Developing nitrogen fertiliser management strategies for canola (*Brassica napus* L.) under conservation agriculture practices in the Western Cape

by

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Thesis presented in partial fulfilment of the requirements for the degree of
Master of Agricultural Science

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1918 · 2018

at
Stellenbosch University
Agronomy, Faculty of AgriSciences

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December 2018

Declaration

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Abstract

Nitrogen (N) is one of the most important nutrients in canola production systems. Improper N supply due to lack of knowledge regarding canola N management and inappropriate fertiliser guidelines, frequently results in low canola yield and profitability in the Western Cape. Current N guidelines are based on international literature or adapted from wheat guidelines. Conservation agriculture practices have also changed soil N dynamics. More N is mineralised from soil organic matter than conventional systems, which were historically practised. Canola N guidelines should therefore be refined to account for the abovementioned changes. The aim of this study was to determine the effect of different topdress N rates, foliar N application at stem elongation and N source on plant parameters, canola seed yield, oil content and N use efficiency, whilst monitoring the effect of different topdress N rates on the soil mineral N concentration at plant, pre-topdress, post topdress and at harvest. This study was conducted at five canola producing areas in the Western Cape during 2016 and 2017. The trial was laid out as a randomised block design consisting of seven different topdress N rates (0, 25, 50, 75, 105, 135 and 165 kg N ha^{-1}) applied at the rosette stage. For all the above mentioned treatments, 25 kg N ha^{-1} was applied at planting. A control treatment was included that received no N. A foliar N application that consisted of 20 kg N ha^{-1} (urea ammonium nitrate) was applied at stem elongation. Five N sources were evaluated, applied as topdressing at rosette stage. Increasing topdress N rate increased ($p<0.05$) soil mineral N concentration. Plant population at harvest and biomass production did not respond ($p<0.05$) to topdress N rates, a result not expected but could be ascribed to the relative dry seasons experienced in 2016 and 2017. Canola yield responded ($p<0.05$) to topdress N rate. Maximum yield response was recorded at lower topdress N rates than expected. The N use efficiency (NUE) decreased ($p<0.05$) as topdressed N rate was increased, with a drastic reduction in NUE when total N application was increased above 25 kg N ha^{-1}. Foliar N application at stem elongation did not ($p>0.05$) influence yield or oil content at most sites. Nitrogen source did not influence ($p>0.05$) plant population, biomass production or yield, except at one site (Langgewens) in the Swartland in 2017 where the urea + inhibitor outperformed LAN. No differences ($p>0.05$) were recorded in oil content between different N sources in 2016. Generally, in 2017, oil content was lower compared to 2016 and inconsistent results were recorded between N sources. This was possibly due to the dry conditions during 2017, which may have influenced oil production. It is apparent that N fertiliser recommendations have to be adjusted for certain areas. Current N recommendations may result in over-fertilisation and reduced profitability at sites in the southern Cape. Current N recommendation at the Swartland sites has a low NUE and further increase in topdress N rates would likely result in pollution of the environment. Nitrogen source did not affect canola productivity. Selection of N source should be based on cost. In general, CA practices tended to decrease fertiliser N requirement for canola production. Refined N fertiliser guidelines may result in more consistent

canola yield and ensure profitability. Guidelines will only be finalised on completion of the research project after at least four years of data capturing.

Uittreksel

Stikstof (N) is een van die belangrikste voedingstowwe in kanolaproduksiesisteme. Onvoldoende N-bemesting a.g.v. onsekerheid t.o.v. kanola N-bestuur lei dikwels tot beperking van kanola-opbrengs en -winsgewendheid in die Wes-Kaap. Tans is kanola N-bemestingsriglyne in die Wes-Kaap gebaseer op internasionale literatuur of aangepas vanaf koring N-bemestingsriglyne. Bewaringslandbou het ook grondstikstofdinamika oor die langtermyn verander. Kanola N-bemestingsriglyne moet dus aangepas word in lyn met die veranderinge om N-bestuurseffektiwiteit te verhoog. Die doel van die studie was om die effek van verskillende N-bemestingspeile, addisionele N-blaarbespuitings by stamverlenging en verskillende N-bronne op plantparameters, kanolasaadopbrengs, olie-inhoud van saad en stikstofverbruiksdoeltreffendheid (NUE) te bepaal, terwyl die effek van verskillende N-bemestingspeile op grond N-inhoud gedurende die groeieseisoen gemonitor is. Die studie is uitgevoer by vyf verskillende kanolaproduksie-areas regoor die Wes-Kaap gedurende 2016 en 2017. Eksperiment een is uitgelê as ’n ewekansige blokontwerp van sewe verskille N-peile (0, 25, 50, 75, 105, 135 and 165 kg N ha^{-1}) wat toegedien is by rosetstadium. Al die bogenoemde N-peile het 25 kg N ha^{-1} met planttyd ontvang. Daar was ook ’n kontrolebehandeling wat geen N gekry het nie. Alle behandelings is vier keer herhaal. Eksperiment twee was ’n addisionele N-blaarbespuiting by stamverlenging teen 20 kg N ha^{-1} UAN. In eksperiment drie is vyf verskillende N-bronne geëvalueer wat ook toegedien is by rosetstadium. Al die behandelings het ook 25 kg N ha^{-1} met planttyd gekry. Verhoging van N-peil het gelei tot ’n verhoging ($p<0.05$) in grond N-inhoud. Verskillende N-peile het geen effek ($p>0.05$) gehad op plantpopulasie en biomassaproduksie by oestyd nie. Die resultaat was onverwags en kan toegeskryf word aan die relatiewe droë jare wat tydens 2016 en 2017 ondervind is. Kanolaopbrengs het verhoog ($p<0.05$) soos N-peil verhoog het. Maksimum opbrengsreaksie was alreeds bereik op ’n laer N-peil as wat verwag is. Stikstofverbruiksdoeltreffendheid het afgeneem ($p<0.05$) soos N-peil verhoog het, met ’n drastiese afname wanneer totale N-bemesting bo 25 kg N ha^{-1}verhoog is. ’n Addisionele N-blaarbespuiting by stamverlenging het geen effek ($p>0.05$) gehad op kanolaopbrengs en –olie-inhoud nie. Stikstofbron het geen effek ($p>0.05$) op plantpopulasie, biomassaproduksie en kanolaopbrengs gehad nie, behalwe by Langgewens in 2017. Urea + inhibeerder het hoër ($p<0.05$) opbrengs gelewer as KAN by Langgewens in 2017. Geen verskil ($p>0.05$) is waargeneem in olie-inhoud tussen verskillende N-bronne tydens 2016 nie. In 2017 was olie-inhoud oor die algemeen laer as in 2016 en wisselvallige olie-inhoudwaardes is waargeneem. Dit kan wees weens die verskriklike droogte tydens die groeiseisoen in 2017 wat olieproduksie negatief kon beïnvloed het. Vanuit die resultate is dit duidelik dat kanola N-bemestingsriglyne in sekere areas gewysig moet word. Huidige N-riglyne kan lei tot oorbemesting in die Suid-Kaap. In die Swartland met die lae NUE is daar ’n groot kans vir omgewingsbesoedeling. Verskillende N-bronne het geen effek op produktiwiteit gehad nie en keuse moet gebaseer word op koste.

Bewaringslandboupraktyke is geneig om die N-bemestingsbehoefte te verlaag in vergelyking met konvensionele praktyke. Verbeterde kanola N-bemestingsriglyne wat die bostaande resultate in ag neem, kan lei tot meer konstante opbrengste wat winsgewendheid sal verbeter. Stikstof N-riglyne sal egter eers gefinaliseer word na vier jaar van data-insameling.

Acknowledgements

I wish to express my sincere gratitude and appreciation to the following persons and institutions:

- My supervisors, Dr Johan Labuschagne and Dr Pieter Swanepoel for their support and guidance during this study.
- Mr Alfred Mokwele, Heinrich van Zyl and Mrs Annemarie van der Merwe for all the help regarding practical management of the canola trials.
- Mr Piet Lombard and Ms Lisa Smorenburg for harvesting of my trials.
- Mr Nicholaas Loubser and Mr WG Treurnicht for allowing me to use their equipment and farms for canola trial sites.
- Dr Mardé Booyse for help with statistical analyses of my data.
- Ms Anélia Marais for help with editing and reviewing of my chapters.
- Staff at the Western Cape Department of Agriculture for assistance during trial management.
- The Western Cape Agriculture Research Trust and Protein Research Foundation (PRF) for their financial assistance throughout the study.
- My girlfriend, Anli van Niekerk for her love and support during this study.

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Chapter 1: Introduction

1.1 Background

Canola (*Brassica napus* L.) is the third most important oilseed crop that is produced throughout the world, following soybean and palm oil (Reyes 2007). Main producing countries include Canada, China and India, which contribute more than 50% of global canola production (Statista 2017). Canola is planted for a wide range of uses, for both human and animal consumption. Canola cooking oil is increasingly being preferred, because of its well-known health properties and uses in the production of, *inter alia*, margarine. Canola's low erucic acid and glucosinolate content is what differentiates it from other *Brassica* spp., and makes it fit for human and animal consumption. High levels of erucic acid and glucosinolates are considered toxic for animal and human health (Allah et al. 2015).

Wheat monoculture was commonly practiced on many of the small grain farms in the Western Cape, particularly in the Swartland region of South Africa. However, environmental sustainability issues, decreasing production potential and weed problems have led to the introduction of crop rotation systems (Makhuvha 2015). Canola was introduced in South Africa in the early 1990s as an alternative commercial crop in crop rotation systems (Eksteen 2014). The Swartland and southern Cape regions with its temperate climate, winter rainfall and suitable soils for wheat production are ideal for canola production (Tesfamariam et al. 2010).

1.2 Problem statement

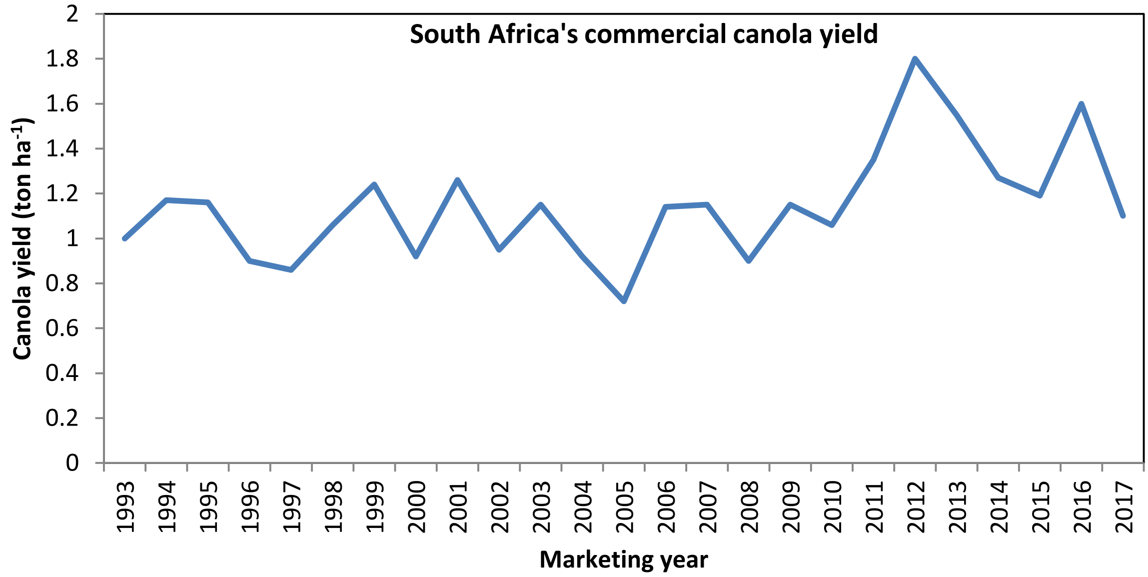

Figure 1.1 South Africa commercial canola yield (ton ha^{-1}) from 1993 to 2017 (SAGIS 2017).

Small grain farmers in the Western Cape who have changed from monoculture wheat systems to conservation agriculture (CA) have experienced a positive effect on the long term economic viability, yield and environmental sustainability of their farming systems (Arshad et al. 2002). Farmers are, however, still experiencing difficulties to achieve stable canola yield. Canola yield in South Africa are still relatively low compared to other Mediterranean climate production areas such as western Australia. Constant pressure on canola profitability due to the cost-price scenario in the Western Cape means that relatively high canola yields need to be obtained to ensure profitability (Hoffman 2011). Farming businesses constantly need to expand to produce at economy of scale. In order to expand, high profits per hectare are needed to cover annual farm loan repayments. Constant high grain yields and efficient use of inputs, amongst others N inputs, are needed to achieve this. Nitrogen (N) is a major input cost in canola production varying between 20% and 35% of total input cost (Sieling and Kage 2009). Uncertainty and lack of knowledge regarding efficient N management of canola under CA practices have, however, made it difficult for farmers to achieve high canola yields (SAGIS 2017) and furthermore high profit. Thus, there is potential to increase profit per hectare through efficient N management strategies which may reduce N inputs but still maintain high canola yields.

Nitrogen is one of the most important fertilisers needed for canola production (Taheri et al. 2012). Inadequate supply of N will restrict yield (Taheri et al. 2012). There is a scarcity of research information available regarding the yield response of canola to timing and rates of N fertilisation (Ghanbari-Malidarreh 2010). Changes in soil N dynamics through the introduction of CA also changed N management strategies including N fertiliser requirements. Conservation agriculture resulted in an increase in available soil N through increased soil carbon (C) content and by creating a more ideal environment for microbial activity (Farage et al. 2007, Lafond et al. 2008). Reduced soil disturbance through no-tillage planters has slowed down the rate of decomposition of soil organic matter (SOM) which has led to increase in soil C content and soil moisture retention capacity, soil conditions that stimulate microbial activity. Promoting microbial activity and diversity through adoption of CA might therefore increase availability of nutrients for plants throughout the growing season. Nitrogen dynamics of soil and N uptake by canola are highly variable due to environmental (especially rainfall regime), soil (*inter alia* C content, soil moisture content and soil temperature) and cultivar influences, which means that each production area will require unique N management strategies (Grant and Bailey 1993, Rathke et al. 2006). It is hypothesised that the current N fertiliser guidelines used in the Western Cape are not necessarily applicable to canola, as these are based on guidelines for wheat, or adopted from international literature. Canola N fertilisation guidelines in the grain producing areas with its unique soils, Mediterranean climate and management principles (i.e. CA), warrants re-evaluation.

1.3 Aim and objectives

The aim of this study was to determine the effect of different topdress N rates, foliar N application at stem elongation and source of N have on plant parameters, canola seed yield, seed oil content and N use efficiency, whilst monitoring the effect of different topdress N rates on the soil mineral N concentration at plant, pre-topdress, post topdress and at harvest. The study was divided into three sections, each with its own objective:

1) The first objective was to determine the effect of different topdress N rates at rosette stage (4 to 5 leaf stage) on plant parameters, canola yield, oil content and N use efficiency, while monitoring the response of N application on soil mineral N content.
2) The second objective was to determine the effect of an additional foliar N application in the form of urea ammonium nitrate (UAN) at stem elongation stage on canola yield and oil content.
3) The third objective was to determine the effect of different N sources on plant parameters, canola yield and oil content.

1.4 Outline of the thesis

This thesis consists of seven chapters, including this introductory chapter which contextualise the study by providing a background of the canola industry in the Western Cape, identifies the problems and gaps in research, and provides the aim and objectives of this study.

Chapter 2 comprises a literature review covering a broad range of N research that has been conducted on canola and CA practices.

Chapter 3 comprises the materials and methods, and includes information about research sites, soil characteristics, weather data and a description of the trial layout, trial management and statistical analyses.

Chapter 4 compromises the results for objective one followed by a discussion of the results

Chapter 5 compromises the results for objective two followed by a discussion of the results

Chapter 6 compromises the results for objective three followed by a discussion of the results

Chapter 7 provides the main conclusion of the study, limitations of the study and recommendation for future studies.

Chapter 2: Literature Review

2.1 Conservation Agriculture

Conservation Agriculture (CA) is based on minimum soil disturbance, crop rotation and maintaining an organic soil cover (FAO 2011). One of the most important aims of CA is the sustainable use of agriculture resources and to improve soil health (Knowler and Bradshaw, 2007). The long-term increase in yield and reduction of fertiliser cost are important indicators of improvement in soil health due to adopting CA (Zimmer and Zimmer-Durand 2011).

2.1.1 *Soil health*

Improvement of soil health under CA is mainly due to increase of soil C content, nutrient recycling and practices promoting soil aggregate stability and microbial activity (Giller et al. 2009). Soil organic matter (SOM) plays a primary role in soil fertility, productivity and sustainability (Chivenge et al. 2007). Soil organic matter is a supplier of nutrients and is a key factor in soil aggregate development and stability (Schulten and Schnitzer 1998, Verhulst et al. 2010). Conservation agriculture practices promote build-up of SOM where reduced or no-tillage has shown to have the greatest effect (Swanepoel et al. 2016). Increased SOM improves physical, chemical and biological properties of soils (Diacono and Montemurro 2010). These properties determine the environment in which soil microbes and roots live in. Improving these properties is critical to create an ideal environment for soil life and provision of plant nutrients necessary for plant growth (Zimmer and Zimmer-Durand 2011).

Conservation agriculture management practices improve soil aggregate stability (Verhulst et al. 2010). Stable soil aggregates have the ideal composition of pore sizes which increase rainfall (water) infiltration and soil moisture retention (Shaxson 2006). Increasing soil water availability will increase rate of soil N mineralisation and improve N uptake efficiency of canola which might lead to increases in productivity (Rathke et al. 2006). The combination of increased water holding capacity and lower evaporation due to residue management (soil cover) will also increase the soil's buffering capacity to reduce the negative effects of dry spells (Kassam et al. 2012).

Mycorrhiza is a group of plant beneficial fungi which accesses and transports nutrients to plants in exchange for carbon (C) (Jones 2010). Thus high soil C content will stimulate mycorrhiza development and thus enhance available nutrients for plant growth. Nitrogen fixing bacteria also derive its energy from C through the conversion of nitrogen gas to ammonium. Farage et al. (2007) showed long-term increases in C content (0.1 to 0.2 t ha^{-1} $year^{-1}$) under CA practices. Soil C content under reduced tillage practices are on average

20% higher compared to soils under conventional tillage (Fernández-Ugalde et al. 2009, Swanepoel et al. 2016) . The accumulation of SOM and reduction in carbon decomposing rate due to reduced tillage results in increased soil C storage (Giller et al. 2009). Results have shown that no-till (NT) results in a 1.5 times slower C decomposition rate, compared to conventional tillage (CT) (Chivenge et al. 2007). However, change in C soil content differs between soil types. Reduced tillage has shown a strong effect on fine-textured soils, but has shown little change in sandy soils (coarse texture). This is primarily due to lack of physical protection of organic matter in sandy soils, which result in greater SOM loss (Giller et al. 2009).

2.1.2 *Soil nitrogen cycle*

Soil N is present in four major forms and converts from one form to another in a process, commonly known as the nitrogen cycle. These forms include organic matter, microbes, and mineral N-forms in soil solution including NH_4^+, NO_3^- and NO_2^- in low concentrations (Cameron et al. 2013). Various processes in the N cycle have an effect on the availability of N to plants and the loss of N to the environment (Heisler 2013).

Processes that increase plant available N include: mineralisation, ammonification and nitrification of N. These processes increase NO_3^- and NH_4^+ in the soil solution. Nitrate and NH_4^+ are the primary two N forms that the roots of the plant absorb (Walworth 2013). Mineralisation is the conversion of organic N from manure, organic matter and crop residue to NH_4^+ as it is decomposed by soil microbes (Heisler 2013). Environmental and soil factors affect microbes and their actions, which in turn determine the rate of N mineralisation in the soil and the amount mineralised through time (Deenik 2006).

Nitrogen Mineralisation: Organic nitrogen → Inorganic nitrogen

Ammonification refers to the conversion of atmospheric N to NH_4^+ through various soil microbes, some symbiotic relations with plants (Deenik 2006).

Ammonification: Organic NH_2^+ - compounds + ammonification bacteria → ammonium (NH_4^+)

Nitrification is the conversion of NH_4^+ to NO_3^- through microbes to obtain energy. Ammonium is rapidly oxidised to NO_3^- when microbial development is limited by available C and energy. Nitrate supply is necessary for an actively growing plant, but is highly susceptible to leaching (Heisler 2013).

Nitrification: Ammonium (NH_4^+) + nitrifying bacteria → Nitrate (NO_3^-)

Nitrogen losses from soils occur as the result of denitrification, volatilisation, leaching and immobilisation. These processes can not only reduce soil fertility and plant yield, but can also have negative effects on the environment (Cameron et al. 2013). Poor management practices are the main cause for N losses. Denitrification is common in poorly drained soils where NO_3^- is converted to N_2 gas.

