1}, such a tendency was only shown at Welgevallen.



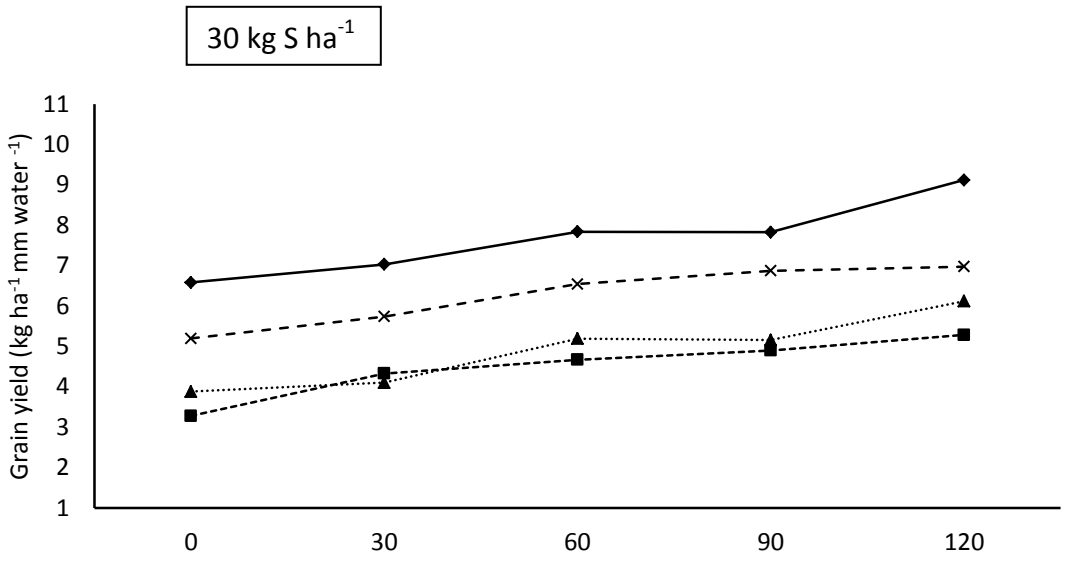


Figure 6.10 Canola yields per mm of water received in 2010 at Elsenburg, Langgewens, Roodebloem and Welgevallen localities at different sulphur (0, 15 and 30 kg ha^{-1}) and nitrogen (0, 30, 60, 90 and 120 kg ha^{-1}) fertilisation rates. (5%LSD= 0.48)

CONCLUSIONS

This study clearly illustrated the importance of sulphur applications to ensure the production of high yielding canola grown in the Western Cape producing area. It also showed that if sulphur is supplied sufficiently nitrogen application rates of more than 120 kg of nitrogen may be needed in high yielding areas to obtain maximum yields. Differenses in response during high and low rainfall growing seasons suggested that sulphur applications may even be more important in low than high rainfall areas as it help to improve the water use efficiency.

This research, however did not give answers with regard to N and S rates needed for maximum yields, optimum time of application and most efficient N and S sources.

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PROTEIENNAVORSINGSTIGTING
PROJEKTE P07/7/86/11, P07/13/145/11, P07/16/166/12, P07/17/167/12
KOSTEPUNT 3764

FINANSIËLE STAAT VIR DIE JAAR GEËINDIG	31/12/2012 TOTAAL	31/12/2012 P07/7/86/11	31/12/2012 P07/13/145/11	31/12/2012 P07/16/166/12	31/12/2012 P07/17/167/12
INKOMSTE	**422 391.36**	**40 931.25**	**43 087.50**	**118 172.00**	**220 200.61**
Rente ontvang	3 552.61	-	-	1 322.00	2 230.61
Skenking: Spesiale Doeleindes	418 838.75	40 931.25	43 087.50	116 850.00	217 970.00
UITGAWES	**191 922.42**	**49 854.50**	**38 114.36**	**28 641.84**	**75 311.72**
Affiliasie en Registrasie	660.00	-	-	240.00	420.00
Beurse	10 000.00	10 000.00	-	-	-
Diverse uitgawes	2 060.28	-	-	760.28	1 300.00
Kopieer- en drukwerk	540.00	270.00	270.00	-	-
Navorsingsmateriaal	40 039.56	16 070.00	13 930.00	4 039.56	6 000.00
Onderhoud van Apparaat	10 273.77	1 170.00	1 103.77	3 000.00	5 000.00
Oorhoofse vervoeruitgawes	11 867.52	3 070.00	6 306.52	1 000.00	1 491.00
Reis- en Verblyfuitgawes	23 013.15	5 110.15	5 203.00	5 000.00	7 700.00
Vergoeding	91 986.44	12 682.65	11 301.07	14 602.00	53 400.72
Vertaalwerk	1 481.70	1 481.70	-	-	-
BEDRYFSURPLUS / (TEKORT)	**230 468.94**	**(8 923.25)**	**4 973.14**	**89 530.16**	**144 888.89**
PLUS: OPGEHOOPTE FONDS OP 01/01/2012	**3 950.11**	**8 923.25**	**(4 973.14)**	**-**	**-**
FONDSE BESKIKBAAR OP 31/12/2012	**234 419.05**	**-**	**-**	**89 530.16**	**144 888.89**
VERPLIGTING OP 31/12/2012	**1 800.40**	**-**	**-**	**-**	**1 800.40**

Opgestel deur: C Ockert
Fakulteitsrekenmeester
Finansiële Dienste
Datum: 31/01/2013