Executive Summary

Project P07/17/167/12

Sulphur- and Nitrogen-fertiliser requirements of canola

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Grain yields obtained with canola in the Western Cape production area are often variable and generally low. In order to compete with cereal crops such as wheat and barley, canola yields need to be increased. Nitrogen (N) and sulphur (S) are important nutrients that affect yield and quality of canola and requirements of canola are much higher than that of wheat. Approximately 40 kg N and 10 kg S are used to produce a yield of 1.0 ton canola per hectare and N:S ratios of 7:1 are recommended. Previous research done in the Western Cape showed that canola does respond positively to nitrogen and sulphur applications, but this research did not address aspects such as nitrogen and sulphur sources, split applications and responses to high application rates.

The aim of the research was to determine optimum N and S rates for canola on different localities (soil and climatic conditions) and compare the efficiency of single and split applications as well as different N and S sources.

The following results were obtained:

1. This research clearly illustrated the need to apply sulphur to canola in the Western Cape production areas in search for higher yields and even high oil contents in the grain.

2. The research also showed that optimum rates for both nitrogen and sulphur depend on soil and climatic conditions. In spite of very low sulphur contents in the soil (as shown by soil analysis at planting), very little support for sulphur applications of more than 30 kg ha^{-1} was found.

3. Responses to sulphur applications are higher in soil with low organic carbon contents and for this reason even more important in the Swartland production area compared to the Southern Cape.

4. Splitting sulphur applications to apply some S as topdressing, did not improve grain yield in this study where gypsum was used as sulphur source, but comparing gypsum to Urea-S

in another trail did not show any yield or quality penalty due to the use of gypsum. Canola producers can for this reason use the cheapest source of sulphur. Gypsum which also contains some calcium and should also beneficial on soil with poor structure and salinity problems.

5. Optimum nitrogen application rates in this study varied between 80 kg N ha^{-1}, in the lower rainfall areas of the Swartland and on soil in the Southern Cape which show high nitrogen and %C contents at planting, to 120 to 160 kg N ha^{-1} in the higher rainfall areas of the Swartland which generally also showed low carbon and nitrogen contents at planting. Highest yields and oil content were only obtained if sufficient amounts of sulphur were also applied.

FINAL REPORT

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INTRODUCTION

Grain yields obtained with canola in the Western Cape production area are often variable and generally low. In order to compete with cereal crops such as wheat and barley, canola yields need to be increased. Nitrogen and sulphur are important nutrients that affect yield and quality of canola (Ahmad *et al*. 1998; Ahmad *et al*. 2007). The nitrogen (N) and sulphur (S) requirements of canola are much higher than that of wheat and approximately 40 kg N and 10 kg S are used to produce a yield of 1.0 ton canola per hectare (Pouzet 1995; Anon 2013). Because S also effects the N use efficiency (Jackson 2000) and N:S ratios of 7:1 are recommended (Grant and Bailey1993). It is for this reason important for N and S to be available in the optimum ratio. Timing of application N and S sources may also be important because requirements differ for different growth stages (Norton 2013) and different N and S sources differ in plant availability and mobility in soil (Jackson 2000; Barker and Pilbeam 2007). Plants absorb N and S mainly as nitrates and sulphates (Barker and Pilbeam 2007; Norton 2013). Both are very, mobile in soil and subjected to leaching (Walker and Booth 1992; Brennan and Bolland 2006). Efficiency of applications may for this reason differ for different localities and soil types and even N and S sources.

Previous research (Ngezimana and Agenbag 2014) showed that canola does respond positively to nitrogen and sulphur applications to soils of the Western Cape, but this research did not address aspects such as nitrogen and sulphur sources, split applications and responses to high application rates.

The aim of the research was to determine optimum N and S rates for canola on different localities (soil and climatic conditions) and compare the efficiency of single and split applications as well as different N and S sources.

MATERIAL AND METHODS

Locality

Field experiments were conducted at a commercial farm, Altona (33’27S; 18’34E), as well as Langgewens (33’27S;18’43E) and Roodebloem (34’13S;19’25E) experimental stations in the Western Cape Province of South Africa during the winter growing seasons of 2012-2014. Both

Altona and Langgewens are in the so-called "Swartland" production area along the western coastal area north of Cape Town. In this area almost 80% of the annual rainfall occurs in winter from April to September, but annual precipitation decreases from 645 mm (long term average) at Altona to 473 mm (long term average) at Langgewens. The Roodebloem locality, are in the Southern Cape production area, with about 65% of the annual precipitation of 563 mm (long term average) in winter.