Denitrification: $2NO_3^- \rightarrow 2NO_2^- \rightarrow N_2O \rightarrow N_2$

Volatilisation is the loss of N through the conversion of NH_4^+ to NH_3 gas, which is released to the atmosphere. The conversion of NH_4^+ to NH_3 gas is controlled by soil pH. Soil factors favourable for volatilisation include high pH soils, high temperature, fertiliser use, soil moisture and soil NH_4^+ concentration (Cameron et al. 2013).

Volatilisation: $NH_4^+ + OH^- \leftrightarrow NH_3 + H_2O$

Nitrate leaching from the root zone into deeper soil layers is not only a loss of available N but also of high concern to water quality (Heisler 2013). Areas with high rainfall and/or high average rainfall intensity, poor irrigation management with over-supply of water and sandy soils (coarse textured) have a high potential of leaching (Liang et al. 2011, Walworth 2013).

Immobilisation is the reverse of mineralisation. It is the temporarily reduction in the plant available N-pool, because of inorganic N that is assimilated back into the microbial population (Deenik 2006).

Immobilisation: Inorganic N → Organic N

Mineralisation and immobilisation can occur simultaneously and is primarily affected by chemical composition of organic matter (e.g. C:N ratio and N content) (Calderón et al. 2005). Organic matter with a high N content and low C:N ratio (lower than 20) will be mineralised to supply N for plant absorption (Probert et al. 2005). Contrary to mineralisation, immobilisation will occur when N content is low and C:N ratio is high (more than 20) (Probert et al. 2005, Masunga et al. 2016). A good understanding of how N cycle functions is important as this will help producers to use nitrogen more efficiently and limit possible adverse impacts on the environment (Walworth 2013).

2.1.3 *Nitrogen mineralisation potential*

Nitrogen is introduced to the soil either through applied fertiliser or mineralisation of crop residue and soil organic matter (Heisler 2013). Nitrogen mineralisation plays a primary role in maintaining available soil N for plant uptake during the growing season (Zhang et al. 2012). Available soil N released through mineralisation can be used to determine supplemental N needed from fertiliser N (Heisler 2013). Farming systems with high N mineralisation potential has lower supplemental (fertiliser) N requirements.

Nitrogen mineralisation occurs through the activity of soil microbes. Factors influencing microbial activity will have an indirect effect on the rate of N mineralisation (Deenik 2006). Soil temperature, moisture- and SOM content influence microbial activity. Microbial activity is limited at low soil temperatures and increases as soil temperature increases. Nitrogen mineralisation potential increases as soil temperature increases from 5°C to 35°C while optimum mineralisation occurs at soil temperatures of 30°C to 35°C (Deenik 2006). Dry soils result in a low N mineralisation rate, because microbial activity is limited due to a lack of water availability. In saturated soils total N mineralisation is limited, because only soil microbes that can survive under anaerobic conditions are active. Soil water content at approximately field capacity (± 60%) has shown to be optimal for microbial activity while soil water content dropping below 15% (dry soil) limits microbial activity (Zhang et al. 2008). Interaction between soil temperature and soil moisture determines microbial activity potential (Sierra 1996). Thus microbial activity will be limited if soil temperature is ideal, but soil moisture is low, and *vice versa* (Figure 2.1).

Soil organic matter is crucial in growth and activity of soil microbes (Masunga et al. 2016). Thus factors influencing SOM content will have an indirect effect on N mineralisation potential of soil. Poor soil management practices, like conventional tillage, which deplete SOM, decrease microbial activity which results in a decrease of soil N mineralisation potential. Higher SOM content under reduced tillage practices compared to conventional tillage is a good indication that CA systems will stimulate growth and activity of soil microbes, leading to increased N mineralisation (Tejada et al. 2009).

Contrasting results about the effect of N fertilisation on net soil N mineralisation have been reported. Dijkstra et al. (2005) and Zhang et al. (2012) reported an increase in net soil N mineralisation with N fertiliser application due to reduced N immobilisation or increased decomposition of organic matter with high N concentrations. However, Chappel et al. (1999) found that N fertilisation had no effect on rate of soil N mineralisation.

Conservation Agriculture is expected to result in N immobilisation in the short-term, but net N mineralisation in the long term (Giller et al. 2009). The time required to achieve net N mineralisation depends on environmental conditions, residue (composition, C:N ratio and rate of addition) and fertiliser N rate. During planting, when residue with a high C:N ratio is incorporated into the soil it is expected that N immobilisation will occur (Giller et al. 2009). It is important to supply N fertiliser to compensate for N immobilisation during this time. Dry or wet seasons create soil temperature and moisture conditions which decrease N mineralisation rate. This can create the expectance for low N mineralisation rate in the Western Cape due to dry summers and cold, moist winters. However, long-term research has shown a higher amount of biological N and greater ability to release N under CA than conventional tilled soil in Mediterranean-type climate (Kassam et al. 2012). Thus enhanced moisture retention and soil temperature stabilisation under CA (Knowler and Bradshaw 2007), may be the contributing factors for net mineralisation in the long term.

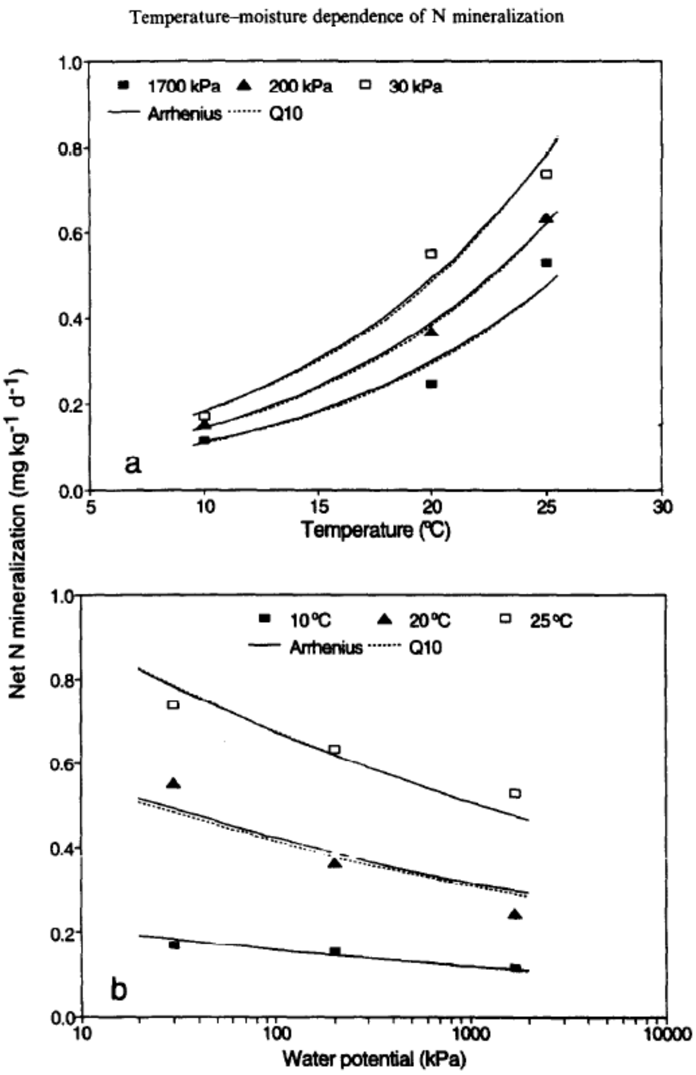

Figure 2.1 Influence and interactions of soil temperature and moisture on soil net N mineralisation (Sierra 1996).

2.2 Nitrogen metabolism in canola

2.2.1 *Function of Nitrogen in canola*

Nitrogen forms part of many plant essential components such as proteins, amino acids, nucleotides and chlorophyll (Grant and Bailey 1993). These components play a critical role in biological processes, which in turn influence a variety of yield components such as branches per plant, length of stem, number and mass of pods and seeds per plant (Ahmadi and Bahrani 2009).

Dark green leaves are a good indication of a healthy canola plant with sufficient available N (Grant and Bailey 1993). Plant tissue analysis during flowering stage can be used to determine N status in canola plants. Whole aboveground plant samples at flowering stage are needed for plant tissue analysis. Canola plants with a sufficient N status will have an N content greater than 2.4% (Canola Council of Canada 2014). Excess N has a negative effect on growth which could restrict canola yield. Excess N promotes lodging which could result in N shortage during growing season during high rainfall periods. Excessive N fertilisation increase biomass production which increase the risk for foliar diseases (dense canopy) and also increases the risk of soil moisture depletion during dry spells which could lead to water shortages (Canola Council of Canada 2014).

Nitrogen deficiency symptoms will first appear on older leaves due to the mobility of the element within the plant. In the event of N deficiency, green-yellow and purple discoloration appears first on the older leaves. Deficient N canola plant also produces fewer and smaller leaves than canola plant that has adequate N supply (Taheri et al. 2012).

2.2.2 *Nitrogen uptake and utilisation*

Canola is a tap rooted plant with an average root depth of 140 cm under ideal conditions (Canola Council of Canada 2014). Inorganic forms of N are taken up by canola roots from the soil solution. These inorganic nitrogen forms include: NO_3^- and NH_4^+ (Bose 2008). Nitrate is more abundant under aerobic soil conditions while NH_4^+ is the major form of N in wet- and acidic soils. Nitrate is highly soluble and is rapidly taken up when plant's growth rate is high. In contrast to NH_4^+, NO_3^- is an anion which restricts binding to negatively charged clay and other binding sites. Thus NO_3^- in soil solution is prone to loses from soil through runoff and deep drainage (leaching). Ammonium is a cation and is adsorbed to the negatively charged binding sites (clay and humus) in the soil, resulting in a lower risk for leaching.

Abovementioned N ions are utilised by plants in several steps such as uptake, assimilation, transportation and remobilisation (Wang et al. 2014). Uptake of ammonium results in acidifying of rhizosphere while nitrate uptake results in alkalisation. These changes in rhizosphere will have a direct effect on plant available nutrients (Xu et al. 2012). Some plants have the ability to manipulate N uptake for NO_3^- and NH_4^+ by releasing oxygen or exudates from roots (Xu et al. 2012). These secretions from roots influence rhizosphere pH which influences plant available N. Plant roots have specific uptake systems for both NO_3^- and NH_4^+ with different affinities. This enables the crop to cope with the variety of nitrate and ammonium concentrations in the soil solution. Both NH_4^+ and NO_3^- transporters and root architecture affect N uptake by roots (Garnett et al. 2009).

Figure 2.2 illustrates the phases in which N management can roughly be divided into. These phases include the vegetative and reproductive phase (Hirel et al. 2007). Young leaves and roots serve as sink organs in the vegetative phase. During the vegetative phase, N is assimilated in young leaves and roots which lead to synthesis of amino acids. These amino acids are then further reduced via the assimilatory pathway to produce enzymes and proteins. Proteins and enzymes play a primary role in the building of different components, structures and photosynthetic machinery within plants. During the reproductive phase (after flowering) N accumulated in vegetative tissue is remobilised and transported to reproductive and storage organs, for example, seeds (Hirel et al. 2007). Shoots and roots now behave as source of N through providing amino acids, released from protein hydrolysis, to these reproductive organs. Some plants continue to absorb N after flowering while others only absorb negligible amounts during this stage. Thus relative contribution of N remobilisation during vegetative and reproductive phases to grain fill varies between species and may be influenced by agronomic conditions which affect N availability through the growing season. Sufficient supply of N during the vegetative stage is therefore of absolute importance to create potential for high yields.

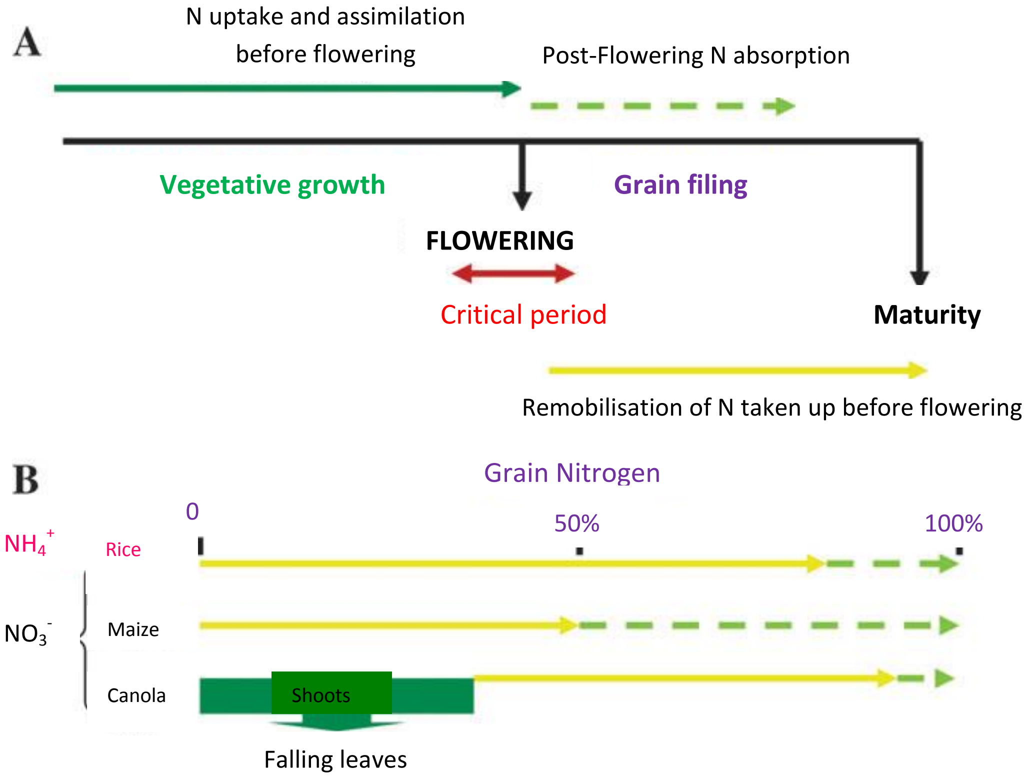

Figure 2.2 Nitrogen management through vegetative and grain filling phases in plant life cycle (Hirel et al. 2007).

2.2.3 *Nitrogen utilisation efficiency (NUE) of canola*

It is important to have a good understanding of canola N dynamics (uptake pattern of N, and capacity to mobilise and transport N), to optimise yield response to N fertiliser application (Hocking et al. 1997). Nitrogen harvest index (NHI) is calculated as the ratio between seed N content and N-fertiliser applied (Hocking et al. 1997). Canola has a high capacity to take up NO_3^- from the soil (Lainé et al. 1993), but several studies have shown that only 50 to 60% of applied N is recovered in seed (Schjoerring et al. 1995, Malagoli et al. 2005). This indicates that canola has a low NHI which means good N management is crucial to avoid N loss through leaching (Rossato et al. 2001).

The main source of N required for grain filling in canola is derived from the mobilisation of N from vegetative tissue (Rossato et al. 2001). Thus, the low NHI can be explained by the inefficiency in which leaf N is mobilised and the high amount of N that is lost with leaf fall. The higher N content in dead leaves compared to that of dead stems and taproots is a good indication of inefficiency of N mobilisation of leaves and significant N that is lost (Hocking et al. 1997). Studies have shown that 10 to 15% of total N is lost due to leaf fall (Schjoerring et al. 1995, Hocking et al. 1997; Rossato et al. 2001; Malagoli et al. 2005). Older leaves which senesce before onset of flower and pod formation mainly transfer N to upper (younger) leaves and storage organs like stems and taproots. These storage organs are later used to supply N during the reproductive tissue. The lower (older) leaves contribute less (30%) total N mobilisation to grain fill compared to mean of 70% for upper leaves. This can be linked to the development of reproductive organs that create a strong sink for upper leaves serving as sources of N.

During vegetative phase N uptake increase and accumulates in leaves, stem and taproots. Reports of N uptake of canola after flowering till harvest have shown contrasting results. Rossato et al. (2001) have shown a decrease in N uptake capacity at flowering to a non-significant level during pod filling, while Malagoli et al. (2005) found that 30% of total N were taken up during flowering and another 11% was accumulated during pod filling. Hocking et al. (1997) also reported significant accumulation of N during flowering (33%) and after flowering (11%). Nitrogen uptake is correlated to the translocation of photo-assimilates from leaves to roots due to photosynthetic activity (Rossato et al. 2001). These photo-assimilates serve as energy for roots to take up N from soil. Leaf N concentration is closely correlated to photosynthesis activity (Rossato et al. 2001). The consistent decline in N concentration of vegetative tissue over time reflects the overall decrease in nitrogen uptake during later growth stages of canola (Hocking et al. 1997). Decline in N concentration is mainly due to leaf abscission which is influenced by environmental conditions. During winter, leaf fall is induced through low temperatures and low light intensity conditions (Malagoli et al. 2005). Water stress conditions and shading of leaves also induce leaf fall (Malagoli et al. 2005). High N fertiliser rate can also induce leaf shading through high biomass production which results in high leaf area index (LAI) values.

Several ways were identified to improve N mobilisation efficiency between the vegetative growth stages and pod filling. This includes genetic and management improvements. Genetic improvements include early flowering cultivars to synchronise greater proportion of lower leaves N mobilisation with pod N demand (Malagoli et al. 2005). Reduction of dry-matter production of pod walls may direct assimilates more efficiently to seed production (Hocking et al. 1997). Proper N management strategies include optimising LAI which limits shading of canola leaves. Thus optimising LAI would increase leaf duration and photosynthetic activity which would increase the N pool size (endogenous N) for pod filling. Optimising N fertiliser management which promotes adequate N supply for canola at high demand growth stages has also shown to increase N recovery efficiency (Ghanbari-Malidarreh 2010). Thus improving management can have a strong effect on N recovery efficiency of canola which could reduce external N inputs.

2.3 Nitrogen fertilisation

2.3.1 *Canola yield response to nitrogen rate*

Several studies have shown that increasing N fertilisation rate will lead to substantial increase in canola seed yield, however at some point additional N supply results in stagnation or reduction in canola yield (Sidlauskas and Bernotas 2003, Rathke et al. 2006, Ghanbari-Malidarreh 2010, Oz et al. 2012; Taheri et al. 2012). Figure 2.3 illustrates a typical response for canola yield to increased N top dress rates. Sidlauskas and Bernotas (2003) reported that seed yield was significantly affected up to a top dress rate of 120 kg N ha^{-1}, where a high yield of 2.4 ton ha^{-1} was obtained. Further increase of N rates higher than 120 kg N ha^{-1} had little effect or lead to reduction of canola yield.

The decline of N-fertiliser recovery at high N rates contributes to the stagnation or decrease of canola yield at some point (Rathke et al. 2006). Nitrogen fertiliser application increase yield by influencing a number of yield components such as branches per plant, length of stem, number and weight of pods and seeds per plant (Ahmadi and Bahrani 2009). Pods per plants have been reported to have the biggest effect on yield compared to other yield components (Ghanbari-Malidarreh 2010). Ghanbari-Malidarreh (2010) and Ozer et al. (1999)

have shown a strong correlation between number of pods and N rate which in turn has a strong effect on seed yield of canola.

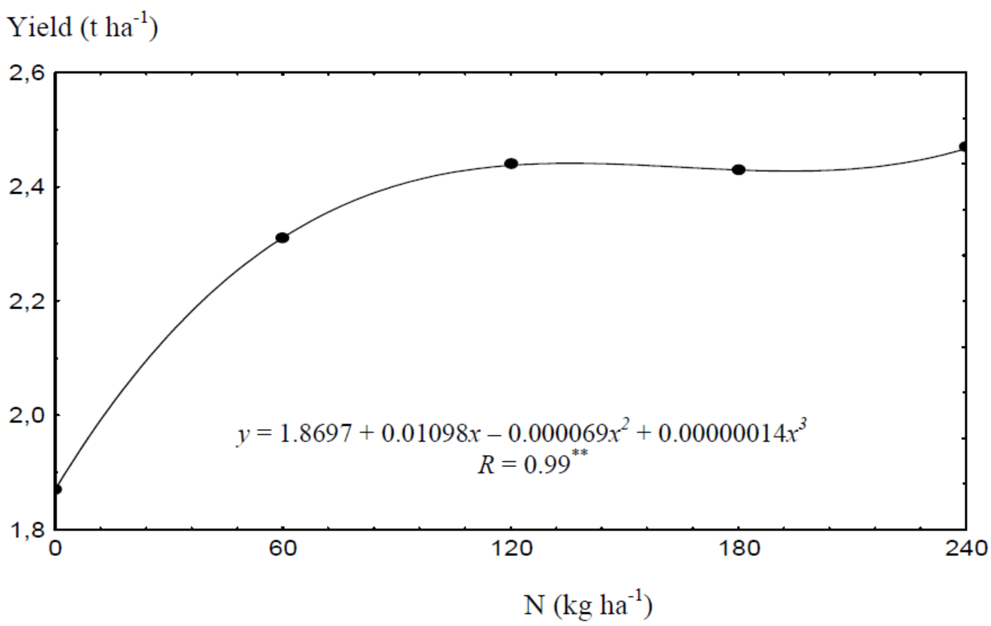

Figure 2.3 Canola yield as a function of nitrogen rate (Sidlauskas and Bernotas 2003).

