Effects of nitrogen and sulphur on seedling establishment, vegetative growth and nitrogen use efficiency of canola (Brassica napus L.) grown in the Western Cape Province of South Africa

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Variability in soil properties and rainfall distribution is generally high in canola growing areas of Western Cape Province of South Africa. Rainfall intensity generally influences soil moisture levels and utilization of major nutrients like nitrogen (N) and sulphur (S) required to maximize canola growth and development. Hence this research was intended to determine effect of soil and climatic differences, as experienced at different localities on seedling establishment, dry matter production and nitrogen use efficiency (NUE) of canola in response to N and S application rates. Canola plant populations (plants m⁻²) were determined at 30 days after planting (DAP), while dry mass was recorded on plots of treatment combinations of S (0, 15 and 30 kg ha⁻¹) and N (0 and 120 kg ha⁻¹) during flowering (90 DAP) at Altona, Elsenburg, Langgewens, Roodebloem, and Welgevallen localities in Western Cape in 2009, 2010 and 2011. Plant populations, dry mass production and NUE differed between localities. N fertilisation increased plant biomass of canola at most localities in the three seasons whilst fertilisation with S resulted in increasing plant dry mass only in 2010. NUE as measured as gram dry matter gain per gram of N applied were affected by S at Altona in 2011.

Key words: Canola, seedling establishment, nitrogen use efficiency, sulphur.

INTRODUCTION

Poor growth of canola (Brassica napus L.) and low yields in the Western Cape Province of South Africa has been ascribed to poor nitrogen (N) fertiliser management options (Hardy et al., 2004; Ngezimana and Agenbag, 2013). In canola, the requirement for N per yield unit is higher than in cereal crops (Oplinger et al., 2000; Hocking and Strapper, 2001; Sylvester-Bradley and Kindred, 2009), but the crop has ability to take up nitrate from the soil and accumulate large quantities of N that is stored in vegetative parts at the beginning of flowering (Laine et al.,1993).

Nitrogen is utilized in the various components of many important structural, genetic and metabolic compounds (Hirel et al., 2007). During the vegetative phase, young developing roots and leaves are mainly the sink organs for the assimilation of inorganic N and the synthesis of
amino acids originating from the N taken up before flowering (Hirel and Lea, 2001). When N is taken up, it forms a major component of chlorophyll which together with increases in leaf-area resulted in a higher net assimilation rate (Yau and Thurling, 1987). High net assimilation rates are important during grain filling stages to ensure a high yielding crop (Rossato et al., 2001). During the grain filling stage, N translocated from leaves and stems to the grains may also result in higher yields (Tatjana et al., 2008). In addition to N, sulphur (S) fertilisation is also considered a critical factor in high yielding canola crops (Fismes et al., 2000). Sulphur concentration in canola plants varies between 1 to 16 g kg⁻¹ dry mass, depending on external supply (Balint and Rengel, 2009). Sulphur is a constituent of certain amino acids needed for protein synthesis in canola. It also affects the quality of canola seed due to its effect on the oil content (Joshi et al., 1998). Deficiency of S will reduce N uptake and for this reason, the application of S needs to be balanced with N for optimum yields (Ceccotti, 1996; Fismes et al., 2000). The optimum N: S ratio reported in literature is variable (Zhao et al., 1993; Ahmad and Abdin, 2000; Fismes et al., 2000; Balint et al., 2008), but the typical ratios range from 7:1 to 5:1. In literature 16 kg S per ton of grain yield produced is recommended, so a three ton crop requires about 50 kg S per hectare (Kimber and McGregor, 1995). However, as the effects of S are related to the N level, such recommendations would be based on N recommendations in the appropriate variety, with inherent soil S levels, regions and yield potential also playing a major role.

Sulphur fertilisation enhanced N efficiency in canola (Ceccotti, 1996), leading to increased N assimilation into leaf protein. Nitrogen use efficiency (NUE) is regarded as the amount of vegetative growth produced per unit of N taken up by the crop (Novoa and Loomis, 1981; Sylvester-Bradley and Kindred, 2009). Environmental factors can also stimulate the development of large sinks, leading to more N and S uptake which may trigger the uptake of other nutrients and thereby increasing growth. Besides effects of fertilising with N and S, vegetative growth of canola plants can also be influenced by inherent soil fertility and climatic conditions. Little is known on the uptake and utilization of N and S by canola in the Western Cape province of South Africa characterised by varying soil properties and rainfall patterns. This study is aimed at determining the effect of soil and climatic differences, on the growth and N use response of canola to N and S application rates.