Soil Characteristics

Soil samples were collected before planting every year at all localities and analyzed for pH, acidity, resistance as well as macro and micronutrients in the laboratories of the Department of Agriculture in the Western Cape at Elsenburg, using standard analytical procedures. Soil nutrient content at the different localities did not vary much between years and only pooled results were shown (Table 1).

Soil at Altona, Langgewens and Roobebloem showed pH with values of pH_{KCl} 5.0 or higher which are within the optimum range for canola growth and yield (Table 1). Percentage C and N at Altona and Langgewens were low when compared to Roodebloem, suggesting a much lower N and S mineralization potential (Barker and Pilbeam 2007) Considering the mean values for macronutrients in the 0-45 cm soil profile, all macronutrients were above the critical levels required for canola growth and production with the exception of potassium at Altona, phosphorus at Altona and Roodebloem and sulphur at all localities With regard to micronutrients, only boron showed low values at all localities. Potassium and phosphorus were applied as fertiliser to all trails at planting while boron was applied as a foliar spray to prevent any deficiencies. Because sulphur and total N levels were low, responses to these elements applied as treatments were expected.

Table 1 Chemical analysis of the soil (0-450 mm) at different localities. Mean values 2012 - 2014

Element	Aim*	Altona	Langgewens	Roodebloem
pH (KCI)	5.00	5.00	5.30	5.30
Ca (cmol kg^{-1})	-	1.99	2.80	4.23
Mg (mg kg^{-1})	-	1.00	0.52	1.09
K (mg kg^{-1})	80.00	42.33	114.67	120.34
Na(mg kg^{-1})	-	25.33	16.00	66.00

P $_{citric\ acid}$(mg kg^{-1})	50.00	50.00	76.67	42.67
Cu (mg kg^{-1})	0.50	0.61	0.96	0.83
Zn (mg kg^{-1})	0.70	1.23	0.80	1.31
Mn (mg kg^{-1})	25	62.26	104.80	44.54
B (mg kg^{-1})	0.50	0.15	0.12	0.33
S (mg kg^{-1})	7.00	2.70	5.07	2.50
C (%)	-	0.57	0.51	1.41
N (%)	-	0.06	0.05	0.13

*Critical content for optimum growth of canola (Anon 2013)

Treatments and experimental layout

Three field trails, lay out as a randomized block design with factorial split plot arrangements and four replications (blocks) were conducted at each locality as follows.

Trail A (N & S rates)

Three sulphur (S) rates of 0, 30 and 60 kg S ha^{-1}, applied as CaSO4 were used in combination with 5 nitrogen (N) rates (0, 40, 80, 120 and 160 kg N ha^{-1} applied as LAN). Sulphur was applied at planting while the N was applied at planting, 30 and 60 days after planting

Trail B (S splitting)

Four S treatments (30 and 60 kg S ha^{-1} at planting or split between planting, 30 and 60 days after planting), as well as a control of 0 kg S ha^{-1} were used in combination with three N rates (0, 80 and 160 kg N ha^{-1}). Gypsum ($CaSO_4$) was used as S source, while LAN was used as a source of N. All N applications were divided between planting, 30 and 60 days after planting.

Trail C (Sources of N & S)

Nitrogen rates of 60 and 120 kg N ha^{-1} were applied as LAN (28% N) or Urea-S (40 %N; 5.5% S). Because Urea-S also contains sulphur, applications of 60 and 120 kg N ha^{-1} respectively added 8.2 and 16.4 kg S ha^{-1} to the soil. For this reason, gypsum ($CaSO_4$) at appropriate rates was added to the LAN treatments to apply the 8.2 and 16.4 kg S ha^{-1} to the soil. Plots receiving no N and/or S were used as control treatments. Nitrogen and sulphur applications were split between planting, 30 and 60 days after planting.

The canola cultivar, Hyola 555TT, was planted at a density of 4 kg ha^{-1} between 22 April and 17 May in all seasons. Optimal agronomic techniques with regard to weed, insect and disease control were used to ensure that these production factors do not have an effect on the results obtained.