Achieving the optimal N rate will not only increase yield, but will also prevent over application of N that can have an adverse effect on soil and plant growth. Applying too much N could cause antagonistic problems and cause Zn, Cu, Ca, Mg and K deficiencies (Kinsey 2006, Zimmer and Zimmer-Durand 2011). High amounts of NH_4^+-N application to the soil can also result to soil acidification in the long-term, which reduce soil pH and may influence soil available nutrients for plant production (Barak et al. 1997).

An appropriate technique to determine optimal N fertiliser rate include the combination of adapting to net soil N release and varying the amount of N fertiliser applied to canola (Ghanbari-Malidarreh 2010). From these results the N fertilisation rate which resulted in highest canola production can be determined. Net soil N release through mineralisation can be predicted through soil sample and plant tissue analysis. Soil samples are taken at the start of the season (pre-planting), while plant tissue analysis can be done during canola flowering stage. Through adjusting N management strategies to soil conditions, agronomic efficiency can be increased and also reduce oversupply of N which would minimise loss of N through leaching (Walworth 2013).

However N dynamics in soil and plant uptake is highly variable and strongly dependent on environmental, soil and cultivar factors (Rathke et al. 2006). Several studies have concluded controversial results due to the strong effect of these factors on optimal N-treatment (Rathke et al. 2006). Thus no general conclusion is possible for optimal N rate, maximum yield and the recommended N fertiliser rate will be area specific.

2.3.2 *Canola oil content response to nitrogen rate*

Canola seed oil production usually decrease as N fertiliser rate increase, opposed to the positive response of yield to N fertilisation (Rathke et al. 2006, Karamanos et al. 2007, Ghanbari-Malidarreh 2010 and Ma and Herath 2016). Reduction of oil content under high N fertilisation rates are due to increased protein content at the expense of oil production (Grant and Bailey 1993; Behrens et al. 2002; Rathke et al. 2005). Contrasting results have, however, been reported by Dreccer et al. (2000) who found no difference in oil content as N fertiliser increased.

Hocking et al. (1997) regarded an oil content of more than 40% to be a good quality standard. This may, however, differ between countries and uses. In Australia an oil content of 42% is regarded as the quality standard and producers will receive price penalties for canola delivered with an oil content of less than 42% (AOF 2016). This is not the case for South Africa, were oil content does not have an influence on price. Currently, there is no urgency among South African producers to take canola oil content in consideration during N management.

2.3.3 *Nitrogen fertiliser splitting during growing season*

Physiological studies on canola have shown critical growth stages where high N supply is needed to ensure high yield potential (Barlog and Grzebisz 2004) (Figure 2.4). Timing N fertiliser to coincide with these high N requirement periods has improved production efficiency of canola (Sidlauskas and Bernotas 2003, Ghanbari-Malidarreh 2010). When compared to a once off N application, split N applications affect yield components which directly affect seed yield, especially higher number of pods per plant (Ghanbari-Malidarreh 2010).

Generally, N split application is divided into three phases which include: planting time, early seedling stages and high N demand growth stages. Nitrogen application at planting compensates for low N mineralisation rate that could hamper seedling growth and affect yield. The second phase refers to high N demand periods as illustrated in Figure 2.4, such as 4-5 leaf stage (stage 2), stem elongation (stage 3) and start of flowering (stage 4) which have shown to have strong relations to N uptake (Rathke et al. 2006). Application of N at stem elongation enhances N uptake during start of flowering. Similar results were obtained by Ghanbari-Malidarreh (2010), who reported that highest yield was obtained when N application was split between planting (25%), stem elongation (50%) and start of flowering (25%). Barlog and Grzebisz (2004) and Cheema et al. (2010) have reported similar results. They found that the highest yield was obtained for N application at planting and stem elongation or start of flowering. Contrasting results have however been reported by Hocking et al. (1997) which reported no yield increase for N topdressing following N applied at planting. Although abovementioned studies differ, several studies have reported that overall split N application strategies promote higher yield compared to single N application strategies (Sidlauskas and Bernotas 2003, Barlog and Grzebisz, 2004, Ghanbari-Malidarreh 2010, Rathke et al. 2005, Kaefer et al. 2015).

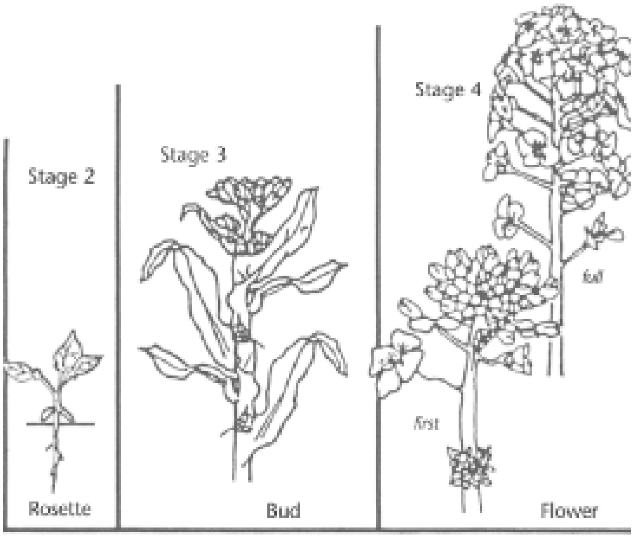

Figure 2.4 Canola high N demand growth stages (Canola Council of Canada 2014).

Optimum time to apply N fertiliser is not only influenced by plant growth stages and N requirements, but is also directly affected by climatic-, soil conditions, N soil content and interaction between these indices. These factors need to be taken into account during N fertilisation management. Sidlauskas and Bernotas (2003) have shown that under poor growing and development conditions split N application could be much less effective if not adapted to environmental conditions. Nitrogen fertiliser management must be adapted with changes in soil moisture content. Applying N fertiliser during dry- or waterlogged soil conditions reduce N-fertiliser recovery and increase risk of N loss through leaching, volatilisation etc., which could restrict canola yields (Gutierrez Boem et al. 1996, Habibzadeh et al. 2013). Thus N split management strategies that focus on sufficient N supply during high demand stages and take climatic conditions to account have shown to not only increase yield but also improve N fertiliser efficiency (Rathke et al. 2006).

2.3.4 *Nitrogen sources*

There are a number of different N fertiliser sources worldwide available that is used for crop production. It is important to have a good understanding about the benefits and drawbacks of each N fertiliser source in order to know how it will affect the farming system. Canola absorbs N derived from N fertiliser in nitrate, ammonium, urea or amino acid forms (Rathke et al. 2006). These N forms differ in terms of effect on crop physiology and response to environmental conditions which affected yield (Grant and Bailey 1993). Therefore, it may be expected that canola yield response to N source may differ, but contrasting results have been found. Kaefer et al. (2015) have shown that yield variables were not influenced by type of N source (ammonium sulphate and urea) used under same management strategies. Similar results were obtained by Behrens et al. (2001) who reported that different N forms (calcium nitrate, ammonium nitrate and ammonium-nitrate inhibitor) had neither an effect on seed yield , N uptake or N balance. According to Ozturk (2010) and Barlog and Grzebisz (2004) N fertiliser source does influence seed canola yield and quality. Maximum yields were obtained with ammonium sulphate (AMS) application when compared to urea and ammonium-nitrate under field conditions (Ozturk 2010). The positive effect of AMS effect on seed yield may be associated with additional S supply (Ozturk 2010). These results may be expected in soils with low sulphur content, because of the high S requirement for canola production (Fismes et al. 2000).

Ammonium sulphate (AMS) is an ideal N source if there is a need for S and is also one of the most cost-effective N and S combination products that can be used for plant production (Kinsey 2006). Ammonium taken up by plant roots is directly assimilated into amino acids (Xu et al. 2012). The reduction of pH through AMS use increases availability of micro-elements uptake which are also highly beneficial for canola production (Ozturk 2010). Ammonium is a cation which readily binds to clay and organic matter which means it is less prone to leaching (Kinsey 2006). Grant and Bailey (1993) have shown that during wet growing conditions, loss of N is lower if N is applied as ammonium compared to nitrate application. The low salt index of AMS is also important to mention since high salt index fertilisers may injure germinating seeds, soil life and may cause damage to roots (Zimmer and Zimmer-Durand 2011). The salt index measures the salt concentration that will be released by the fertiliser into the soil solution. Low salt index refers to slow release of N into soil solution which reduces risk of root burn. High salt index fertilisers cause high salt concentrations in the soil solution restricting water supply to the geminating seedling. High salt concentrations can cause plant roots to lose water back to the soil solution and restrict plant growth. The combination of abovementioned benefits makes AMS a popular N-fertiliser source to use for crop production (Kinsey 2006, Zimmer and Zimmer-Durand 2011).

Fertilisers that supply N in the NO_3^- form are highly mobile in soil solution and can be beneficial in emergency situations where N is quickly needed to avoid reduction of yields. In general plants absorb N mainly in the nitrate form after which it is reduced to ammonium and then assimilated into amino acids (Xu et al. 2012). The lack of binding sites for this anion N source means that nitrate is either taken up by plants or leached out with water moving through soil solution (Kinsey 2006). The high risk of nitrate associated with N loss through leaching could lead to shortages through growing season which could restrict yield (Kinsey 2006). Bose (2008) has shown that N availability throughout growing season can be increased by splitting nitrate fertiliser application. Therefore, good management of nitrate fertiliser is critical to minimise high N losses (Walworth 2013).

Dry application of urea and incorporating anhydrous ammonia gas have a high risk for N loss through volatilisation (Zimmer and Zimmer-Durand 2011). Urea converts to ammonia gas to nitrite to nitrate, unfavourable soil conditions (aerobic and dry) would prevent ammonia gas to absorb to clay and humus and high losses of N can occur through volatilisation of ammonia gas (Kinsey 2006). Timing of urea fertiliser prior to rainfall is an important strategy to reduce N loss through volatilisation. Bouwman et al. (2002) have reported that rain (10-16 mm) following urea application within 3-8 hours reduced volatilisation between 80 and 93%. A delay of 24 hours following urea application only reduced volatilisation by 33%. These results are, however, highly dependent on rate of urea hydrolysis which is determined by soil moisture content of the soil surface prior to urea application (e.g. dry soil may prevent hydrolysis until rainfall occurs) (Rochette et al. 2009). Effective management of urea application can make it a very cost-effective source to use due to its lower cost compared to other N sources.

Polymer coated urea or N- (n-butyl) thiophosphoric triamide (NBPT) inhibitor-treated urea reduce total N-loss through volatilisation compared to application of untreated-urea (Rochette et al. 2009) (Figure 2.5). Bishop and Manning (2011) have shown that addition of inhibitor (NBPT) to urea fertiliser can reduce ammonia volatilisation between 28% and 88%. The inhibitor allows urea to remain on soil surface without conversion to ammonia. Thus N loss through volatilisation is reduced and urea can remain on soil surface until washed into the soil with rain. Polymer-coated urea is also an effective method to reduce N loss through volatilisation. Rochette et al. (2009) reported a low 4% N loss of total applied N with use of coated urea. The polymer coating reduces initial dissolution of urea, prior to significant rainfall which reduce N losses via volatilisation (Bishop and Manning 2011).

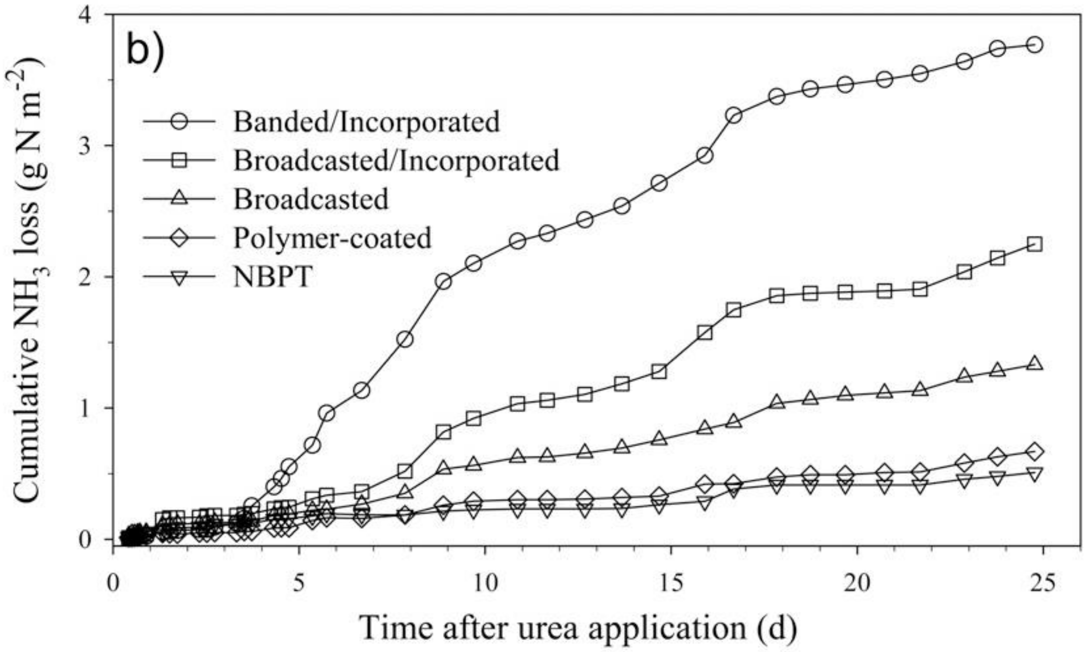

Figure 2.5 Cumulative NH_3^- losses from different application methods and urea types (Rochette et al. 2009).

Anhydrous ammonia gas is a highly concentrated nitrogen source (82%) which stimulates microbial activity and result in high decomposing rate of organic matter (Zimmer and Zimmer-Durand 2011). Anhydrous ammonia gas injected into soil may results in large amounts of carbon leaving the soil into the atmosphere as carbon dioxide due to high increase in microbial activity.

2.3.5 *Foliar application of nitrogen*

One important strategy that has been identified to increase N fertiliser efficiency involves N foliar application of canola (Grant and Bailey 1993, Rathke et al. 2006, Khalid et al. 2016). Gooding and Davies (1992) have shown that foliar fertiliser application reduced N losses through leaching and denitrification compared to soil applied fertiliser N. Small amounts of urea foliar application in combination with a carbon acid source (humate, ±0.2%) have shown to maximise yield response to N fertiliser (Sait 2003). Dry application of urea mainly ends up as NO_3^--N in the plant. High energy input is required to convert nitrate to amines to amino acids and then to leaf protein. The foliar route into the plant is much more efficient, thus much less urea can be used in foliar application compared to dry application. Urea is an amine which means that it is readily converted into amino acids and then proteins. When applying urea as foliar application the nitrate-based energy loss step is avoided and urea is directly taken up as amine and converted to proteins. It is advised to combine foliar applied urea with a carbon acid source like humates. The humates act as a buffer for fertiliser for slow release of minerals to avoid mineral losses and enhance N uptake (Sait 2003, Zimmer and Zimmer-Durand 2011).

Chapter 3: Material and Methods

3.1 Study sites

This study was conducted on five sites in the canola production areas across the Western Cape Province of South Africa during the 2016 and 2017 growing seasons. Selection of farms for study sites was based on variation in climate and soil conditions which has an influence on soil and plant response to N application. These farms included Uitkyk (34°9’38’’S, 21°9’6’’ E) near Riversdale, Tygerhoek Research Farm (34°08'56.5"S 19°54'09.9"E) near Riviersonderend, Langgewens Research Farm (33°16'34.8"S 18°42'15.3"E) near Moorreesburg, Nuhoop (32°54'49.2"S 18°55'58.9"E) near Porterville and Klipvlei (33°17'04.9"S 18°21'04.0"E) near Darling (Figure 3.1). Uitkyk (East Rûens) and Tygerhoek (West Rûens) are situated in the southern Cape and Langgewens, Nuhoop and Klipvlei in the Swartland. Klipvlei is situated in the sandveld area of the Swartland, Nuhoop in the Red Karoo area and Langgewens in the higher rainfall central area of the Swartland.

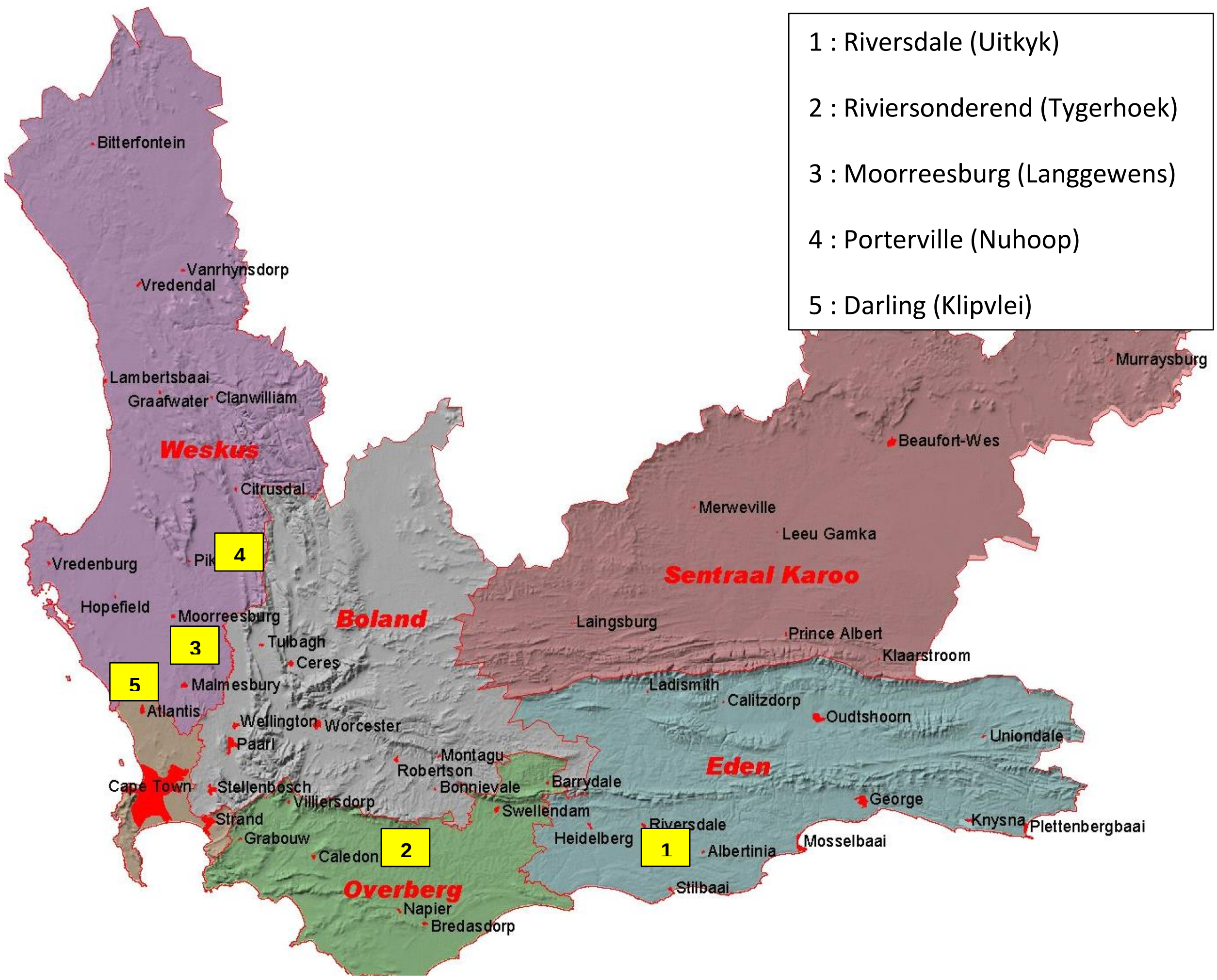

Figure 3.1 Map of the Western Cape and locations of the five research sites used in this study (Mycape 2017).

3.2 Climate

Study sites in the southern Cape and Swartland have a Mediterranean-type climate with the highest proportion of rainfall occurring from April to October. There is a slight difference in rainfall distribution between regions. The Swartland receives approximately 80% of its total rainfall between April and October while the southern Cape receives approximately 60% in the eastern parts to 75% in the western parts in the same months.

During the 2016 season, Nuhoop experienced a dry period after planting which resulted in very low seedling survival. Although data was collected, it was not suitable to satisfy certain objectives of this study and was therefore omitted from the 2016 results. Darling experienced similar dry conditions after planting during 2017, therefore no data was collected at Darling during the 2017 season. Decagon mini weather stations (Data loggers) were installed at each site to monitor soil temperature, moisture and rainfall during growing period.