MATERIALS AND METHODS

Locality

Field experiments were conducted in the Western Cape province of South Africa during the canola growing seasons (May-October) of 2009, 2010 and 2011 at Altona (33°42’S; 18°37’E, 42 m.a.s.l.), Elsenburg (33°51’S; 18°51’E; 117 m.a.s.l.), Langgewens (33°17’S; 18°40’E, 91 m.a.s.l.), Welgevallen (33°52’S; 18°42’E, 119 m.a.s.l.) and Roodebloem (34°22’S; 19°52’E, 132 m.a.s.l.). On average, Elsenburg (358.8 mm) received a higher rainfall for the period from planting to 90 days after planting (DAP) per season than Welgevallen (331.8 mm), Langgewens (282.9 mm), Altona (240.5 mm) and Roodebloem (230.2 mm). Temperatures were generally favourable for canola production although the 2010 season was considerably warmer at all localities with higher mean monthly temperatures compared to the 2009 and 2011 growing seasons. Average N-mineralization potential determined using the indophenol-blue (Keeney et al., 1882) and salicylic acid methods (Cataldo et al., 1975) in the 0 to 200 mm soil profile were as follows: Altona 111.3 kg N ha⁻¹ (2011 only), Elsenburg 92.0 kg N ha⁻¹ (2009 to 2011), Langgewens 56.8 kg N ha⁻¹ (2009 to 2011), Roodebloem 59.9 kg N ha⁻¹ (2009 to 2011) and Welgevallen 93.5 kg N ha⁻¹ (2010 only).

Experimental procedure

The experiments were laid out in a randomized block design with the factorial split plot arrangement replicated four times. Sulphur was applied in the form of gypsum (CaSO₄·2H₂O) with 16% S while, N was applied in the form of Limestone Ammonium Nitrate (LAN) with 28% N. Treatments consisted of three sulphur rates (0, 15 and 30 kg S ha⁻¹) as a main factor and two nitrogen rates (0 and 120 kg N ha⁻¹) as a sub factor. For the 120 kg N ha⁻¹ treatment, 30 kg N ha⁻¹ was 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. Canola cultivar Stubby was planted on all localities in 2009, whilst Bravo was planted in 2010 and 2011 seasons. All planting was done at a planting density of 4 kg ha⁻¹. Standard agronomic practices were equally carried on all subplots throughout the experimental period. Plant densities were recorded at 30 DAP by counting the number of plants in two rows of a one meter length per replication, and presented as plants m⁻². At 90 DAP, a net plot of 0.5 m² per replication was sampled and dried for 72 h at 80°C in plots of the treatment combinations of S (0, 15 and 30 kg ha⁻¹) and N (0 and 120 kg ha⁻¹) to determine dry mass production. It is however, important to note that at the sampling stage only 90 kg N ha⁻¹ was already applied to the 120 N treatments. Nitrogen use efficiency at 90 DAP (NUE120) was expressed as gram dry mass produced per gN added according to Novoa and Loomis (1981) using the following equation:

\[
\text{NUE 120 (gDM g N⁻¹) = \frac{\text{DM (g m⁻²) - DM control (g m⁻²)}}{\text{N added (g m⁻²)}}
\]

Data recorded was analyzed, using analysis of variance (ANOVA) (Statistica 11). Because different cultivars were planted in different seasons, data analysis was done for each season. To measure response to treatments at different localities, locality was therefore also considered as a factor. Interaction effects were compared using least significant difference (LSD) test at 5% level of probability. Any treatment means found to be significantly different were separated using Fischer’s protected LSD₀.₀₅.

RESULTS

Plant density

Plant densities for all three seasons ranged between 42 to 81 plants m⁻² for the various treatment combinations. In 2009, Langgewens (56 plants m⁻²) and Roodebloem (55
Table 1. Canola plants m\(^{-2}\) at Roodebloem, Elsenburg and Langgewens localities at S fertilisation rates of 0, 15 and 30 kg ha\(^{-1}\) and N fertilisation rates of 0, 30, 60, 90 and 120 kg ha\(^{-1}\) at 30 DAP in 2009.