Data collected

At 90 days after planting (about full flowering stage) plants from control plots as well as the 160 kg N and 60 kg S ha^{-1} were sampled and analysed, using standard analytical procedure, to see whether treatments had any effect on plant nutrient contents.

At maturity grain yields were determined by strait harvesting the plots of 5x3 meters using a plot harvester. Grain samples were used to determined protein and oil content.
Agronomic use efficiencies (AE) of N was calculated using the following equations

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

Statistical analysis

Different localities were analysed separately because of large soil and climatic differences between localities.

RESULTS AND DISCUSSION

Plant analysis at 90 days after planting

Due to differences in soil characteristics, plants sampled at flowering stage (90 days after planting) at different localities also showed differences with regard to chemical composition (Table 2), but with the exception of boron no deficient levels were recorded. At Altona which showed low soil potassium levels, lower plant potassium levels in spite of potassium applied at planting were recorded. Plant potassium levels at Altona were however still above critical levels for optimum plant growth and yield.

The application of 160 kg N and 60 kg S ha^{-1} resulted in significant higher plant N levels at Altona and Roobebloem, but not at Langgewens (Table 2). The absence off a response in plant N at

Langgewens may be due to the lower soil N at this locality (Table 1), because it is well known that at low N supply levels, plants will rather respond with increased biomass production and not chemically to increases in N supply. Chemical responses (higher plant N) to fertiliser applications in plants are in general only shown when plant growth (higher plant biomass) is restricted by other growth factors (Barker and Pilbeam 2007). Surprisingly sodium (Na) and manganese (Mn) content also increase with N and S applications at some of the localities. The higher Mn content may be the result of an acidifying effect of the high N and S applications as Mn become more plant available at lower soil pH values (Barker and Pilbeam 2007). The recorded increases in sodium content are difficult to explain.

Table 2 Chemical analysis of canola plants grown without any fertiliser (0NS) compared to plants receiving 160 kg N and 60 kg S ha^{-1} (160N60S) at 90 days after planting. Mean values for 2012-2014.

Element	**Critical values***	**Altona**		**Langgewens**		**Roodebloem**	
		0NS	**160N60S**	**0NS**	**160N60S**	**0N**	**160N60S**
N (%)	2.4	3.2^{b}	4.2^{a}	3.9^{ab}	3.9^{ab}	3.3^{b}	4.1^{a}
P (%)	0.24	0.6^{a}	0.5^{a}	0.6^{a}	0.6^{a}	0.6^{a}	0.6^{a}
K (%)	1.4	3.0^{b}	2.9^{b}	5.5^{a}	6.2^{a}	4.8^{ab}	4.3^{ab}
Ca (%)	0.49	3.5^{a}	3.3^{ab}	3.3^{ab}	2.9^{b}	2.2^{c}	2.5^{bc}
Mg (%)	0.19	0.4^{a}	0.5^{a}	0.5^{a}	0.4^{a}	0.3^{a}	0.3^{a}
Na (%)	300-5000	5622^{b}	9605^{a}	5440^{b}	4769^{bc}	3855^{c}	7843^{a}
Fe (mg kg^{-1})	50-300	206^{c}	319^{c}	543^{b}	580^{b}	740^{a}	771^{a}
Cu (mg kg^{-1})	2.6	4.7^{a}	4.7^{a}	5.1^{a}	5.3^{a}	4.4^{a}	5.0^{a}
Zn (mg kg^{-1})	14.0^{a}	20.7^{a}	32.8^{a}	23.5^{a}	33.3^{a}	24.5^{a}	34.4^{a}
Mn(mg kg^{-1})	14.0	25.8^{c}	47.9^{b}	44.7^{b}	64.0^{a}	28.3^{c}	$38.4b^{c}$
B (mg kg^{-1})	29.0	26.9^{a}	32.1^{a}	28.3^{a}	26.3^{a}	33.7^{a}	34.9^{a}
Al (mg kg^{-1})	-	220.0^{c}	290.0^{c}	568^{a}	640^{a}	460^{b}	480^{b}
S (%)	0.24	0.4^{a}	0.5^{a}	0.5^{a}	0.5^{a}	0.5^{a}	0.5^{a}

**Minimum values needed for optimum growth and development at flowering (Canola Council of Canada,* 2007)

Means in the same row for each one treatment with at least a common letter are not significantly different, LSD $_{0.05}$

Trail A (Nitrogen and sulphur rates)

Grain Yield and Agronomic use efficiencies (AE) of N

Grain yield of canola increased significantly on all localities due to increasing N application rates, but responses differed between localities and also due to sulphur application rates (Table 3).