3.2.1 *Uitkyk (Riversdale)*

Riversdale has a long-term average rainfall of 430 mm year^{-1} of which 60% occurs between April and September. Rainfall was relatively well distributed between April to September 2016, without severe dry spells. Total rainfall measured between April and September 2016 amounted to 236 mm, which is similar to long-term rainfall average of 253 mm (Figure 3.2). During 2017, Riversdale experienced a very dry April, May, June and July. Total rainfall measured between April and September 2017 amounted to 120 mm (Figure 3.2). Rainfall, volumetric soil water content (VWC) and soil temperature for Riverdale 2016 and 2017 can be seen in Figure 3.3 and Figure 3.4.

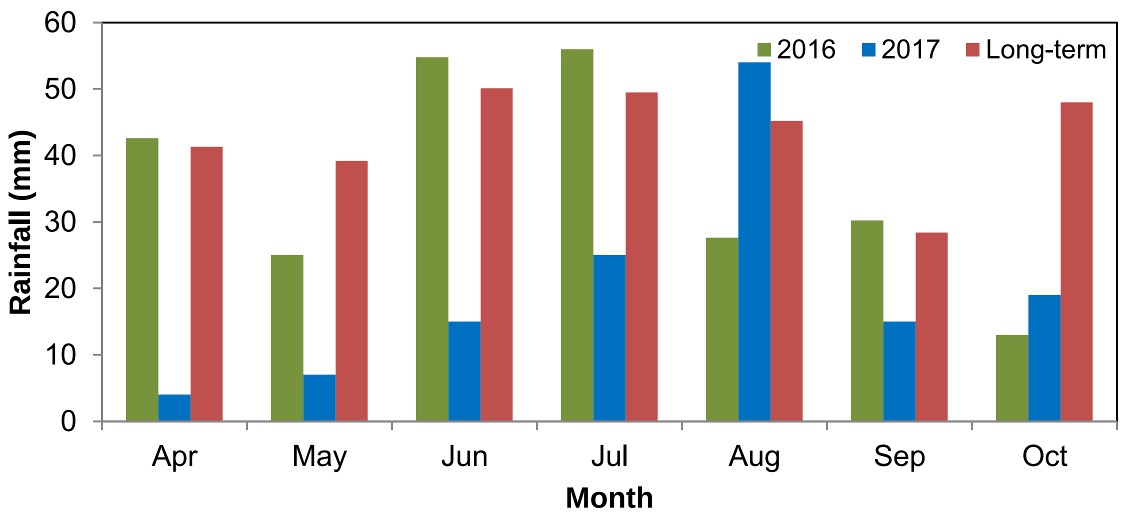

Figure 3.2 April to October 2016, 2017 monthly rainfall and long-term rainfall at Riversdale.

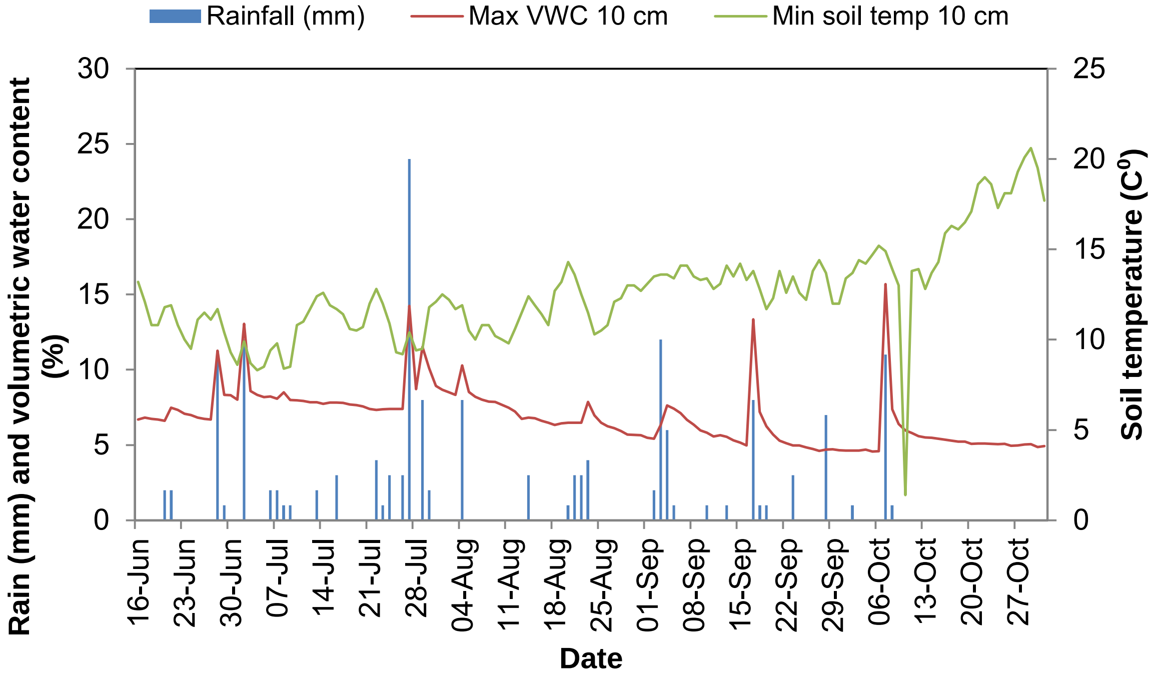

Figure 3.3 Rainfall (mm), maximum volumetric soil water content (VWC, %) and minimum soil temperature (ºC) at a 10 cm depth at Riversdale 2016.

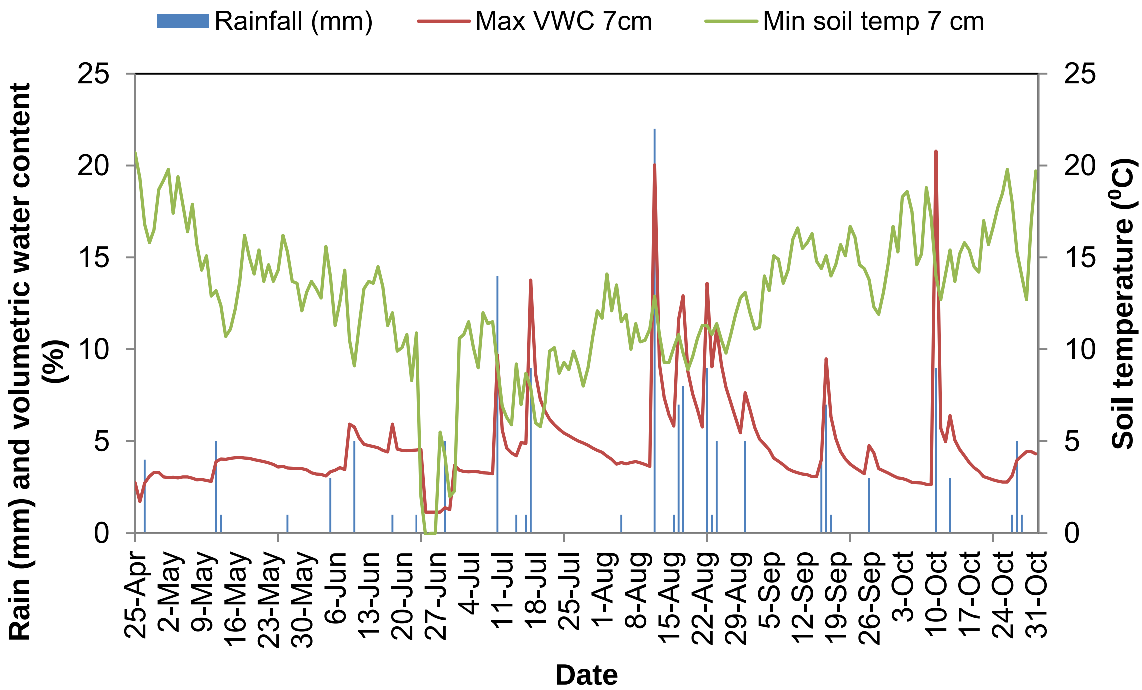

Figure 3.4 Rainfall (mm), maximum volumetric soil water content (VWC, %) and minimum soil temperature (ºC) at a 7 cm depth at Riversdale 2017.

3.2.2 *Tygerhoek (Riviersonderend)*

Tygerhoek has a long-term average rainfall of 450 mm year^{-1} of which 68% occurs between April and October. Very low rainfall during May 2016 delayed seedling emergence after planting. Seeds only germinated after sufficient rainfall in June 2016. From July to October 2016 rainfall data was similar to long-term rainfall (Figure 3.5). Except for a dry May and October, Tygerhoek received average rainfall during the 2017 growing season (Figure 3.5). Total rainfall measured between May to October 2017 (growing season) amounted to 197 mm, which is lower compared to long-term total of 255 mm for the same period. Figure 3.6 shows soil water content and soil temperature at Tygerhoek 2016. Rainfall, VWC and soil temperature for Tygerhoek 2017 can be seen in Figure 3.7.

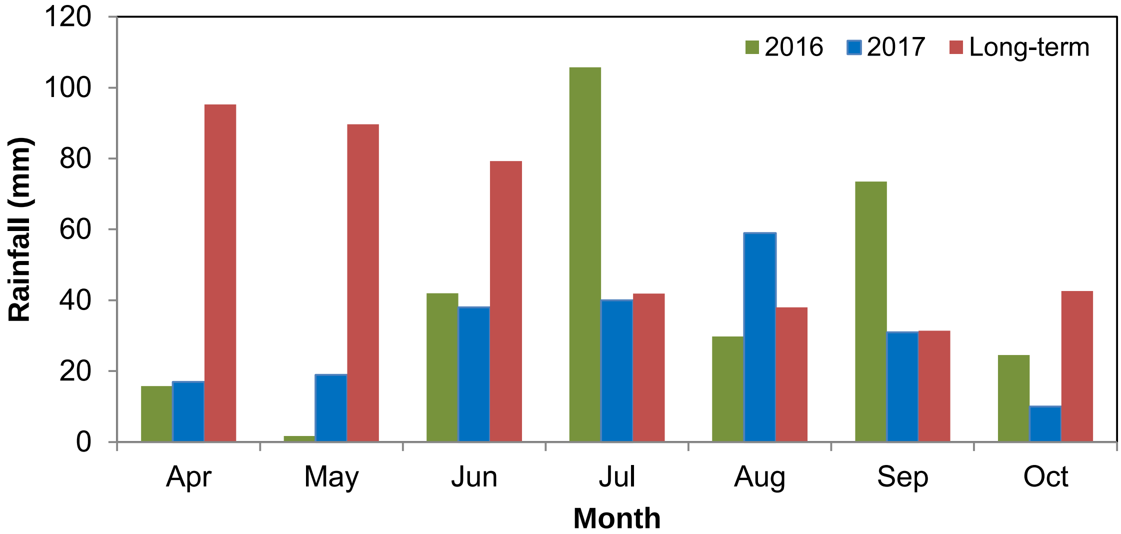

Figure 3.5 May to October 2016, 2017 monthly rainfall and long-term rainfall at Tygerhoek.

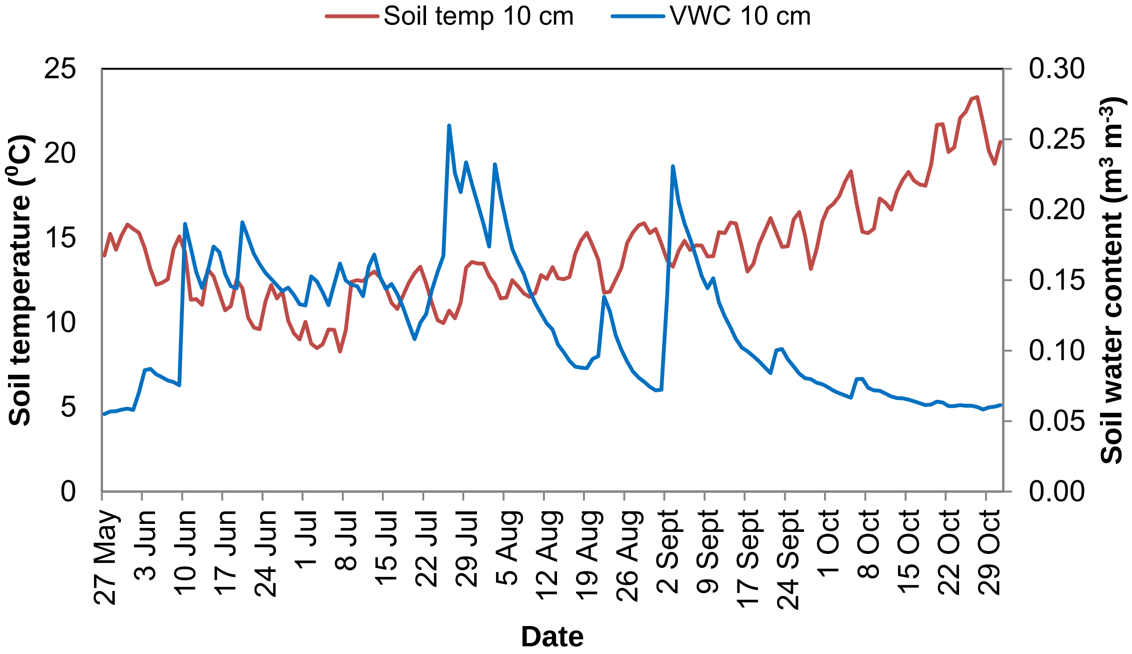

Figure 3.6 Volumetric soil water content (VWC, m^3 m^{-3}) and soil temperature (ºC) at a 10 cm depth at Tygerhoek 2016.

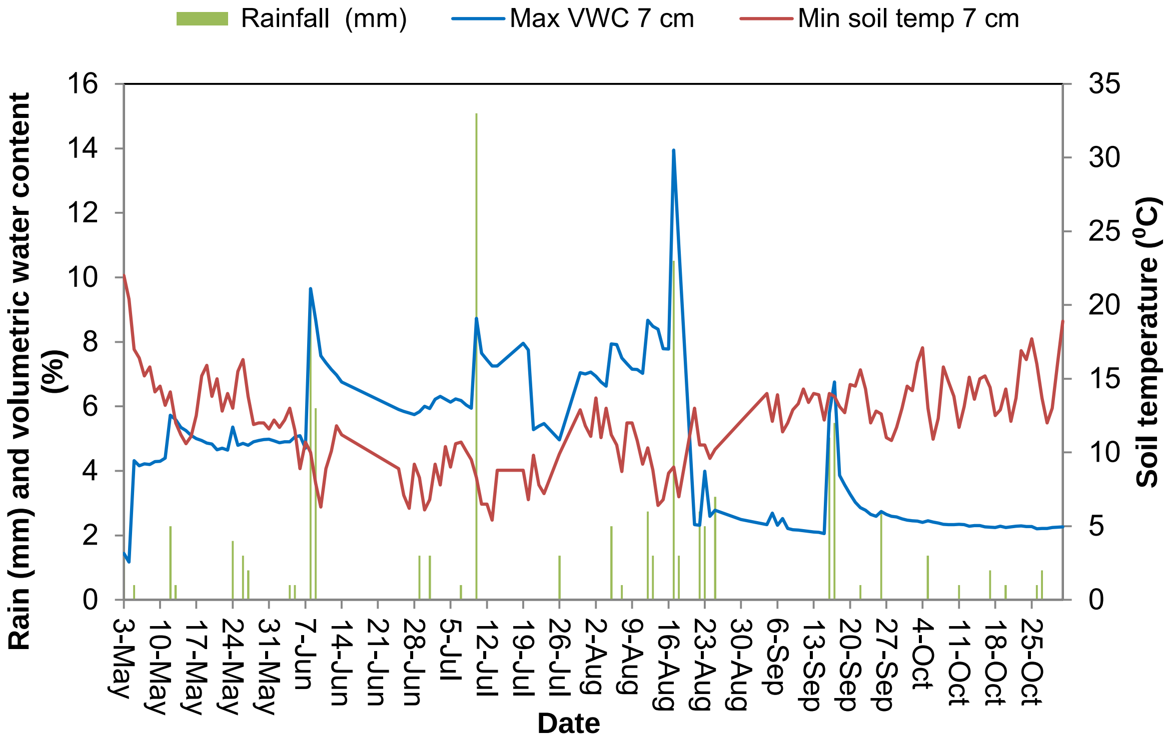

Figure 3.7 Rainfall (mm), maximum volumetric soil water content (VWC, %) and minimum soil temperature (ºC) at a 7 cm depth at Riversdale 2017.

3.2.3 *Langgewens (Moorreesburg)*

During the 2016 season, Langgewens experienced an abnormally dry May with only 6.4 mm measured which is much lower than the long term rainfall average for May (20.8 mm) (Figure 3.8). From June to September rainfall measured was similar to long term rainfall data. Langgewens experienced a dry 2017 growing season compared to 2016, receiving below average rainfall from April to September. Total rainfall measured from April until September amounted to 170 mm, which is below the long-term average rainfall of 315 mm for the same period. Due to faulty data logger, only the rainfall and ambient temperature data were recorded for Langgewens during 2016 and 2017 (Figure 3.9 and Figure 3.10).

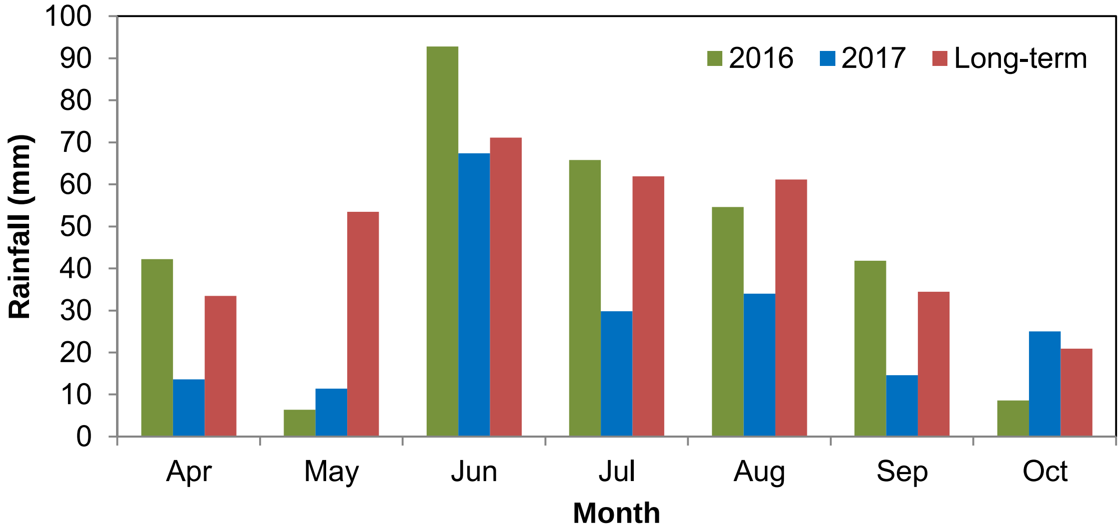

Figure 3.8 Langgewens monthly rainfall recorded during 2016, 2017 and long-term rainfall data.

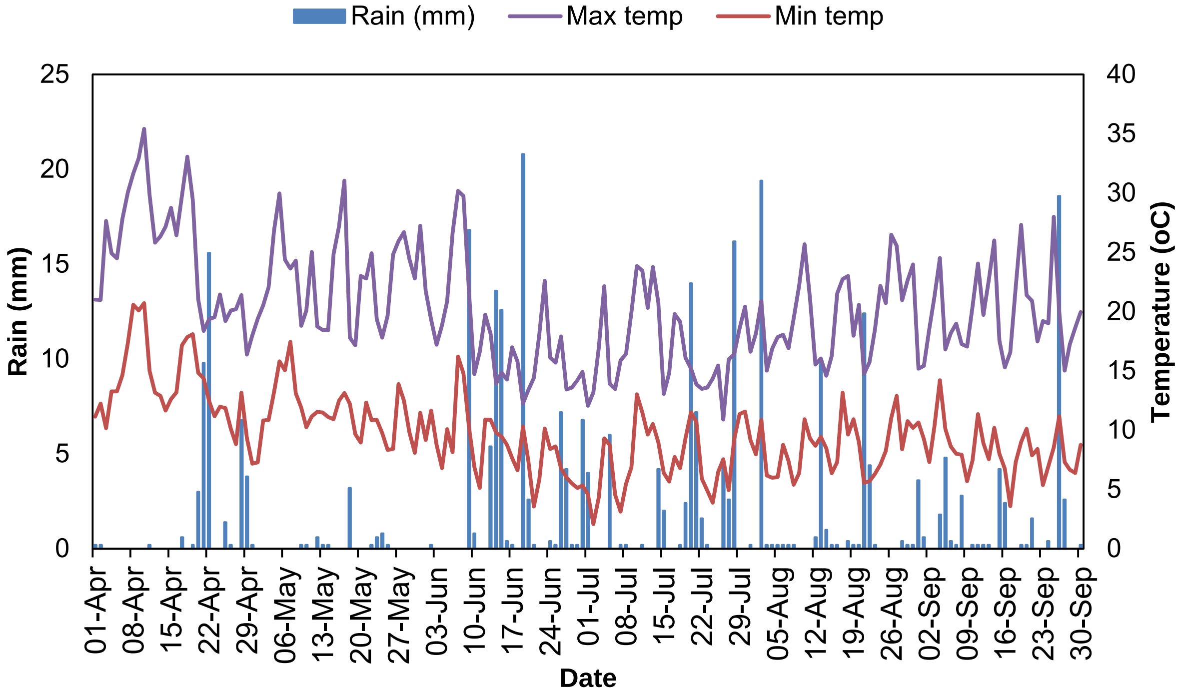

Figure 3.9 Rainfall (mm), maximum and minimum air temperatures (°C) at Langgewens 2016.