<table>
<thead>
<tr>
<th>Locality (L)</th>
<th>S rate (kg ha(^{-1}))</th>
<th>N rate (kg ha(^{-1}))</th>
<th>Mean</th>
<th>Locality Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>30</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>Roodebloem</td>
<td>15</td>
<td>58</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>62</td>
<td>44</td>
<td>60</td>
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<tr>
<td></td>
<td>N mean</td>
<td>58</td>
<td>55</td>
<td>55</td>
</tr>
<tr>
<td>Elsenburg</td>
<td>15</td>
<td>48</td>
<td>43</td>
<td>53</td>
</tr>
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<td>45</td>
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<tr>
<td></td>
<td>N mean</td>
<td>50</td>
<td>44</td>
<td>50</td>
</tr>
<tr>
<td>Langgewens</td>
<td>15</td>
<td>55</td>
<td>43</td>
<td>50</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>N mean</td>
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<td>50</td>
<td>55</td>
</tr>
<tr>
<td>Mean</td>
<td>54</td>
<td>49</td>
<td>53</td>
<td>55</td>
</tr>
</tbody>
</table>

LSD\(_{0.05}\): LXNXS 14

Table 2. Canola plants m\(^{-2}\) at Roodebloem, Elsenburg, Langgewens and Altona localities at N fertilisation rates of 0, 30, 60, 90 and 120 kg ha\(^{-1}\) at 30 DAP in 2011.

<table>
<thead>
<tr>
<th>Locality (L)</th>
<th>N rate (kg ha(^{-1}))</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>Roodebloem</td>
<td>53</td>
<td>59</td>
</tr>
<tr>
<td>Elsenburg</td>
<td>39</td>
<td>43</td>
</tr>
<tr>
<td>Langgewens</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>Altona</td>
<td>51</td>
<td>50</td>
</tr>
<tr>
<td>Mean</td>
<td>53</td>
<td>53</td>
</tr>
</tbody>
</table>

LSD\(_{0.05}\): LXN 12

Plants m\(^{-2}\) had on average significantly more plants m\(^{-2}\) compared to Elsenburg (48 plants m\(^{-2}\) when counted at 30 DAP (Table 1). During 2010 season, mean plant density at Welgevallen (36 plants m\(^{-2}\)) was significantly lower compared to Elsenburg (77 plants m\(^{-2}\)), Roodebloem (70 plants m\(^{-2}\)) and Langgewens (69 plants m\(^{-2}\)). During 2011 season, mean plant density at Elsenburg (44 plants m\(^{-2}\)) was lower than at Altona (50 plants m\(^{-2}\)), Roodebloem (59 plants m\(^{-2}\)) and Langgewens (63 plants m\(^{-2}\)) (Table 2).

A significant interaction effect between localities, N and S rates (in 2009 season) and between localities and N rates (in 2011 season) at P<0.05 with regard to plant densities suggested that N and S application rates affected the germination and establishment of canola at the different localities (Tables 1 and 2).

Dry mass

Dry mass at 90 DAP differed significantly between localities and were affected by N application rate in all seasons, while S as a main factor had a significant effect on dry mass in 2010 only. During this season the application of 15 kg S ha\(^{-1}\) resulted in an increase in plant dry mass from 243.74 to 286.62 gm\(^{-2}\) when compared to the control where no S was applied. Significant N x locality (2010), S x locality (2011) and N x S x locality (2011) interactions however indicated that dry mass responses to S and N varied between localities.

In general, higher N application rates resulted, as can be expected, in higher dry mass regardless of season (Figure 1). During 2009, highest dry mass yields at 90 DAP were measured at Langgewens (173.77 gm\(^{-2}\)) followed by Roodebloem (138.26 gm\(^{-2}\)), with Elsenburg (99.41 gm\(^{-2}\)) showing the lowest dry mass at 90 DAP (Figure 2). Dry mass produced during 2010 season at Langgewens, Elsenburg and Roodebloem were generally higher than that of 2009 season as a result of higher plant populations and responded positively to nitrogen applications (Figure 3). Dry mass at Welgevallen was however significantly less and did not show a significant
Figure 1. Above ground dry mass m$^{-2}$ of canola plants at 90 DAP in response to 0 and 120 kg N ha$^{-1}$ in 2009, 2010 and 2011 seasons. Means for each one season with at least a common letter are not significantly different, LSD 0.05.

Figure 2. Above ground dry mass m$^{-2}$ of canola plants at 90 DAP during the 2009 season at different localities. Mean values represented by different or same letters are statistically significant or no significant, respectively, LSD 0.05.
increase due to N applications. During 2011, plants at Langgewens and Elsenburg responded positively to nitrogen application, but a poor response was shown at Roodebloem and Altona (Figure 4).

**Nitrogen use efficiency**

In spite of nitrogen use efficiency (NUE) values for the 120 N treatment, calculated by using the NUE equation of Novoa and Loomis (1981), that ranged between -2.0 and +15.0 in 2009, no significant differences in the amount of dry mass produced per kg of N added at different sulphur rates were found at any of the localities. On average higher efficiencies were obtained during the 2010 season (19 g plant dry mass g⁻¹ N added) when compared to 2009 (7 g plant dry mass g⁻¹ N added) and efficiencies differed significantly between localities. In 2010, Roodebloem showed a significantly higher NUE compared to Elsenburg, Langgewens and especially Welgevallen which had the lowest NUE with a mean value of 7 (Figure 5). In 2011, NUE values at Altona and Roodebloem were significantly lower compared to Elsenburg and Langgewens.