If no N was applied, sulphur has an effect at Altona and Roodebloem, but not at Langgewens. At the Swartland localities of Altona and Langgewens, which showed lower C and N soil contents before planting compared to Roodebloem, grain yields were significantly increased due to S applications for all N treatments from 40 to 160 kg N ha^{-1}, but no yield differences were recorded when S application was increased from 30 to 60 kg S per ha^{-1}. Although grain yields at the higher rainfall locality, Altona, were unexpectedly lower than at Langgewens, highest yields were obtained where 120-160 kg N and 30-60 kg S ha^{-1} were applied. At the lower rainfall locality, Langgewens, N rates above 80 kg N ha^{-1} and S rates of more than 30 kg ha^{-1}, had no effect on grain yield. At Roodebloem which showed higher C and N soil contents before planting, no grain yield increases were obtained at N application rates of more than 80 kg N ha^{-1} and at these rates (>80 kg N ha^{-1}), S applications also had no significant effect on grain yield during the period 2012- 2014.

Agronomic use efficiencies (AE) of N decreased at all localities with an increase in N application rate. Although grain yield were not significantly increased with increases in N application rates from 80 to 120 kg ha^{-1}, values for agronomic use efficiencies of N at rates of 120 kg N ha^{-1} were still higher than 4.5 at all localities. Applications of nitrogen fertilizer at this rate will for this reason still improve profit margins of canola if the cost of 1kg of nitrogen fertilizer does not exceed 4.5 times the price of 1kg of canola grain.

Table 3 Effect of increasing nitrogen (N) and sulphur (S) application rates on grain yield of canola at different localities (2012-2014) with Agronomic use efficiencies (AE) of N in (-).

Nitrogen	**Sulphur**	**Grain Yield kg-ha^{-1}**		
(kg ha $^{-1}$)	**(kg ha $^{-1}$)**	**Altona**	**Langgewens**	**Roodebloem**
0	0	1194e	1553f	1243f
	30	1257de	1599ef	1561e

	60	1315d	1607ef	1578e
	Mean	**1255C**	**1586C**	**1461C**
40	0	1351d	1735de	1662e
	30	1477c	1934c	1700de
	60	1593bc	1922c	1849cd
	Mean	**1474B (5.47)**	**1864B (6.95)**	**1737B (6.90)**
80	0	1516c	1974b	1899bc
	30	1698b	2156a	1948abc
	60	1742b	2194a	1959abc
	Mean	**1652A (4.96)**	**2108A (6.52)**	**1935A (5.92)**
120	0	1668b	1949bc	2074a
	30	1907a	2196a	2068a
	60	1894a	2232a	2053ab
	Mean	**1823A (4.73)**	**2126A (4.51)**	**2065A (5.03)**
160	0	1554c	1891cd	1987abc
	30	1975a	2163a	2008abc
	60	1881a	2145a	2016ab
	Mean	**1803A (3.42)**	**2066A (3.00)**	**2003A (3.38)**

Means in the same row for each one treatment with at least a common letter are not significantly different, LSD $_{0.05}$

Grain oil and protein content

Although the oil content in the canola grain tend to decrease and the protein tend to increase with increasing nitrogen application rates at all localities for the period 2012-2014, responses in oil content were affected by sulphur application rates (Table 4). At Altona, oil content showed significant increases with the application of 60 kg S ha^{-1} at all N application rates except the highest rate of 160 kg N ha^{-1}. At Roodebloem the increase in oil content due to the application of 60 kg S ha^{-1} was also recorded where no N was applied. Grain protein content did not show any significant response to S application on any of the localities tested for the period 2012 to 2014.