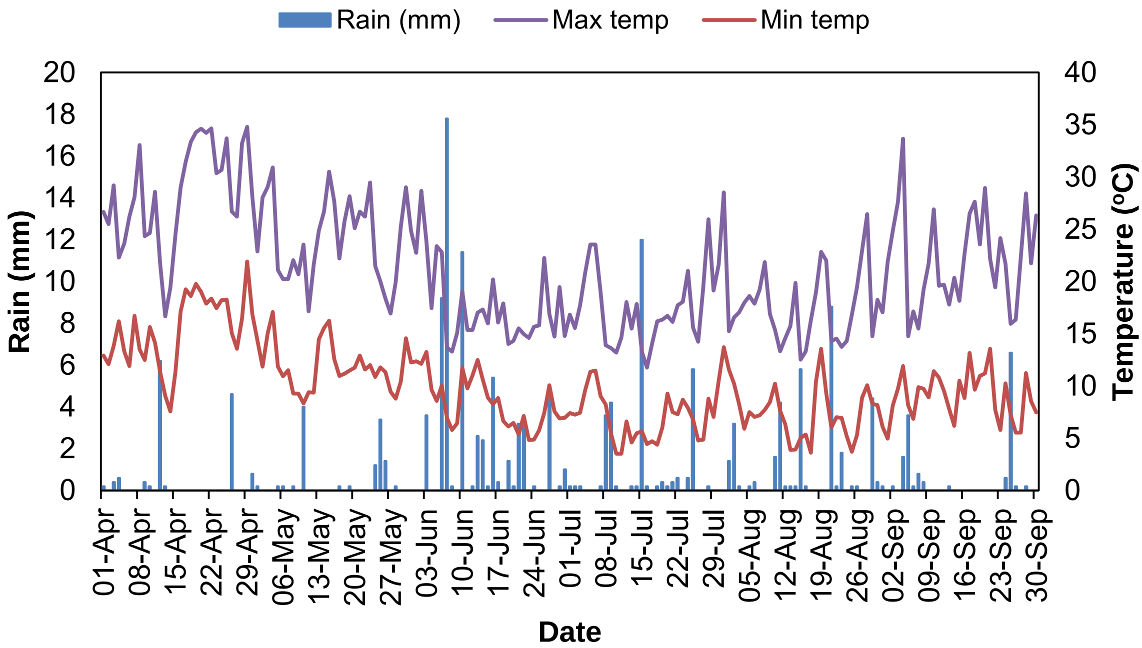

Figure 3.10 Rainfall (mm), maximum and minimum air temperatures (°C) at Langgewens 2017.

3.2.4 *Nuhoop (Porterville)*

Porterville experienced a very dry 2017 growing season with much lower rainfall recorded compared to long-term rainfall for the same period. Only 142 mm rain was recorded for May until October 2017, which is very low when compared to the long-term average of 473 mm for the same period (Figure 3.11). Rainfall, VWC and soil temperature can be seen in Figure 3.12 at Porterville 2017.

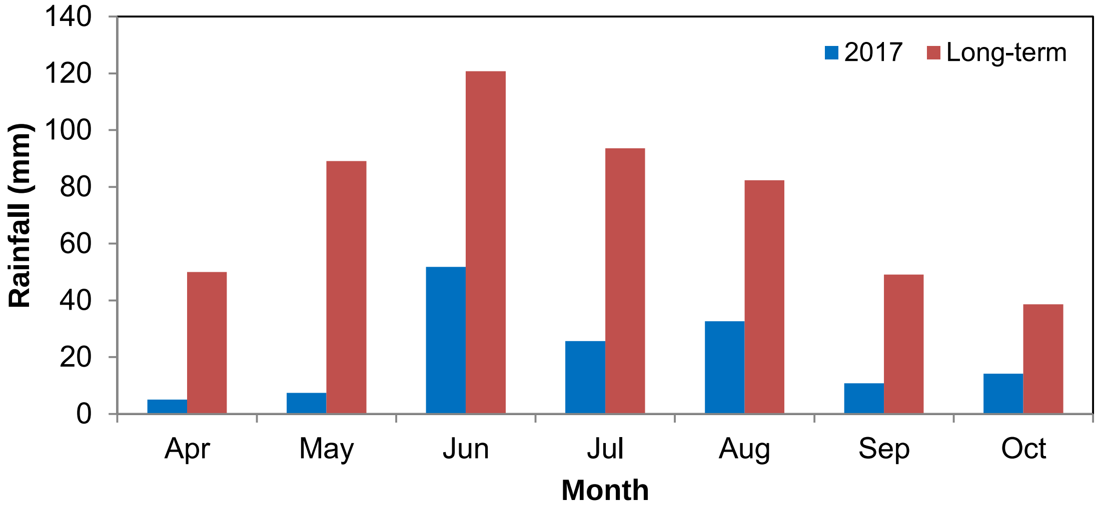

Figure 3.11 May to October monthly rainfall recorded during 2017 and long-term rainfall at Porterville.

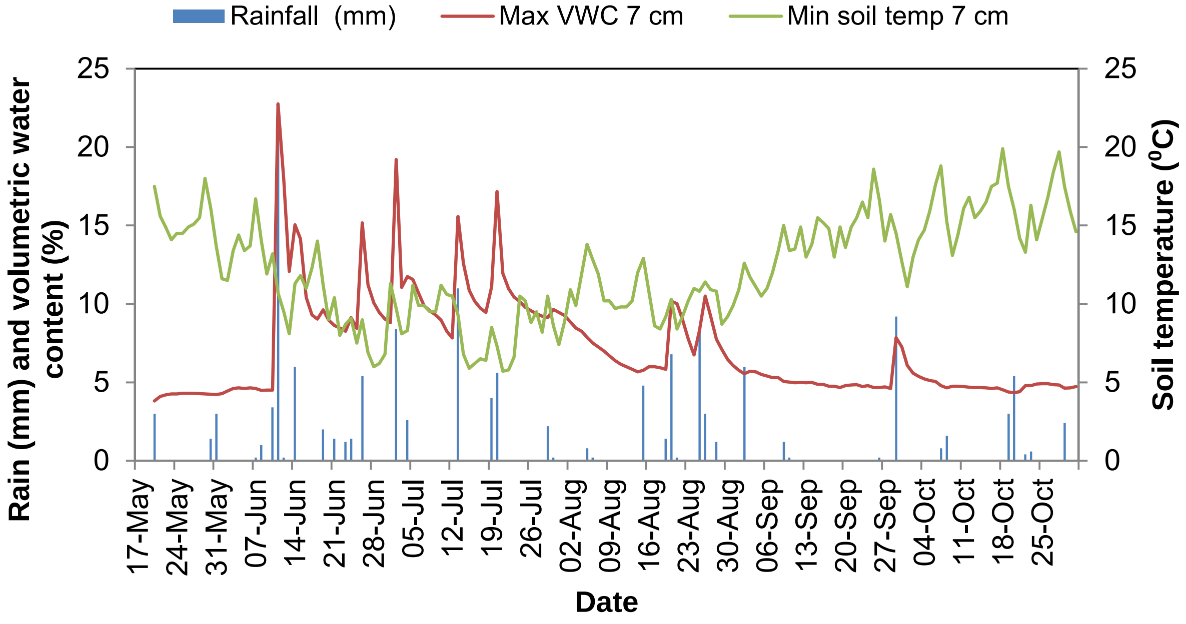

Figure 3.12 Rainfall (mm), maximum volumetric soil water content (VWC, %) and minimum soil temperature (ºC) at a 7 cm depth at Porterville 2017.

3.2.5 *Klipvlei (Darling)*

Darling has a long-term average rainfall of 418 mm year^{-1}. Darling experienced a relative dry period during May at the beginning of the growing season (Figure 3.13). Rainfall was well distributed between June and September 2016. Rainfall, VWC and soil temperature can be seen in Figure 3.14 at Darling 2016.

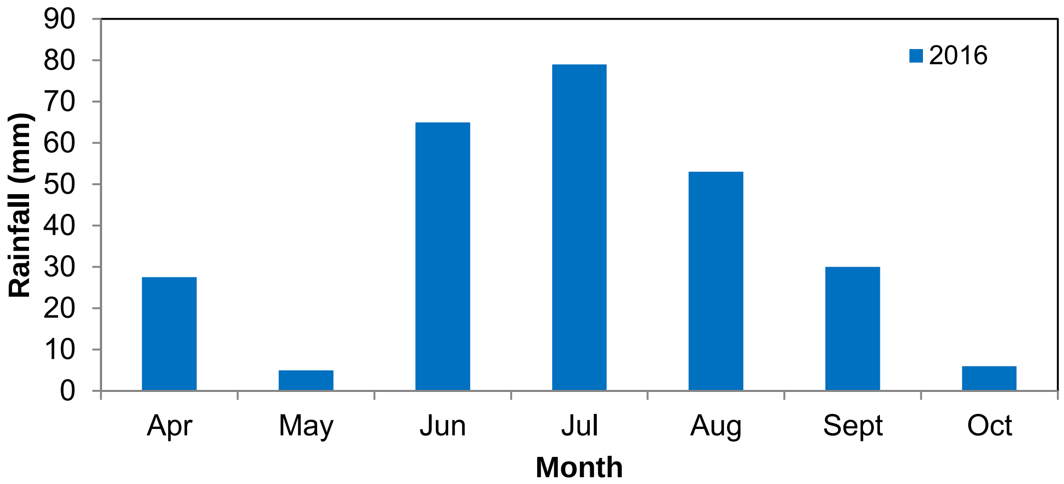

Figure 3.13 May to October 2016 monthly rainfall recorded and long-term rainfall at Darling.

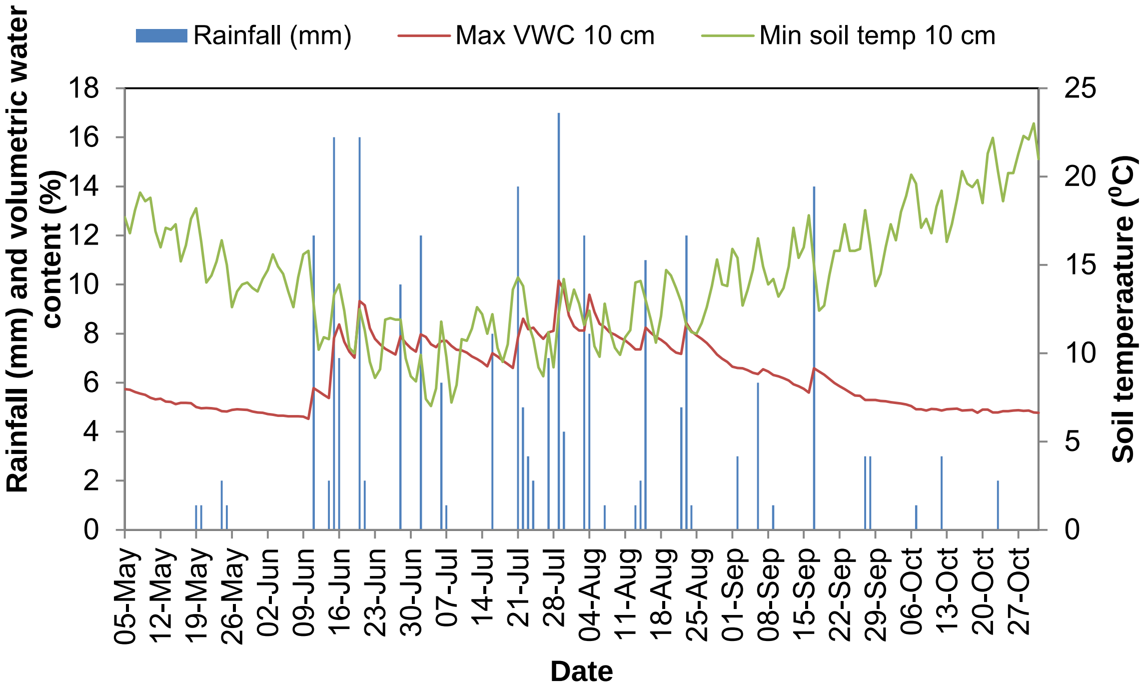

Figure 3.14 Rainfall (mm), maximum volumetric soil water content (VWC, %) and minimum soil temperature (ºC) at a 10 cm depth at Darling 2016.

3.2.6 *Rainfall and soil moisture between pre-topdress and post-topdress soil sampling events*

Table 3.1 Summarises total rainfall and average maximum VWC recorded at a 15 cm depth. Due to faulty data loggers, all data was not available for publishing. The total rainfall (mm) and average maximum volumetric water content (% or m^3 m^{-3}) of the soil, at a depth of 15 cm, between pre- and post topdress soil sampling events at Riversdale, Tygerhoek, Langgewens, Porterville and Darling 2016 and 2017

	2016		2017	
Site	**Rain (mm)**	**VWC Max**	**Rain (mm)**	**VWC Max**
Riversdale	*	*	23.0	6.0%
Tygerhoek	*	0.15 m^3 m^{-3}	15.0	8.3%
Langgewens	29.4	*	11.4	*
Porterville	43.0	12.2%	5.8	6.3%
Darling	55.0	7.3%	4.2	3.8%

*No data collected

3.3 Soil

3.3.1 *Uitkyk (Riversdale)*

Riversdale has shallow to medium deep sandy loam soils with a red-grey colour derived from marine sediments and bokkeveld shales. Soil forms dominant at Riversdale included Klapmuts, Glenrosa and Swartland (Soil Classification Working Group 1991).

3.3.2 *Tygerhoek (Riviersonderend)*

Tygerhoek's soil is characterised as poorly developed, shallow shale-derived soils with a high coarse fragment proportion. Oakleaf, Glenrosa and Swartland are the dominant soils forms found at Tygerhoek (Soil Classification Working Group 1991).

3.3.3 *Langgewens (Moorreesburg)*

Mostly grey shallow and medium deep soils are found at Langgewens. Soils are sandy loam shale-derived with a high coarse fragment. The dominant soil forms at Langgewens are Oakleaf, Swartland, Glenrosa and Klapmuts (Soil Classification Working Group 1991).

3.3.4 *Nuhoop (Porterville)*

Porterville has deep reddish coloured clay loam soils which are developed on old pre-weather that are acid. About 25% of the area consists of termite mounds called *heuweltjies* with medium deep to shallow neutral soils. Soil forms dominant at Porterville include Bainsvlei and Bloemendal (Soil Classification Working Group 1991).

3.3.5 *Klipvlei (Darling)*

Darling has medium deep sandy soils with grey to red colour. These soils have a relatively low carbon- and clay content compared to the other research sites. The dominant soil form at Darling is Namib (Soil Classification Working Group 1991).

3.3.6 *Soil analyses*

During March 2016 and 2017 (prior to planting), soil samples were collected to a depth of 300 mm (in one increment) and analysed to determine the soil fertility status. Soil samples were analysed using standard procedures described by the Non-affiliated Soil Analysis Work Committee (1990) as specified below. The results of the soil analyses are summarized in Tables 3.2 to 3.5.

Methods used in soil analysis:

- Potassium chloride (KCl) method to determine soil pH
- Citric acid extract to determine macro nutrients potassium (K), calcium (Ca) and magnesium (Mg)
- Ammonium EDTA extract to determine copper (Cu), zinc (Zn) and manganese (Mn)
- Calcium chloride extract to determine boron (B)
- Walkley-Black method to determine organic carbon (C)
- Olsen method to determine phosphorus (P)

Table 3.2 Chemical soil analyses of samples taken to a depth of 300 mm at Darling, Langgewens, Porterville, Riversdale and Tygerhoek March 2016. Soil samples analysed for C and N content using a Leco TruspecR analyser

Chemical analysis	Darling	Langgewens	Porterville	Riversdale	Tygerhoek
pH (KCl)	5.2	5.3	5.1	5.8	5.8
Resistance (ohm)	1525	673	355	1023	351
Ca (mg kg^{-1})	219.0	596.0	462.0	854.0	927.0
Mg (mg kg^{-1})	47.4	83.7	107.4	119.5	227.7
Na (mg kg^{-1})	16.5	23.5	74.0	33.7	194.0
K (mg kg^{-1})	33.0	181.5	152.5	244.3	192.5
S (mg kg^{-1})	4.6	13.2	13.0	6.0	11.2
P (mg kg^{-1})	53.5	48.3	65.5	31.0	24.8
CEC (cmol$_c$ kg^{-1})	2.1	4.7	4.7	6.1	8.0
Cu (mg kg^{-1})	1.9	1.5	3.3	0.8	1.4
Zn (mg kg^{-1})	1.5	1.7	2.8	0.9	1.5
Mn (mg kg^{-1})	5.4	118.1	405.1	52.5	119.4
B (mg kg^{-1})	0.1	0.3	0.6	0.4	0.9
C (%)	0.4	0.8	0.6	0.9	1.2
C:N Ratio	9.5	7.1	6.0	6.6	6.1

Table 3.3 Chemical soil analyses of samples taken to a depth of 300 mm at Darling, Langgewens, Porterville, Riversdale and Tygerhoek March 2017

Chemical analysis	Darling	Langgewens	Porterville	Riversdale	Tygerhoek
pH (KCl)	4.7	5.4	5.3	5.3	5.7
Resistance (ohm)	1510	843	620	703	560
Ca (mg kg^{-1})	144.0	833.0	508.0	837.3	979.0
Mg (mg kg^{-1})	51.6	108.9	165.6	126.0	221.7
Na (mg kg^{-1})	23.0	22.3	76.0	42.3	141.3
K (mg kg^{-1})	45.0	141.8	70.0	200.3	134.0
S (mg kg^{-1})	7.7	11.3	8.4	9.5	8.7
P (mg kg^{-1})	55.0	80.8	48.0	40.3	26.5
CEC ($cmol_c$ kg^{-1})	1.7	5.8	5.0	6.6	7.7
Cu (mg kg^{-1})	0.5	1.3	1.3	0.6	0.8
Zn (mg kg^{-1})	1.3	2.0	1.6	1.0	1.3
Mn (mg kg^{-1})	3.2	88.0	157.7	46.3	59.8
B (mg kg^{-1})	0.1	0.4	0.2	0.3	0.6
C (%)	0.2	1.0	0.9	1.0	1.2
C:N Ratio	8.3	15.1	13.0	10.1	14.5

Table 3.4 Physical soil properties in samples taken to a depth of 300 mm at Darling, Langgewens, Porterville, Riversdale and Tygerhoek 2016. The hydrometer method (using sodium hexametaphosphate) was used to determine particle size

Locality	Sand (%)			Silt (%)	Clay (%)	Stone (%)
	Coarse	Medium	Fine			
Darling	38.0	24.5	29.5	4.0	4.0	4.0
Langgewens	20.8	7.6	38.5	10.5	22.5	57.0
Porterville	11.5	9.5	45.0	18.0	16.0	22.0
Riversdale	30.7	13.5	27.0	15.3	17.3	71.0
Tygerhoek	23.5	13.5	17.3	17.0	28.8	51.5

Table 3.5 Physical soil properties in samples taken to depth of 300 mm at Darling, Langgewens, Porterville, Riversdale and Tygerhoek 2017

Locality	**Sand (%)**			**Silt (%)**	**Clay (%)**	**Stone (%)**
	Coarse	**Medium**	**Fine**			
Darling	33.0	25.0	22.0	12.0	8.0	2.0
Langgewens	19.3	8.8	40.0	22.0	10.0	41.0
Porterville	20.0	26.0	22.0	18.0	14.0	35.0
Riversdale	25.3	8.7	36.0	19.3	10.7	43.0
Tygerhoek	19.0	7.3	31.8	28.5	13.5	44.0

3.4 Experimental design and treatments

Three different trials were done to determine the effect of N rates, timing of N application and source of N on canola yield and oil content, whilst monitoring the effect of different N rates on soil mineral N content throughout the growing season. These results will be combined to develop optimal N management strategies at each locality. The first trial entailed varying top dressed N rate at 4 to 5 leaf stage (rosette stage). The second trial was to determine the effect of adding second N topdressing at stem elongation to the first topdressing at 4 to 5 leaf stage (above-mentioned treatments). This second N topdressing was applied as a foliar UAN application. The third trial was done to evaluate five different N fertiliser sources applied at site specific rates. At all experimental sites the rotation system included canola following wheat.