Sulphur application did not influence NUE of canola as measured at 90 DAP in any of the seasons, but a significant S x Locality interaction was recorded in 2011. In this growing season, the application of S improved NUE at 90 DAP at Altona, but not at other localities (Table 3).

**DISCUSSION**

The recommended plant densities for canola is between 50 and 80 plants² (Anon, 2008) with a seeding rate of 4 to 6 kg ha⁻¹. Germination and emergence of canola seedlings are reduced by low temperatures, very high or low soil moisture contents as well as other physical and chemical soil properties. Lower plant densities at Welgevallen in 2010 and Elsenburg in 2009 and 2011, could therefore be the result of the high rainfall and assumed lower soil temperatures. Amongst other factors, Mendham and Salisbury (1995) also reported on the poor plant establishment of canola during conditions of excessive soil moisture. Addition of high rates of N fertiliser, especially when soil moisture is limited, can reduce canola seedling emergence and survival (http://www.canolacouncil.org/chapter9), but from this study no clear trends were found in plant population responses with regard to the locality, N and S treatment.

Considering the mentioned higher N mineralization potential of the soil at Elsenburg compared to Roodebloem and Langgewens, together with the significantly lower rainfall received at Langgewens and Roodebloem, it was expected that the dry mass produced...
**Figure 4.** Effects of increasing N application rates on plant above ground dry mass m$^{-2}$ at 90 DAP during the 2011 season at different localities. Mean values represented by different or same letters are statistically significant or no significant, respectively, LSD $0.05$.

**Figure 5.** Nitrogen Use Efficiency (gram dry matter gain per kg of N applied) at 90 DAP at different localities in 2010 (top) and 2011 (bottom) seasons. Mean values represented by different or same letters are statistically significant or no significant, respectively, LSD $0.05$. 
Table 3. Effects of Sulphur on Nitrogen Use Efficiency (gram dry matter gain per kg of N applied) at 90 DAP at different localities in 2011 season.

<table>
<thead>
<tr>
<th>Locality (L)</th>
<th>S rate (kg ha⁻¹)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Roodebloem</td>
<td>7.5</td>
<td>-2.3</td>
</tr>
<tr>
<td>Elsenburg</td>
<td>11.8</td>
<td>20.5</td>
</tr>
<tr>
<td>Langgewens</td>
<td>18.2</td>
<td>13.3</td>
</tr>
<tr>
<td>Altona</td>
<td>-26.0</td>
<td>8.2</td>
</tr>
<tr>
<td>Mean</td>
<td>2.9</td>
<td>9.9</td>
</tr>
</tbody>
</table>

at Elsenburg would be higher than at other localities. However, lower plant populations at Elsenburg were most probably the reason for lower dry mass observed. This however, does not mean localities with a lower plant populations such as Welgevallen and Elsenburg (2009 and 2011) will necessarily had a lower yield potential, as canola has the ability to compensate for lower plant populations as shown by Angadi et al. (2003). The poor response to nitrogen at Altona can be ascribed to the inherently high soil mineral nitrogen content (111.3 kg N ha⁻¹). At Roodebloem, assumed low moisture levels as a result of the low rainfall might have result in poor N uptake and plant growth. The significantly low NUE values observed at Altona compared to Elsenburg and Langgewens were likely because soils at Altona contain significantly low levels of S compared to other localities. Abdullah et al. (2010) ascribed the lack of response in NUE due to application of S in canola to results (Fismses et al., 2000; Jackson, 2000; Jan et al., 2002) which indicate that inadequate S supply are usually shown in a delay and poor flowering of canola which may result in poor seed yield and quality (Ngazimana and Agenbag, 2013). However, if S is severely lacking deficient symptoms can be shown during vegetative growth and can ultimately affect the utilization of N as shown at Altona.

Conclusions

Although germination and emergence of canola seedlings varied between localities with some having a plant population of less than the recommended density, nitrogen and sulphur application rates had little or no effect. Variation between localities was most probably due to high rainfall hence assumed very high soil moisture contents as well as other physical and chemical soil properties at some localities. Fertilisation with N increased biomass of canola in all three canola growing seasons. Effects of N were however dependent on locality in 2010 and 2011 seasons. High NUE was on localities with low inherent N mineralization potential and lower rainfall (presumably less N loss due to drainage). Sulphur is more important for reproductive development (grain yield and quality) than vegetative growth (DM production).

Conflict of Interest

The author(s) have not declared any conflict of interest.

REFERENCES