Table 4 Effect of nitrogen (N) and sulphur (S) fertiliser applications on oil and protein content (0% moisture) of canola at different localities (2012-2014)

Nitrogen	**Sulphur**						
(kg ha $^{-1}$)	**(kg ha $^{-1}$)**	**Altona**		**Langgewens**		**Roodebloem**	
		% Oil	**% Prot**	**% Oil**	**% Prot**	**% Oil**	**% Prot**
0	0	38.7^{f}	18.2^{c}	37.6^{b}	21.7^{a}	38.8^{c}	18.6^{a}
	30	41.3^{def}	19.3^{bc}	38.9^{ab}	21.6^{a}	40.8^{c}	19.0^{a}
	60	46.6^{a}	19.2^{bc}	40.9^{a}	21.7^{a}	44.2^{a}	18.4^{a}
	Mean	**42.2^{A}**	**18.9^{B}**	**39.1^{A}**	**21.6^{A}**	**41.3^{A}**	**18.7^{A}**
40	0	40.0^{f}	19.3^{bc}	38.9^{abc}	21.8^{a}	40.8^{c}	19.0^{a}
	30	39.9^{f}	19.2^{c}	38.8^{abc}	22.0^{a}	39.6^{c}	18.5^{a}
	60	45.4^{ab}	18.7^{c}	39.7^{ab}	21.3^{a}	44.0^{a}	18.6^{a}
	Mean	**41.8^{A}**	**19.1^{B}**	**39.1^{A}**	**21.7^{A}**	**41.5^{A}**	**18.7^{A}**
80	0	40.1^{def}	19.2^{c}	37.0^{c}	21.6^{a}	41.0^{bc}	19.3^{a}
	30	39.6^{f}	19.5^{abc}	38.5^{abc}	22.4^{a}	39.9^{c}	19.4^{a}
	60	44.0^{abc}	19.3^{bc}	37.2^{c}	21.6^{a}	43.9^{ab}	19.7^{a}
	Mean	**41.2^{A}**	**19.3^{B}**	**37.5^{A}**	**21.9^{A}**	**41.6^{A}**	**19.5^{A}**
120	0	40.0^{f}	19.8^{abc}	37.4^{bc}	22.6^{a}	39.8^{c}	20.5^{a}
	30	39.4^{f}	20.4^{abc}	38.0^{bc}	23.0^{a}	39.6^{c}	19.9^{a}
	60	42.8^{bcd}	20.8^{abc}	37.1^{c}	22.8^{a}	40.0^{c}	19.8^{a}
	Mean	**40.7^{A}**	**20.3^{AB}**	**37.5^{A}**	**22.8^{A}**	**39.8^{A}**	**20.1^{A}**
160	0	40.6^{def}	21.2^{abc}	37.6^{bc}	22.8^{a}	39.6^{c}	20.7^{a}
	30	39.9^{f}	21.8a	38.3^{bc}	22.9^{a}	38.6^{c}	19.6^{a}
	60	41.2^{def}	21.8a	36.7^{c}	22.8^{a}	40.3^{c}	20.6^{a}
	Mean	**40.5^{A}**	**21.6A**	**37.5^{A}**	**22.8^{A}**	**39.5^{A}**	**20.3^{A}**

Means in the same row for each one treatment with at least a common letter are not significantly different, LSD $_{0.05}$

Trail B (Split sulphur applications)

<u>Grain yield</u>

In this trail the application of nitrogen (N) also resulted in significant increases in grain yield at all localities for the period 2012-2014, but responses were also affected by sulphur (S) applications (Table 5). If no N was applied, S applications did not have a significant effect on grain yield at any of the localities tested for the period 2012-2014, but where 80 or 160 kg N ha^{-1} was applied, the application of S resulted in significant increases in grain yield.

At Altona, no difference in grain yield was recorded comparing S applications of 30 and 60 kg ha^{-1}. Splitting (10 kg S x 3 or 20 kg S x 3) the S application between planting, 30 and 60 days after planting also had no effect on grain yield. At Langgewens, splitting of the 60 kg S application into three applications of 20 kg S ha^{-1} resulted in significant lower yields where 80 kg N was applied, but not so if 160 kg of N was applied. At Roodebloem, 60 kg S ha^{-1} at planting resulted in significantly higher grain yields compared to 30 kg S when applied in combination with 80 or 160 kg N ha^{-1}. Splitting of the S application had no effect on grain yield where 80 kg N was applied, but in combination with a 160 kg N application, three applications (planting , 30 and 60 days after planting) of 10 kg S ha^{-1} instead of 30 kg at planting, resulted in significant higher grain yields for the period 2012-2014.