3.4.1 *The effect of topdress N rate on soil mineral N concentration, plant parameters, canola seed yield, oil content and N use efficiency (NUE).*

The experimental design was a randomised block design consisting of seven N top dressed rate treatments plus a control, replicated in four blocks, except for the research site at Riversdale where only three blocks were available. The seven top dress N rates included 0 kg ha^{-1}, 25 kg ha^{-1}, 50 kg ha^{-1}, 75 kg ha^{-1}, 105 kg ha^{-1}, 135 kg ha^{-1} and 165 kg ha^{-1} (Table 3.6). All treatments received 25 kg N ha^{-1} at plant except control plots. Nitrogen topdressing was applied with LAN+S (24%N; 3%S) a week before N needs increased dramatically (± 40 days after planting at 4 to 5 leaf growth stage) (Rathke et al.2006). Plot sizes were 6.3 m x 2.1 m and buffer zones were planted (without N) between treatments to prevent lateral movement of N between plots.

Table 3.6 Summary of trial one: Nitrogen treatments and their description pertaining to the N input at planting and 4 to 5 leaf stage

N at plant (kg ha^{-1})	N treatment	Top dress N rate (kg ha^{-1})	Total N input (kg ha^{-1})
0	C (control)	0	0
25	T0	0	25
25	T1	25	50
25	T2	50	75
25	T3	75	105
25	T4	105	135
25	T5	135	165
25	T6	165	190

3.4.2 ***The effect of topdress N rate plus foliar N application at stem elongation on canola seed yield and oil content.***

The second trial was done to determine the effect of an additional foliar N application (subsequent to top dressing at 4 to 5 leaf stage) at stem elongation on yield and oil content. Trial one was divided into split-plots to accommodate for the additional foliar N application of the second trial. Therefore this study had the same experimental design and plot sizes (6.3 m x 2.1 m) as trial one. All treatments received 25 kg N ha^{-1} at plant except control plots that received 0 kg N ha^{-1}. Nitrogen foliar application was applied as 20 kg N ha^{-1} UAN (32% N) plus humic acid (0.2%). Humic acid was added to N foliar application to reduce the potential for fertiliser burn on leaves. In 2016 only 10 kg ha^{-1} foliar N was applied due to application error. Foliar N treatments included 0+F kg ha^{-1}, 25+F kg ha^{-1}, 50+F kg ha^{-1}, 75+F kg ha^{-1}, 105+F kg ha^{-1}, 135+F kg ha^{-1} and 165+F kg ha^{-1} (Table 3.7).

Table 3.7 Summary of trial two: N treatments and their description pertaining to the N input at planting, 4 to 5 leaf stage and stem elongation

N at plant (kg ha^{-1})	**N treatment**	**Top dress N rate (kg ha^{-1})**	**Foliar N rate (kg ha^{-1})**		**Total N input (kg ha^{-1})**	
			2016	**2017**	**2016**	**2017**
0	C (control)	0	10	20	10	20
25	T0+F	0	10	20	35	45
25	T1+F	25	10	20	60	70
25	T2+F	50	10	20	85	95
25	T3+F	75	10	20	110	120
25	T4+F	105	10	20	140	150
25	T5+F	135	10	20	170	180
25	T6+F	165	10	20	200	210

3.4.3 *The effect of N source fertiliser on plant parameters, canola seed yield and oil content.*

Nitrogen source plots were also laid out as a complete randomised block design and replicated four times, except at Riversdale where only three replications were possible. Different N sources evaluated included limestone ammonium nitrate (LAN, 28% N), ammonium sulphate (AMS, 21% N, 24% S), LAN + S (24% N, 3% S), urea (46% N) and urea + urease inhibitor (46% N). All plots received 25 kg N ha^{-1} at planting and N top dressing was applied at 4 to 5 leaf stage (same as study one and two). Nitrogen rates applied were based on current recommendations for canola at each locality (Table 3.8). Plot sizes were 9 m x 2.1 m with buffer zones planted between plots.

Table 3.8 Topdress N rate (kg ha^{-1}) of N source treatments at each specific locality during 2016 and 2017

Site	Top dress N rate (kg ha^{-1})
Riversdale	45
Tygerhoek	68
Langgewens	70
Porterville	55
Darling	53

3.5 Crop management

3.5.1 *Pre-plant activities*

Fields were sprayed, if necessary, with a non-selective herbicide (paraquat) before planting to ensure a weed free seedbed at planting. Plots were also measured and marked to ensure accurate planting and collection of soil samples at each plot. Throughout growing season all crops were managed according to best practices for each site.

3.5.2 *Activities at planting*

A no-till tine planter with knife-point openers (300 mm row-spacing) were used to plant canola at Langgewens, Darling and Porterville. At Riversdale and Tygerhoek, a double disc planter (175 mm row-spacing) was used to plant canola. Different planters used between sites were due to practical and logistical reasons.

Each topdressed N rate and N source plot received a total of 25 kg N ha^{-1} at planting. Only 15 kg ha^{-1} NPK fertiliser, 1:1:1 (33) + S, were band placed with the planter and 10 kg N ha^{-1} 1:0:0 (24.5) + S were broadcasted by hand. During 2017, fertiliser N banded with disc planter was reduced to 5 kg N ha^{-1} NPK fertiliser, 1:1:1 (33) + S, to reduce seed burn and 20 kg N ha^{-1} 1:1:1 (33) + S, were broad casted by hand over plots. Control plots received 15 kg P ha^{-1} (single superphosphate, 8.75% P) during planting to compensate for the P applied in fertiliser mix for N treatment plots. To ensure sufficient S supply 300 kg ha^{-1} gypsum was applied before plant at all sites. During 2017 Riversdale was replanted on 19-Jun and Tygerhoek on 05-Jun due to poor seedling emergence following the dry period after the first planting date.

Table 3.9 Planting dates at each locality for 2016 and 2017

Locality	Planting dates	
	2016	2017
Riversdale	27-Apr	26-Apr
Tygerhoek	03-May	03-May
Langgewens	10-May	17-May
Porterville	21-Apr	16-May
Darling	21-Apr	18-May

3.6 Data collection

3.6.1 *Soil mineral N*

Soil mineral N content (mg kg^{-1}) of each N top-dress treatment combination was monitored by collecting soil samples to depth of 300 mm at planting, before top-dress, 10 to 14 days post topdress and after harvesting. Soil samples were oven dried at 40°C for at least 48 hours and sieved (2 mm). Only pre-plant soil samples were analysed for total C and N content (%) and C/N ratio. Soil samples were analysed for C and N content by using a Leco TruspecR analyser. The hydrometer method (using sodium hexametaphosphate) was used to determine particle size (physical properties) (ALASA 2004).

Total NH_4^+ and NO_3^- concentrations in soil were extracted from soil samples with a 1N KCl solution. A SEAL AutoAnalyzer 3 was used to determine ammonium content colorimetrically after reaction with a sodium salicylate, sodium nitroprusside and sodium hypochlorite solution. This solution was buffered at a pH of 12.8 to 13.0. A SEAL AutoAnalyzer 3 was also used to determine nitrate concentration. This was done through reduction of NO_3^- to NO_2^- using a copper-cadmium reduction column, where after the nitrate reacted with sulfanilamide under acidic conditions, using N-1-naphthylethylenediamine dihydrochloride (ALASA 2004)

3.6.2 *Crop development*

Plant population after establishment was determined three to four weeks after emergence. Seedlings were counted per meter row length and replicated 12 times per treatment combination.

Plant population after establishment was determined by converting the number of seedlings m^{-1} to seedlings m^{-2} using the following formulas:

- Disc planter (175 mm row spacing) = seedlings m^{-1} / 0.175
- Tine planter (300 mm row spacing) = seedlings m^{-1} / 0.3

Plant population at harvest and aboveground biomass was determined at physiological maturity (time of swathing). Plant population at harvest was calculated in the same way as mentioned above.

Aboveground biomass samples were collected by cutting three 1 m samples at soil level and replicated four times per treatment. Plants were then dried at 40ºC for three days and weighed to determine biomass yield (kg ha^{-1}). Biomass yield (kg ha^{-1}) was calculated by dividing biomass (kg) by biomass sample area for each plot.

Biomass sample area for different planters:

- Disc planter (175 mm row spacing) = 10000/(0.175 x 3)
- Tine planter (300 mm row spacing) = 10000/(300 x 3)

3.6.3 *Seed yield and oil content*

Plots were harvested with a trial harvester. After harvesting seed was cleaned and yield (kg ha^{-1}) and oil content (%) determined. Yield for each plot were calculated by dividing seed weight per plot by area of plot and converted to kg ha^{-1}. Canola seed samples were analysed for oil content by scanning each sample as duplicates in the reflectance mode between 950 - 1650 nm and recorded as log (1/R) at 2 nm increments of the near-infrared region on a Perten DA7200 Diode Array analyser (Perten Instruments AB, Huddinge, Sweden).

Approximately 100 g of each canola seed sample was packed into an open rotating sample cup with a diameter of 75 mm (AOAC Official Method 989.03) to determine oil content.

3.6.4 *Nitrogen use efficiency (NUE)*

Nitrogen use efficiency at each N rate was determined by dividing yield by total N application.

NUE = Yield (kg ha^{-1}) / (N at plant (kg ha^{-1}) + N rate (kg ha^{-1}))

3.6.5 *Statistical analyses*

The data was subjected to analysis of variance (ANOVA) using General Linear Models Procedure (PROC GLM) of SAS software (Version 9.2; SAS Institute Inc., Cary, USA). The Shapiro-Wilk test was performed to test normality of residuals (Shapiro and Wilk 1965). Fisher's least significant difference was calculated at the 5% level to compare treatment means (Ott 1998). A probability level of 5% was considered significant for all significance tests.

Chapter 4: The effect of topdress N rate on soil mineral N concentration, plant parameters, canola seed yield, oil content and N use efficiency (NUE).

4.1 Riversdale (Uitkyk)

4.1.1 *Soil mineral N concentration*

Figure 4.1 summarises the soil mineral N concentration of the soil at the different sampling events. In general, soil mineral N concentration did not differ ($p>0.05$) considerably at pre-planting, pre-top dress and post-harvest compared within sampling event in 2016 (Figure 4.1). Post topdress soil mineral N concentration increased ($p<0.05$) as topdressed N rate increased. Similar response was recorded in 2017 where there was no difference ($p>0.05$) in soil mineral N concentration between N rates at planting and pre-top dress sampling events. Post topdress soil mineral N concentration increased ($p<0.05$) as topdressed N rate increased. There was, however, no difference ($p>0.05$) in soil mineral N concentration treatments from control up to 75 kg ha^{-1} (Figure 4.2). Soil mineral N concentration recorded a weaker response to N top dressings in 2017 compared to 2016 (Figure 4.3). At harvest soil mineral N concentration recorded inconsistent results which ranged between 10 and 24 mg N kg^{-1}.

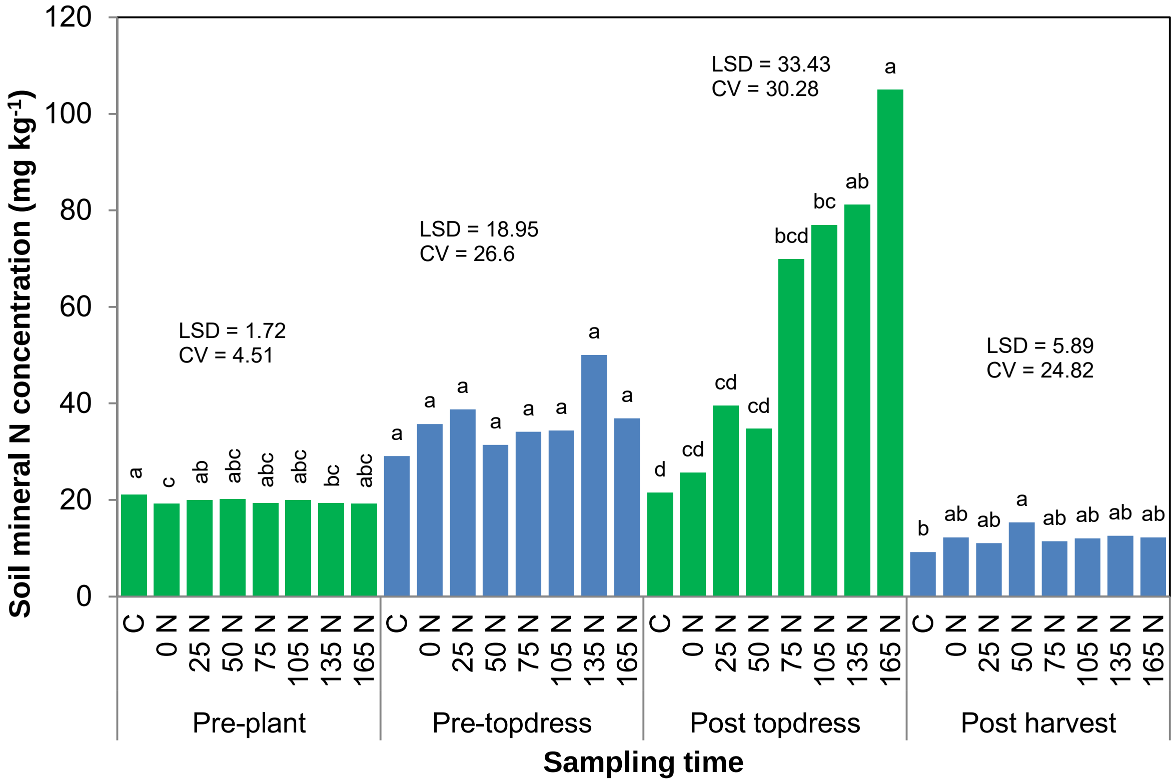

Figure 4.1 Soil mineral N concentration (mg kg^{-1}) in the 0-300 mm soil layer as influenced by topdress N rate (kg ha^{-1}) at pre-planting, pre- and post topdress N as well as residual mineral N at harvesting at Riversdale 2016. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different letters within a sampling event indicate significant differences between soil mineral N concentrations at the 5% level.

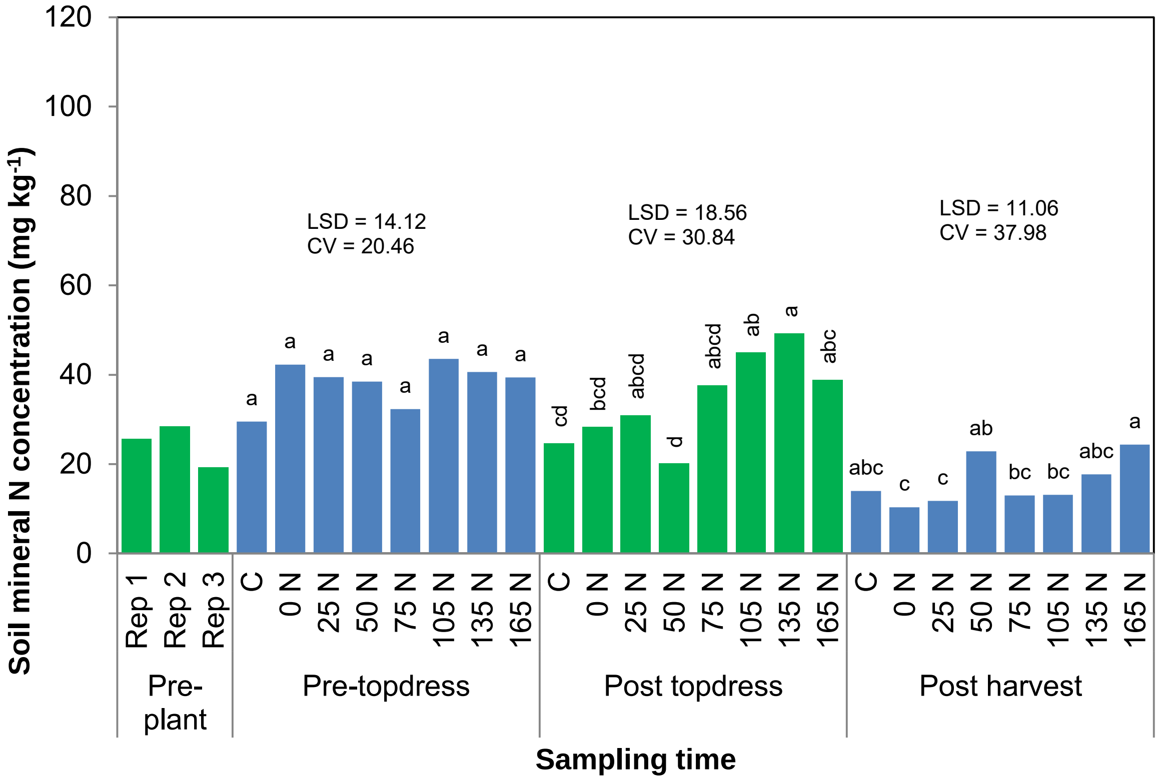

Figure 4.2 Soil mineral N concentration (mg kg^{-1}) in the 0-300 mm soil layer as influenced by topdress N rate (kg ha^{-1}) at pre-planting, pre- and post topdress N as well as residual mineral N at harvesting at Riversdale 2017. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different letters within a sampling event indicate significant differences between soil mineral N concentrations at the 5% level.

Figure 4.3 summarises the effect of topdressed N rate on soil mineral N concentration at Riversdale 2016 and 2017.

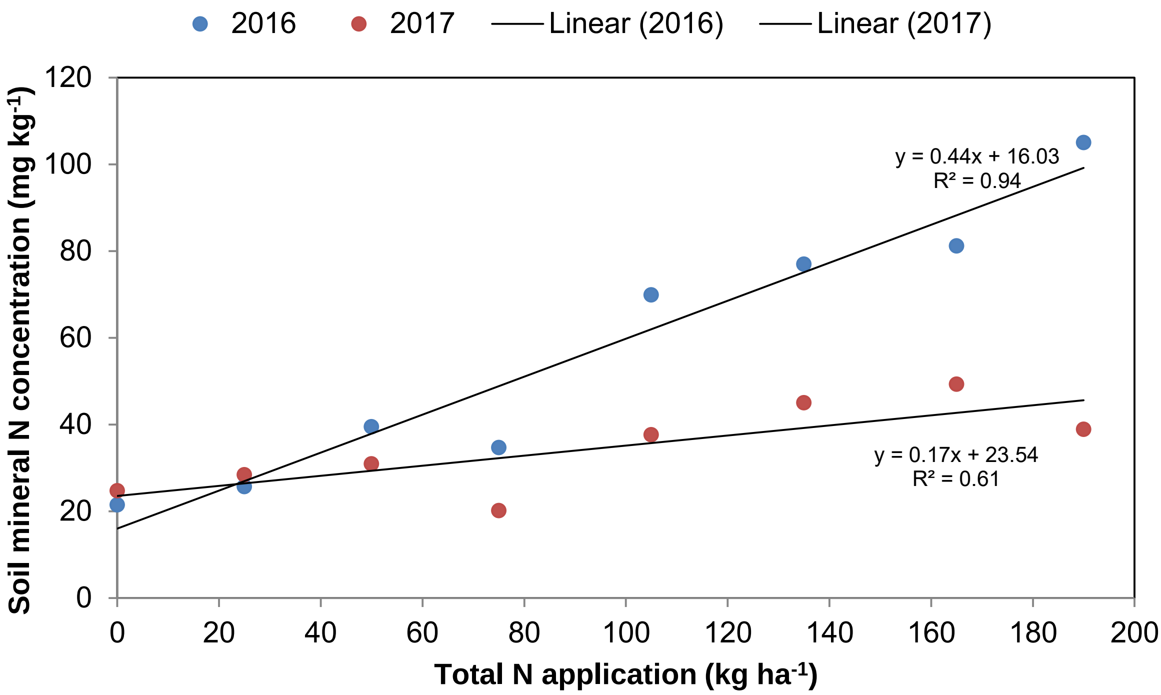

Figure 4.3 Pearson regression analysis between topdress N rate (kg ha^{-1}) and soil mineral N concentration post topdress (mg kg^{-1}) at a 300 mm depth at Riversdale 2016 and 2017.

4.1.2 *Plant parameters*

Plant population after establishment did not differ ($p>0.05$) between treatments in 2016 (Table 4.1). Although significant differences ($p<0.05$) were recorded between plant population in 2016 at harvest, results were inconsistent during 2016. Biomass production was not influenced ($p>0.05$) by N top dressed rate in 2016, except for the 165 kg N ha^{-1} treatment, that produced higher ($p<0.05$) biomass compared to the treatments varying between control to 105 kg N ha^{-1}. In 2017, plant population after establishment data were not determined due to unequal establishment because of the drought. Plant population at harvest recorded inconsistent results and no differences ($p>0.05$) were recorded on biomass production between different N rates (Table 4.2).