This generally poor results obtained with split applications of sulphur are in contrast to literature (Canola Council of Canada 2007; Jackson 2000) which showed that top dressing (splitting) with sulphur during the growing season can be use with good results. These results may be due to the use of Gypsum as source of fertiliser in this trail. Gypsum is known to have a low solubility and may therefore need to some time to become plant available.

Table 5 Effect of split sulphur (S) applications on grain yield of canola grown with different nitrogen (N) rates at different localities 2012-2014

Nitrogen kg ha^{-1}	**Sulphur kg ha $^{-1}$**	**Grain Yield (kg ha $^{-1}$)**		
		Altona	**Langgewens**	**Roodebloem**
0	0	1666^{c}	1755^{e}	1338^{f}
	30	1632^{c}	1713^{e}	1353^{f}
	60	1744^{bc}	1719^{e}	1303^{f}

	10x3	1683^{c}	1725^{e}	1373^{f}
	20x3	1655^{c}	1728^{e}	1363^{f}
	Mean	**1676^{B}**	**1728^{B}**	**1346^{B}**
80	0	1800^{b}	1904^{d}	1553^{e}
	30	2053^{a}	2110^{abc}	1743^{cd}
	60	2121^{a}	2209^{a}	1888^{ab}
	10x3	2144^{a}	2202^{a}	1848^{abc}
	20x3	2127^{a}	2069^{bc}	1813^{bcd}
	Mean	**2049^{A}**	**2098^{A}**	**1769^{A}**
160	0	1827^{b}	1994^{cd}	1535^{e}
	30	2024^{a}	2128^{ab}	1730^{d}
	60	2030^{a}	2073^{bc}	1848^{abc}
	10x3	2090^{a}	2180^{ab}	1873^{ab}
	20x3	2028^{a}	2060^{bc}	1955^{a}
	Mean.	**2000^{A}**	**2087^{A}**	**1788^{A}**

Means in the same row for each one treatment with at least a common letter are not significantly different, LSD $_{0.05}$

Grain oil and protein content

As shown for grain yield, topdressing with gypsum as a source of sulphur did not have a large effect on oil and protein content of canola grain for the period 2012-2014 at the three localities tested (Table 6). Increasing the sulpur from 0 to 60 kg S ha^{-1}, applied at planting or split between planting, 30 and 60 days after planting, did not has any effect on grain oil or grain protein content on any of the localities if no nitrogen was applied.

In combination with nitrogen applications of 80 and 160 kg N ha^{-1}, canola oil content did increase if sulphur was applied at Altona and Langgewens, but with the exception of 30 kg S split in combination with 80 kg N at Langgewens, topdressing with sulphur (splitting) did not has any effect. At Roobebloem where soil analysis at planting showed higher organic material (%C) contents, sulphur applications did not have any effect on oil content of canola.

The protein content of canola grain was increased by nitrogen application at Altona, but not so at Langgewens and Roobebloem. At these localities, sulphur applications, applied at planting or split did not have any effect on grain protein content. At Altona grain protein content was decreased by sulphur applications if used in combination with 80 and 160 kg N ha^{-1}, but splitting the sulphur applications again did not have any effect.

Table 6 Effect of split sulphur (S) applications on grain oil and protein content (0% moisture) of canola grown with different nitrogen (N) rates at different localities 2012-2014

Nitrogen	**Sulphur**	**Altona**		**Langgewens**		**Roodebloem**	
kg ha^{-1}	**kg ha $^{-1}$**	**% Oil**	**% Prot**	**% Oil**	**% Prot**	**% Oil**	**% Prot**
0	0	38.7^{bc}	21.8^{c}	35.3^{cdef}	23.2^{a}	38.7^{de}	19.6^{a}
	30	38.7^{bc}	21.2^{c}	34.8^{def}	23.8^{a}	38.0^{e}	20.8^{a}
	60	38.5^{c}	22.2^{bc}	35.6c^{def}	23.4^{a}	38.2^{e}	20.9^{a}
	10x3	39.0^{abc}	22.2^{bc}	34.0^{f}	23.2^{a}	37.4^{e}	20.8^{a}
	20x3	38.3^{c}	21.5^{c}	34.6^{ef}	23.8^{a}	38.0^{e}	20.6^{a}
	Mean	**38.6^{A}**	**21.8^{B}**	**34.9^{B}**	**23.5^{A}**	**38.1^{B}**	**20.5^{A}**
80	0	35.3^{d}	24.6^{a}	33.7^{f}	23.8^{a}	41.9^{a}	20.6^{a}
	30	40.5^{a}	21.0^{d}	39.2^{a}	22.2^{a}	40.9^{abc}	19.5^{a}
	60	40.4^{a}	21.5^{cd}	38.8^{a}	22.4^{a}	40.8^{abc}	19.7^{a}
	10x3	40.0^{ab}	21.2^{cd}	36.3^{bcde}	22.5^{a}	40.0^{cd}	19.4^{a}
	20x3	40.4^{a}	21.6^{cd}	37.0^{abc}	22.4^{a}	40.9^{abc}	19.7^{a}
	Mean	**39.3^{A}**	**22.0^{AB}**	**37.0^{A}**	**22.7^{A}**	**40.9^{A}**	**19.8^{A}**
160	0	36.8^{d}	25.4^{a}	33.8^{f}	23.9^{a}	39.7^{cd}	21.3^{a}
	30	38.4^{c}	23.1^{bc}	35.7^{bcdef}	22.8^{a}	39.7^{cd}	19.9^{a}
	60	38.6^{bc}	23.9^{ab}	36.8^{bc}	22.7^{a}	40.4^{bc}	20.4^{a}
	10x3	39.7^{abc}	22.7^{bcd}	37.7^{ab}	22.3^{a}	40.9^{abc}	19.7^{a}
	20x3	39.7^{abc}	22.7^{bcd}	36.0^{bcde}	22.5^{a}	41.5^{ab}	20.1^{a}
	Mean	**38.6^{A}**	**23.6^{A}**	**36.0^{AB}**	**22.8^{A}**	**40.4^{A}**	**20.3^{A}**

Means in the same row for each one treatment with at least a common letter are not significantly different, LSD $_{0.05}$

Trail C (Sulphur sources)

In this trail, limestone ammoniumnitrate (LAN, 28%N) and gypsum (16.8% S), which were used as sources for nitrogen and sulphur in earlier trails, was compared with Urea-S (40% N, 5.5% S). Nitrogen rates of 60 and 120 kg N ha^{-1} were used while 8.2 and 16.4 kg S ha^{-1} were applied.

Grain yield showed significant increases with increases in N and S application rates at all localities for the period 2012-2014, but source of N and S did not have any effect (Table 7).

At Altona a significant decrease in oil content was recorded due to the application of N and S, but no differences due to N and S source was shown. Compared to the control where no N or S was applied, protein content was increased due to the application of 120 kg N and 16.4 kg S using LAN and gypsum as a source, but no significant differences were shown between N and S sources or rates.

At Langgewens the 60 Urea-S, unexpectedly showed higher oil content when compared to LAN plus gypsum treatments, but this tendency was not shown for the 120 Urea-S treatments. No treatment differences due to treatments were shown for grain protein content, while at Roodebloem, neither oil nor protein showed any differences due to N and S application rates or sources.

These results that source of N and S is not important. Producers can for this reason use the cheapest or most convenient source of nitrogen and sulphur. It must however be keep in mind that Urea-S contain only 5.5% S. On soil with low S contents, or under conditions where little N fertiliser is needed, this low percentage S may result in sub-optimal S applications.

Table 7 Effect of different rates of limestone ammonium nitrate (LAN) plus gypsum and Urea-S (U-S) as nitrogen and sulphur sources on grain yield, oil content and protein content (0% moisture) of canola grown at different localities for the period 2012-2014

Treatments		**Altona**			**Langgewens**			**Roodebloem**		
N kg ha^{-1}	Source	Yield kg ha^{-1}	% Oil	% Prot	Yield kg ha^{-1}	% Oil	% Prot	Yield kg ha^{-1}	% Oil	% Prot
0		1235^{c}	39.5^{a}	21.7^{b}	1246^{c}	36.8^{ab}	24.4^{a}	1149^{c}	36.5^{a}	20.9^{a}
60	LAN	1658^{b}	36.3^{b}	23.0^{ab}	1619^{b}	35.3^{b}	24.2^{a}	1304^{b}	36.3^{a}	20.2^{a}
60	U-S	1713^{b}	37.6^{b}	22.7^{ab}	1658^{b}	37.9^{a}	24.2^{a}	1332^{b}	36.7^{a}	20.1^{a}
120	LAN	1813^{a}	36.8^{b}	23.4^{a}	1772^{a}	35.1^{b}	24.5^{a}	1509^{a}	35.6^{a}	21.2^{a}
120	U-S	1787^{a}	37.1^{b}	22.6^{ab}	1839^{a}	36.2^{ab}	23.5^{a}	1591^{a}	35.7^{a}	20.0^{a}

Means in the same row for each one treatment with at least a common letter are not significantly different, LSD $_{0.05}$

Conclusions

This research clearly illustrated the need to apply sulphur to canola in the Western Cape production areas in search for higher canola yields and even high oil contents in the grain.