Table 4.1 Influence of fertiliser N treatments (kg ha^{-1}) on plant population after establishment (m^{-2}), plant population at harvest (m^{-2}) and biomass production (kg ha^{-1}) at Riversdale 2016

Treatment	**Plant population after establishment (m^{-2})**	**Plant population at harvest (m^{-2})**	**Biomass (kg ha^{-1})**
C	53 [a]	37 [a]	7444 [b]
0	36 [a]	33 [ab]	7089 [b]
25	39 [a]	32 [ab]	7222 [b]
50	38 [a]	29 [b]	7037 [b]
75	39 [a]	30 [ab]	6407 [b]
105	43 [a]	32 [ab]	6778 [b]
135	38 [a]	33 [ab]	8815 [ab]
165	38 [a]	29 [b]	10259 [a]
CV (%)	22.7	13.0	16.7
LSD (0.05)	17.0	7.8	2436.4

Means without a common letter following the value in the same column differed significantly (P = 0.05).

Table 4.2 Influence of fertiliser N treatments (kg ha^{-1}) on plant population at harvest (m^{-2}) and biomass production (kg ha^{-1}) at Riversdale 2017

Treatment	**Plant population at harvest (m^{-2})**	**Biomass (kg ha^{-1})**
C	35 [ab]	4254 [a]
0	34 [b]	6794 [a]
25	41 [ab]	6540 [a]
50	33 [b]	6032 [a]
75	36 [ab]	6984 [a]
105	49 [a]	5714 [a]
135	46 [ab]	4825 [a]
165	38 [ab]	6667 [a]
CV (%)	18.5	34.8
LSD (0.05)	14.6	3641.0

Means without a common letter following the value in the same column differed significantly (P = 0.05)

4.1.3 *Yield and oil content*

Application of N as a top dressing in 2016 resulted in higher (p<0.05) yields compared to control and 0 kg ha^{-1} treatments (Figure 4.4). Oil content in 2017 decreased (p<0.05) as top dressed N rate increased. Canola oil content decreased (p<0.05) as top dressed N rate increased. During 2017, N applied as topdressing recorded low yield response. Similar yields were recorded between N rates, except for 50 kg ha^{-1} which was higher (p<0.05) than control and 165 kg ha^{-1} (Figure 4.5). Oil content in 2017 decreased (p<0.05) as top dressed N rate increased.

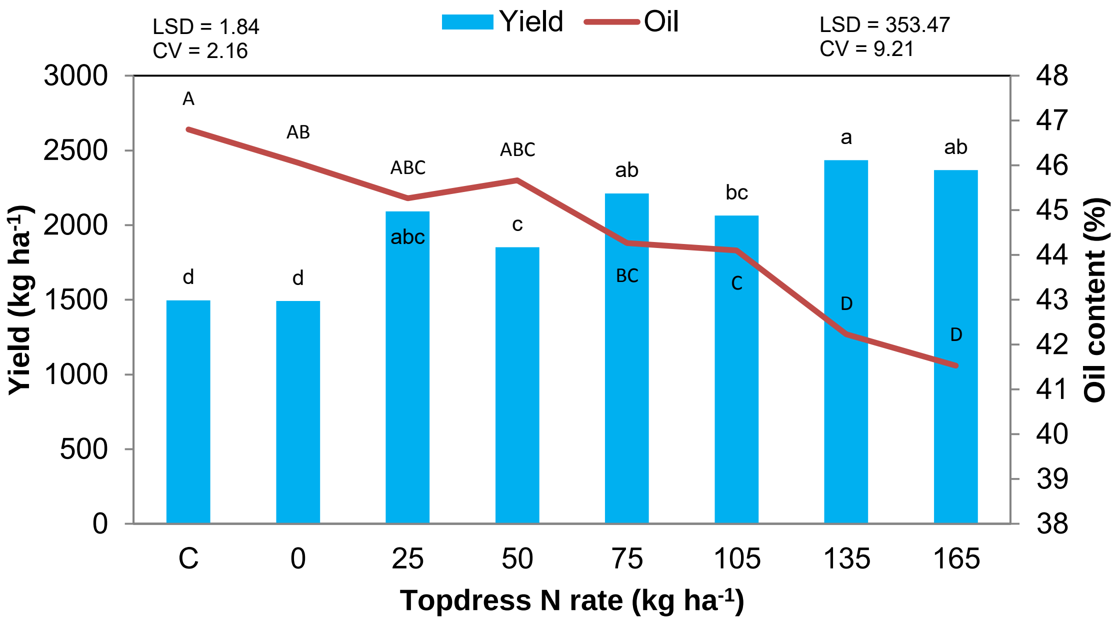

Figure 4.4 Influence of topdress N rate (kg ha^{-1}) on canola yield (kg ha^{-1}) and oil content (%) at Riversdale 2016. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = N rate topdressed in kg N ha^{-1}. Bars with different lowercase letters indicate significant differences between mean yields at a 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

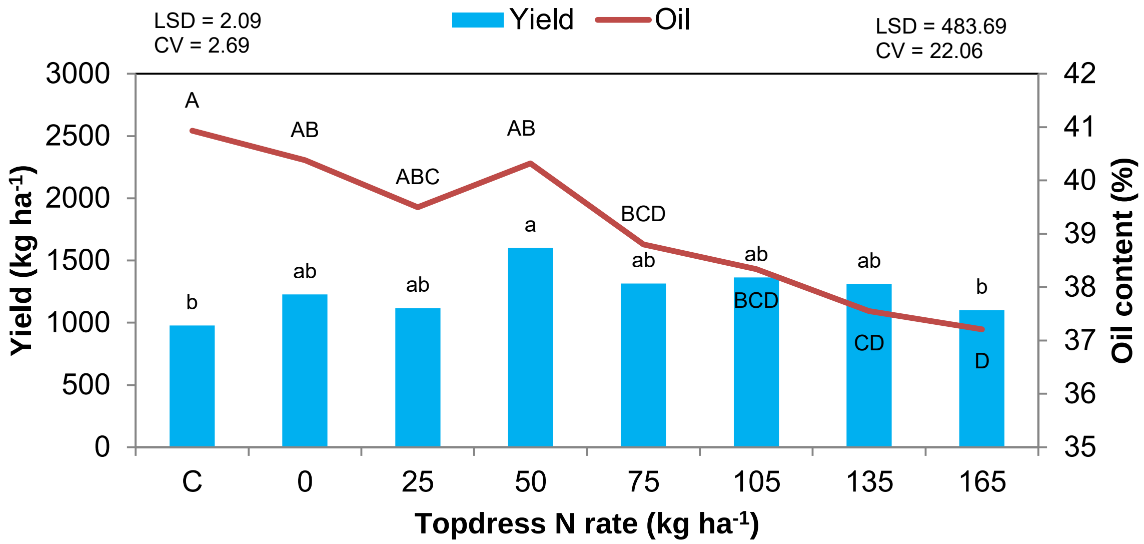

Figure 4.5 Influence of topdress N rate (kg ha^{-1}) on canola yield (kg ha^{-1}) and oil content (%) at Riversdale 2017. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = N rate top-dressed in kg N ha^{-1}. Bars with different lowercase letters indicate significant differences between mean yields at a 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

4.1.4 *Nitrogen use efficiency (NUE)*

During 2016 and 2017, NUE of canola decreased ($p<0.05$) as total N rate increased (Figure 4.6).

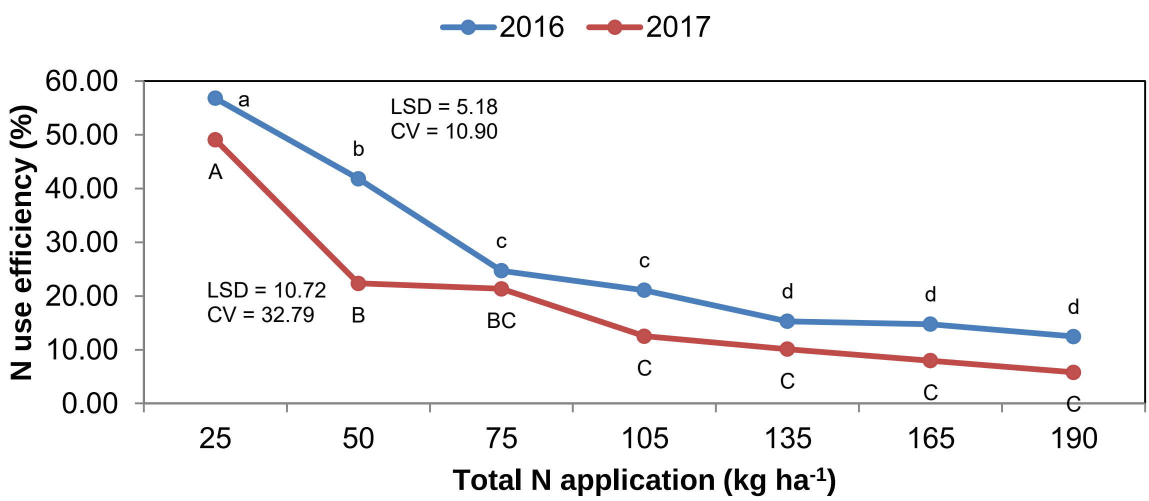

Figure 4.6 Nitrogen use efficiency (NUE) of canola as influenced by N topdress rate at Riversdale 2016 and 2017. Lines with different letters indicate significant differences between mean oil content at a 5% level, with uppercase letters for 2017 and lowercase letters for 2016 results.

4.2 Tygerhoek (Riviersonderend)

4.2.1 *Soil mineral N concentration*

In 2016 no differences ($p>0.05$) in soil mineral N concentration were recorded at pre-planting and post harvesting (Figure 4.7). Although pre-topdress differences ($p<0.05$) in soil mineral N concentration were recorded, differences were inconsistent and ranged between 44.37-65.75 mg kg^{-1}. Post topdress soil mineral N concentration followed a similar response as reported at Riversdale, namely an increase ($p<0.05$) in soil mineral N concentration as N topdressed rate increased. As expected, the highest ($p<0.05$) soil mineral N concentration was recorded at a topdress rate of 165 kg ha^{-1}, however it did not differ ($p>0.05$) from 135 kg ha^{-1}. Soil mineral N concentration did not record a big response to N topdressing at Tygerhoek in 2017 (Figure 4.8). Pre-topdress soil mineral N concentration recorded no difference ($p>0.05$) between N rates. Post topdress soil mineral N concentration increased ($p<0.05$) as topdress N rate increased. At harvest soil mineral N concentration recorded similar results between N rates, except for 105 kg ha^{-1} N rate which was higher ($p<0.05$) than C, 0 kg ha^{-1} and 75 kg ha^{-1} N rates.

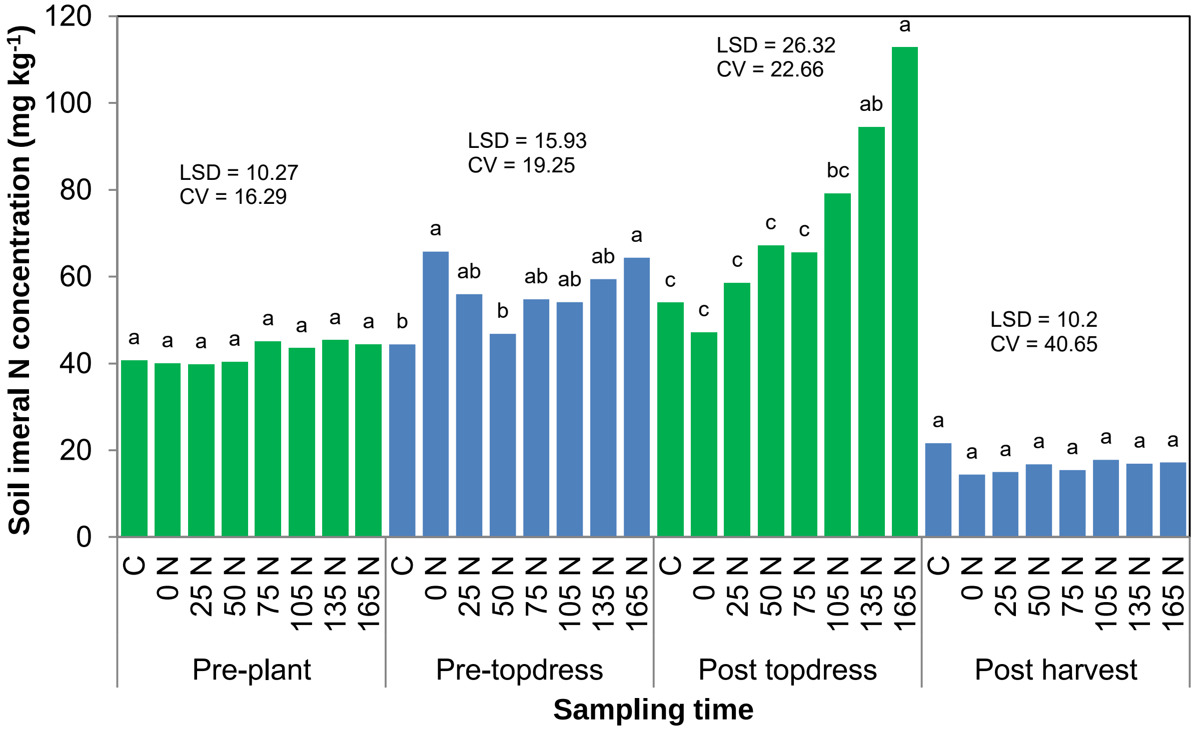

Figure 4.7 Soil mineral N concentration (mg kg^{-1}) in the 0-300 mm soil layer as influenced by topdress N rate (kg ha^{-1}) at pre-planting, pre- and post topdress N as well as residual mineral N at harvesting at Tygerhoek 2016. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different letters within a sampling event indicate significant differences between soil mineral N concentrations at the 5% level.

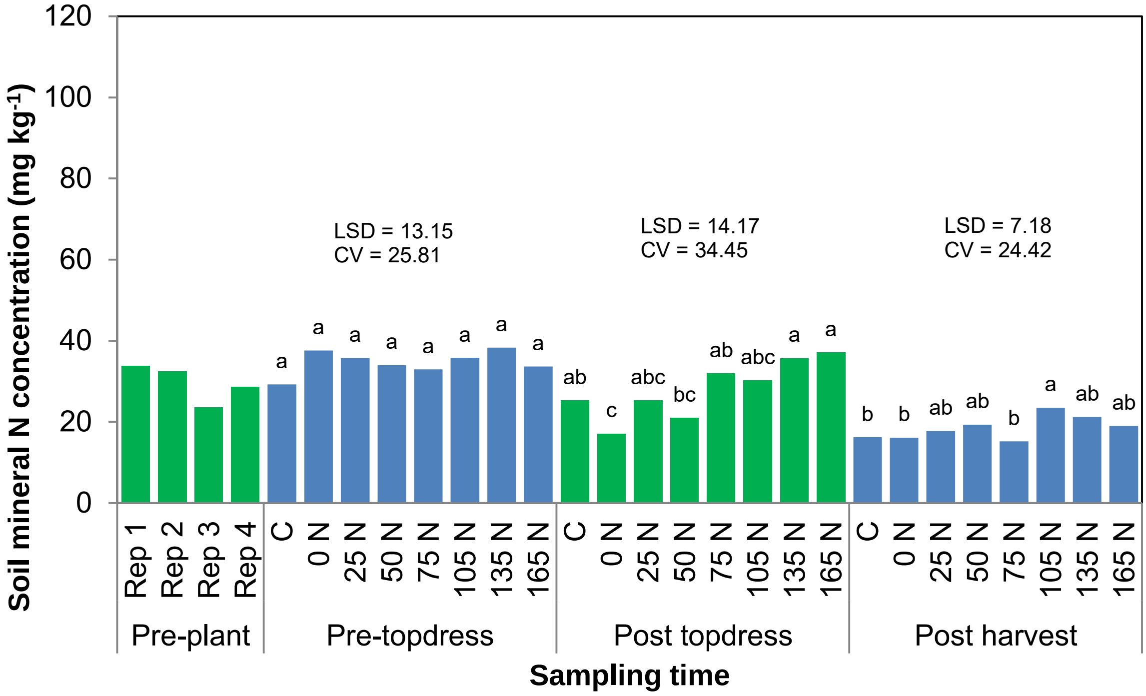

Figure 4.8 Soil mineral N concentration (mg kg^{-1}) in the 0-300 mm soil layer as influenced by topdress N rate (kg ha^{-1}) at pre-planting, pre- and post topdress N as well as residual mineral N at harvesting at Tygerhoek 2017. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different letters within a sampling event indicate significant differences between soil mineral N concentrations at the 5% level.

Figure 4.9 summarises the effect of topdressed N rate on soil mineral N concentration at Tygerhoek 2016 and 2017.

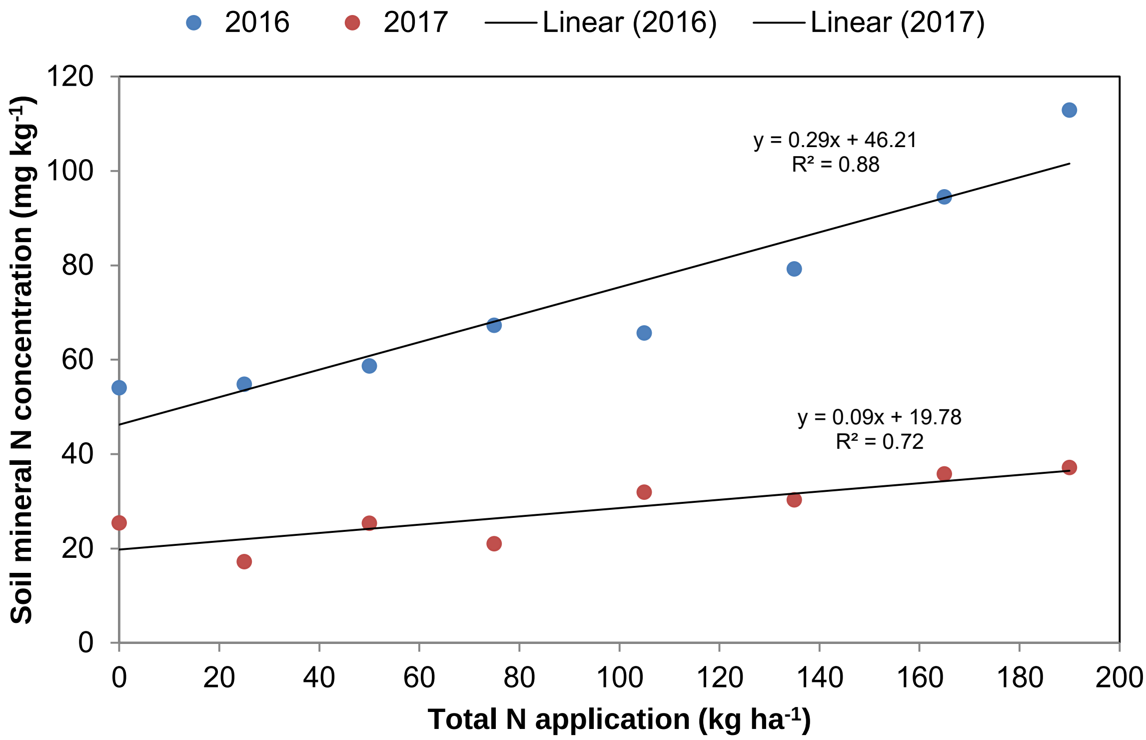

Figure 4.9 Pearson regression analysis between topdress N rate (kg ha^{-1}) and soil mineral N concentration post topdress (mg kg^{-1}) at a 300 mm depth at Tygerhoek 2016 and 2017.

4.2.2 *Plant parameters*

Topdressed N rate did not influence ($p<0.05$) plant population after establishment and plant population at harvest during 2016 and 2017. No differences ($p>0.05$) was recorded in biomass production at Tygerhoek during 2016 for the different treatments evaluated (Table 4.3). In 2017 biomass production was not determined due to poor seedling emergence, which led to high variation in canola plant sizes and would have resulted in inaccurate biomass production results.

Table 4.3 Influence of fertiliser N treatments (kg ha^{-1}) on plant population after establishment (m^{-2}), plant population at harvest (m^{-2}) and biomass prduction (kg ha^{-1}) at Tygerhoek 2016

Treatment	Plant population after establishment (m^{-2})	Plant population at harvest (m^{-2})	Biomass (kg ha^{-1})
C	32 [a]	27 [a]	7167 [a]
0	23 [a]	20 [a]	7167 [a]
25	25 [a]	25 [a]	6854 [a]
50	22 [a]	24 [a]	7521 [a]
75	30 [a]	24 [a]	6896 [a]
105	22 [a]	21 [a]	6000 [a]
135	27 [a]	20 [a]	7438 [a]
165	27 [a]	24 [a]	7000 [a]
CV (%)	35.5	27.6	25.7
LSD (0.05)	13.5	9.3	2706.6

Means without a common letter following the value in the same column differed significantly (P = 0.05).

Table 4.4 Influence of fertiliser N treatments (kg ha^{-1}) on plant population after establishment (m^{-2}) and biomass production (kg ha^{-1}) at Tygerhoek 2017

Treatment	Plant population after establishment (m^{-2})	Plant population at harvest (m^{-2})
C	67 [a]	34 [a]
0	65 [a]	27 [a]
25	67 [a]	27 [a]
50	65 [a]	27 [a]
75	63 [a]	29 [a]
105	65 [a]	39 [a]
135	66 [a]	30 [a]
165	57 [a]	31 [a]
CV (%)	14.2	26.9
LSD (0.05)	13.9	12.9

Means without a common letter following the value in the same column differed significantly (P = 0.05).