The research also showed that optimum rates for both nitrogen and sulphur depend on soil and climatic conditions. In spite of very low sulphur contents in the soil (as shown by soil analysis at planting), very little support for sulphur applications of more than 30 kg ha^{-1} was found. Responses to sulphur applications are higher in soil with low organic carbon contents and for this reason even more important in the Swartland production area compared to the Southern Cape. Splitting sulphur applications to apply some as topdressing, did not improve grain yield in this study where gypsum was used as sulphur source, but comparing gypsum to Urea-S in another trail did not show any yield or quality penalty due to the use of gypsum. Canola producers can for this reason use the cheapest source of sulphur. Gypsum which also contains some calcium should be especially beneficial on soil with poor structure and salinity problems.

Optimum nitrogen application rates in this study varied between 80 kg N ha^{-1} in the lower rainfall areas of the Swartland and on soil in the Southern Cape which show high nitrogen and %C contents at planting, but even on this localities agronomic use efficiencies of nirogen indicated that applications of 120 kg N ha^{-1} could still improve the profit margins of canola as long as the cost of nitrogen application per kilogram does not exceed 4.5 times the price of 1 kg of canola grain. In the higher rainfall areas of the Swartland which generally also show low carbon and nitrogen contents at planting, optimum rates varied between 120 and 160 kg N ha^{-1}, but highest yields and oil content were only obtained if sufficient amounts of sulphur are also applied.

Literature

Ahmad A., Abraham G., Gandotra YP., Abrol P. and Abdin MZ. 1998. Interactive effect of nitrogen and sulphur on growth and yield of rapeseed mustard (*Brassica juncea* L.Czern and Coss and *Brassica* campestris L.) genotypes. J. Agronomy and Crop Science 181, 193-199.

Ahmad G., Jan A., Arif M., Jan, MT. & Khattak, RA. 2007. Influence of nitrogen and sulphur fertilization on quality of canola (*Brassica napus* L.) under rainfed conditions. Journal of Zhejiang University Science 8(10), 731-737.

Anon. 2013. Canola Handleiding, Proteïn Research Foundation, Box 1564, Rivonia, 2128.

Barker, AV. and Pilbeam, DJ. 2007. Handbook of Plant Nutrition. CRC Press, Boca Raton, Florida, USA.

Brennan, RF. and Bolland, MDA. 2006. Soil and tissue tests to predict the sulfur requirements of canola in south-western Australia. Australian J. Exp. Agr. 46(8) 1061-1068.

Canola Council of Canada 2007. Canola Production Manual

Grant, CA. and Bailey, LD. 1993. Fertility management in canola production. Can. J. Plant Sci. 73, 651-670.

Jackson, GD. 2000. Effects of Nitrogen and Sulfur on canola yield and nutrient uptake. Agron. J. 92, 644-649.

Ngezimana, W. & Agenbag, GA. 2014. The effect of nitrogen and sulphur on the grain yield and quality of Canola (Brassica napus L.) grown in the Western Cape. South African Journal of Plant and Soil 31(2), 69-75.

Norton R. 2013. 4R Canola Nutrition Guide. Canola Technology Update: Plant Nutrition. International Plant Nutrition Institute, Australia.

Pinkerton A. 1998. Critical sulfur concentrations in oilseed rape (*Brassica napus*) in relation to nitrogen supply and plant age. Australian J. of Exp. Agr. 38, 511-522.

Pouzet A. 1995. Agronomy. In D. Kimber & D.I. McGregor (eds.): Brassica Oilseeds Production and utilization. CAB International.

Walker KC. and Booth E.J., 1992. Sulphur research on oilseed rape in Scotland. Sulphur in Agr. 16, 15-19.