4.2.3 *Yield and Oil Content*

The control treatment produced a lower ($p<0.05$) seed yield compared to treatments that received N (Figure 4.10). Yield increased ($p<0.05$) as N topdress rate was increased, reaching a maximum response ($p<0.05$) at 25 kg ha^{-1}. In 2016 oil content did not differ ($p>0.05$) between treatments, except at 165 kg ha^{-1} which recorded lower ($p<0.05$) oil content compared to 0 kg ha^{-1} and 25 kg ha^{-1}. Yield in 2017 did not differ ($p>0.05$) between treatments, except at 135 kg ha^{-1} that was higher ($p<0.05$) than control and 105 kg ha^{-1} treatments (Figure 4.11). Oil content decreased ($p<0.05$) as N rate increased in 2017. There was however no difference ($p>0.05$) in oil content from control to topdressed N rate of 105 kg ha^{-1}.

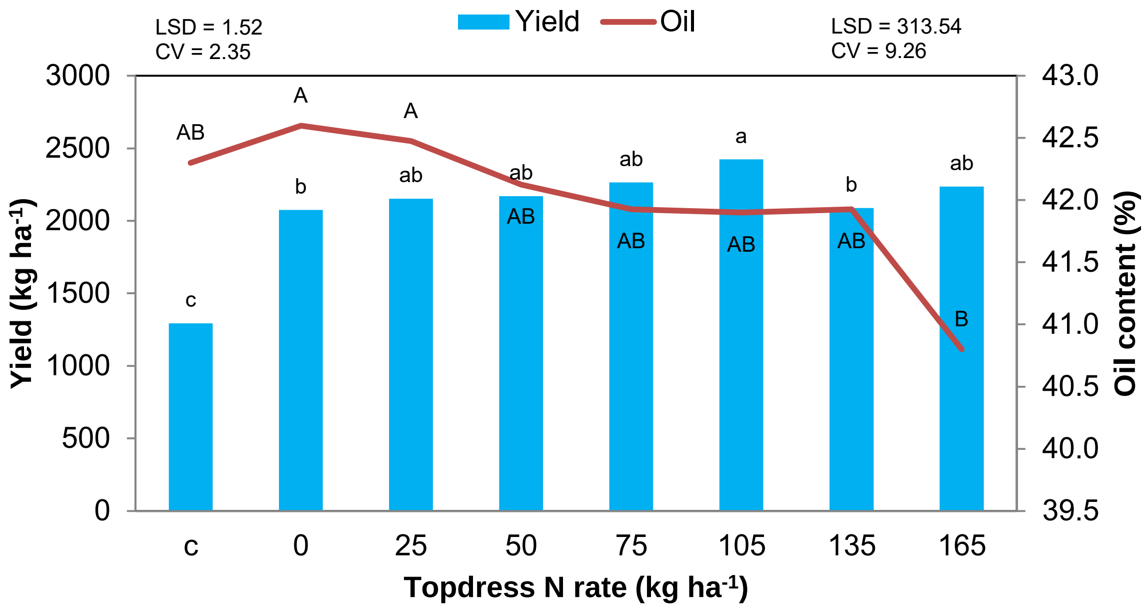

Figure 4.10 Influence of topdress N rate (kg ha^{-1}) on canola yield (kg ha^{-1}) and seed oil content (%) at Tygerhoek 2016. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different lowercase letters indicate significant differences between mean yields at a 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

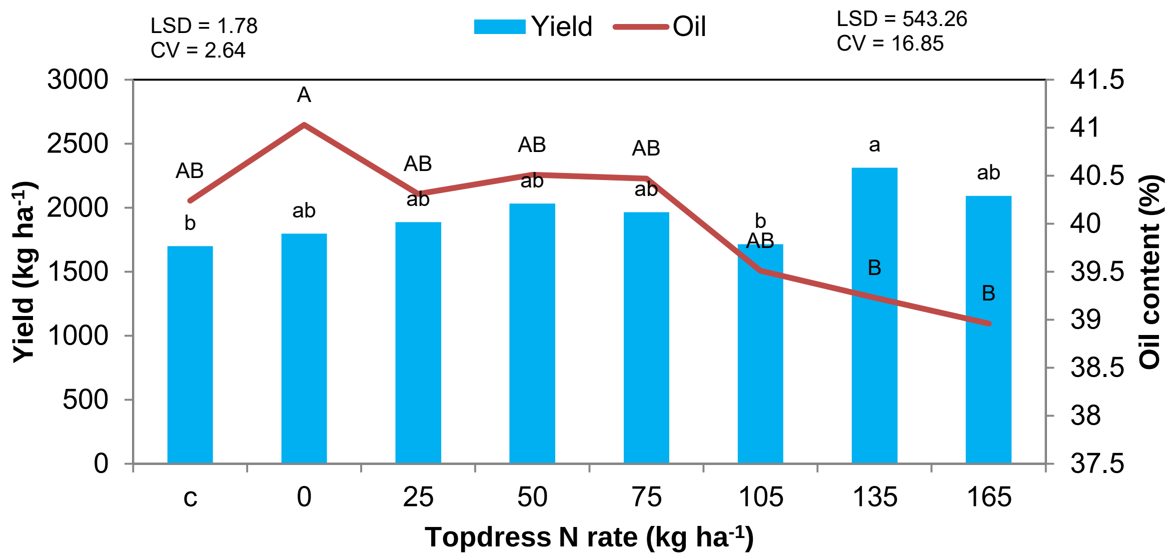

Figure 4.11 Influence of topdress N rate (kg ha^{-1}) on canola yield (kg ha^{-1}) and seed oil content (%) at Tygerhoek 2017. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different lowercase letters indicate significant differences between mean yields at a 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

4.2.4 *Nitrogen use efficiency (NUE)*

NUE decreased ($p<0.05$) as total N rate increased from 0 kg ha^{-1} to 190 kg ha^{-1} during 2016 and 2017 (Figure 4.12).

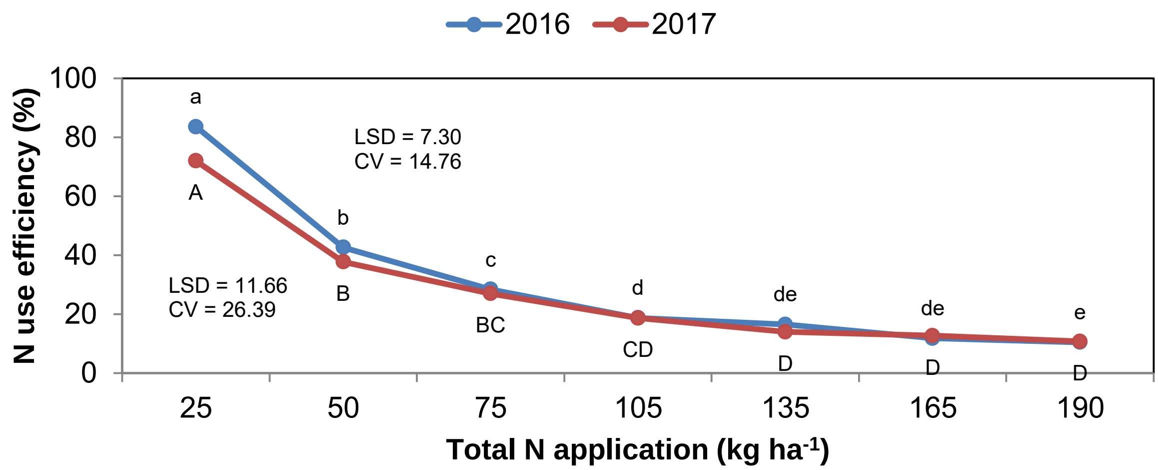

Figure 4.12 Nitrogen use efficiency (NUE) as affected by N topdress rate and distribution of N application at Tygerhoek 2016 and 2017. Lines with different letters indicate significant differences between mean oil content at a 5% level, with uppercase letters for 2017 and lowercase letters for 2016 results.

4.3 Langgewens (Moorreesburg)

4.3.1 *Soil mineral N concentration*

Soil mineral N concentration did not differ ($p>0.05$) at pre-planting and at pre-topdress sampling events in 2016 (Figure 4.13). Post topdress soil mineral N concentration increased ($p<0.05$) as topdressed N rate increased. At harvest no differences ($p>0.05$) in soil mineral N concentration was recorded, except for the 165 kg ha^{-1} treatment that resulted in higher ($p<0.05$) soil mineral N levels compared to the other topdressed N rates. Similar results were recorded in 2017 as in 2016, where the biggest differences in soil mineral N concentration was recorded at post topdress. Soil mineral N concentration reached a maximum ($p<0.05$) at 105 kg ha^{-1}, and no significant increase ($p>0.05$) was observed at higher N rates. Soil mineral N concentration recorded low response to N topdressings in 2017 (Figure 4.15). Soil mineral N concentration at post-harvest recorded no difference ($p>0.05$), except for 165 kg ha^{-1} which was higher ($p<0.05$) compared to control, 25 kg ha^{-1}, 50 kg ha^{-1}, 75 kg ha^{-1} and 105 kg ha^{-1}.

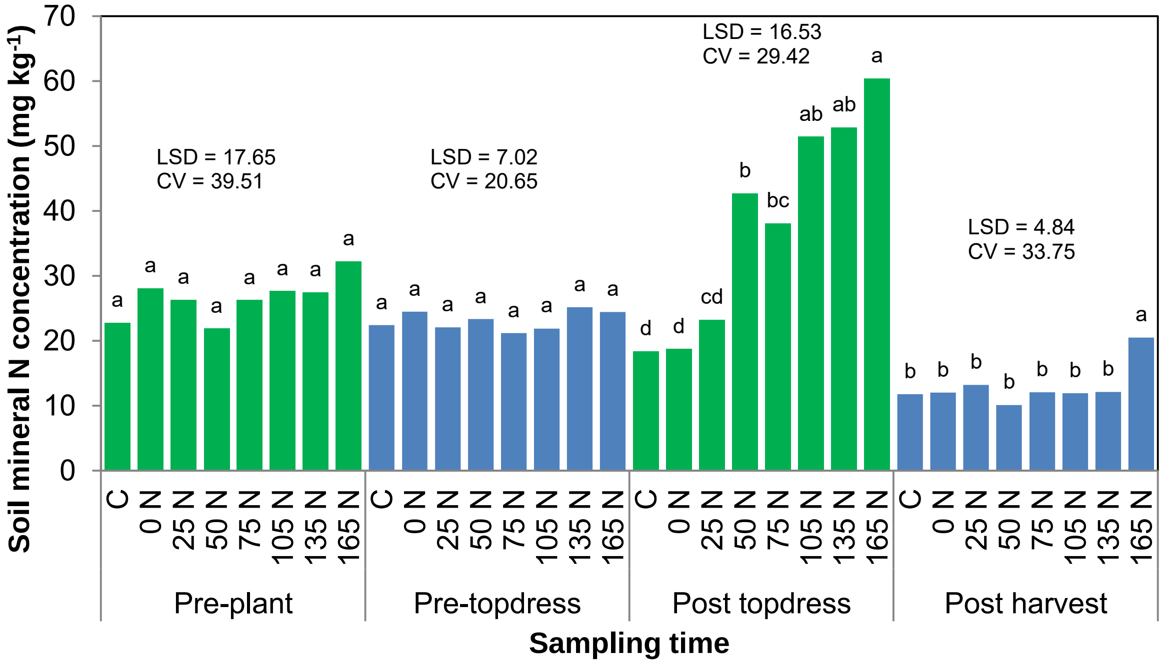

Figure 4.13 Soil mineral N concentration (mg kg^{-1}) in the 0-300 mm soil layer as influenced by topdress N rate (kg ha^{-1}) at pre-planting, pre- and post topdress N as well as residual mineral N at harvesting at Langgewens 2016. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different letters within a sampling event indicate significant differences between soil mineral N concentrations at the 5% level.

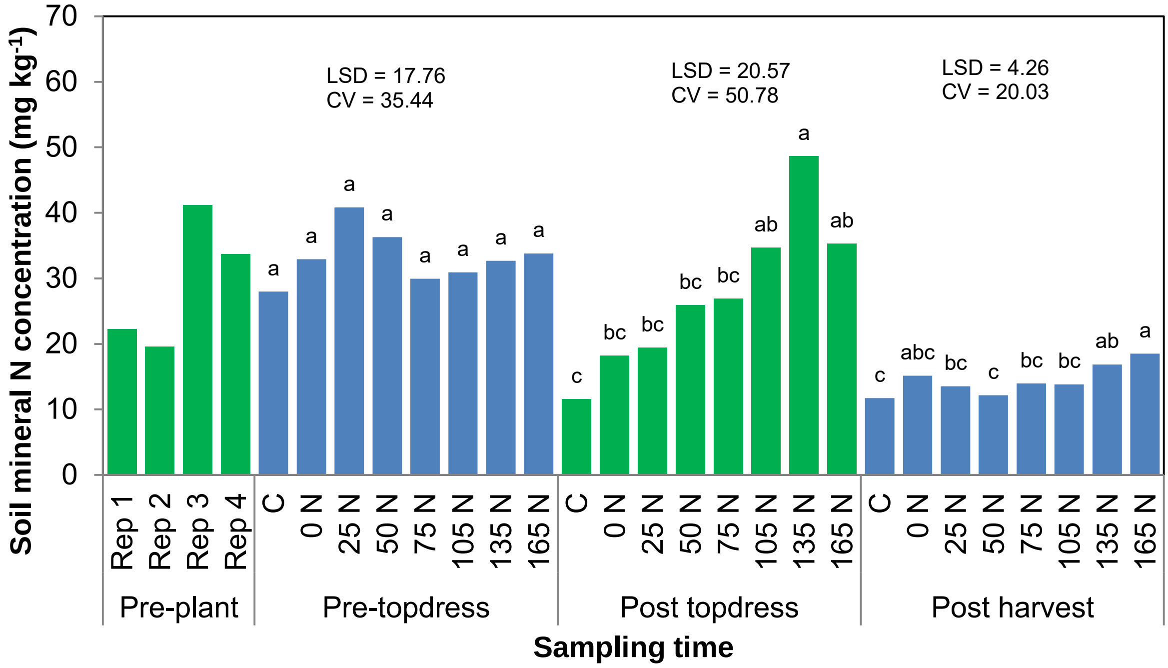

Figure 4.14 Soil mineral N concentration (mg kg^{-1}) in the 0 – 300 mm soil layer as influenced by topdress N rate (kg ha^{-1}) at pre-planting, pre- and post topdress N as well as residual mineral N at harvesting at Langgewens 2017. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different letters within a sampling event indicate significant differences between soil mineral N concentrations at the 5% level.

Figure 4.15 summarises the effect of topdressed N rate on soil mineral N concentration at Langgewens 2016 and 2017.

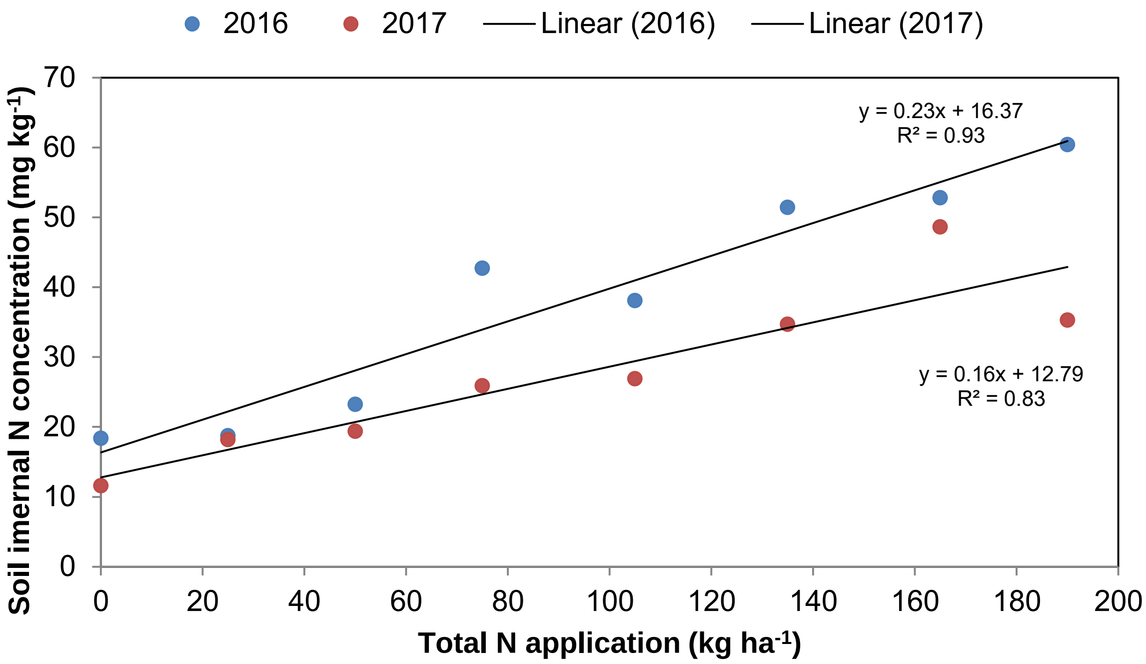

Figure 4.15 Pearson regression analysis between topdress N rate (kg ha^{-1}) and soil mineral N concentration post topdress (mg kg^{-1}) at a 300 mm depth at Langgewens 2016 and 2017.

4.3.2 *Plant parameters*

In 2016, no differnces (p>0.05) were recorded on plant population after establishment between all treatments. Differences (p<0.05) were however recorded in biomass production (Table 4.5). High N rate treatments (135 kg ha^{-1} and 165 kg ha^{-1}) resulted in mean biomass production of 9152.5 kg ha^{-1}, higher (p<0.05) than the 5611 kg ha^{-1} produced at 25 kg ha^{-1}. In 2017 control treatment recorded higher (p<0.05) plant population after establishment compared to applied N rates. Plant population at harvest recorded inconsistent resulted varying between 35 and 48 plant m^{-2}. No differences (p>0.05) were recorded in biomass production between N rates.

Table 4.5 Influence of fertiliser N treatments (kg ha^{-1}) on plant population after establishment (m^{-2}) and biomass prduction (kg ha^{-1}) at Langgewens 2016

Treatment	Plant population after establishment (m^{-2})	Biomass (kg ha^{-1})
C	35 ^{a}	7195 ^{abc}
0	31 ^{a}	7278 ^{abc}
25	36 ^{a}	5611 ^{c}
50	27 ^{a}	5722 ^{ab}
75	29 ^{a}	8167 ^{ab}
105	29 ^{a}	7333 ^{abc}
135	38 ^{a}	9333 ^{a}
165	32 ^{a}	8972 ^{a}
CV (%)	33.8	22.6
LSD (0.05)	16.3	2471.6

Means without a common letter following the value in the same column differed significantly (P = 0.05).

Table 4.6 Influence of fertiliser N treatments (kg ha^{-1}) on plant population after establishment (m^{-2}), plant population at harvest (m^{-2}) and biomass production (kg ha^{-1}) at Langgewens 2017

Treatment	Plant population after establishment (m^{-2})	Plant population at harvest (m^{-2})	Biomass (kg ha^{-1})
C	57 ^{a}	48 ^{a}	3750 ^{ab}
0	45 ^{b}	35 ^{b}	3000 ^{a}
25	48 ^{b}	35 ^{b}	3083 ^{ab}
50	45 ^{b}	35 ^{b}	5667 ^{a}
75	44 ^{b}	40 ^{ab}	5037 ^{a}
105	46 ^{b}	37 ^{ab}	4833 ^{a}
135	45 ^{b}	36 ^{b}	5037 ^{a}
165	42 ^{b}	38 ^{ab}	4778 ^{a}
CV (%)	11.6	19.9	22.0
LSD (0.05)	8.0	11.0	1713.2

Means without a common letter following the value in the same column differed significantly (P = 0.05).

4.3.3 *Yield and Oil content*

Canola yield increased (p<0.05) as N rate increased from 0 kg ha^{-1} to 105 kg ha^{-1} followed by no difference (p>0.05) in yield as N rate was further increased to 165 kg ha^{-1} at Langgewens 2016 (Figure 4.16). Canola oil content decreased (p<0.05) as N topdress rate was increased in 2016. At Langgewens in 2017, similar results were recorded as those reported for Riversdale and Tygerhoek, namely that increasing N rate did not (p>0.05) increase yield (Figure 4.17). No difference (p>0.05) in yield was recorded between control and N rate treatments. In 2017 similar oil content results were recorded as in 2016, namely that as topdressed N rate increased oil content decreased (p<0.05). Control treatment recorded higher oil content (p<0.05) than 165 kg ha^{-1} oil content.

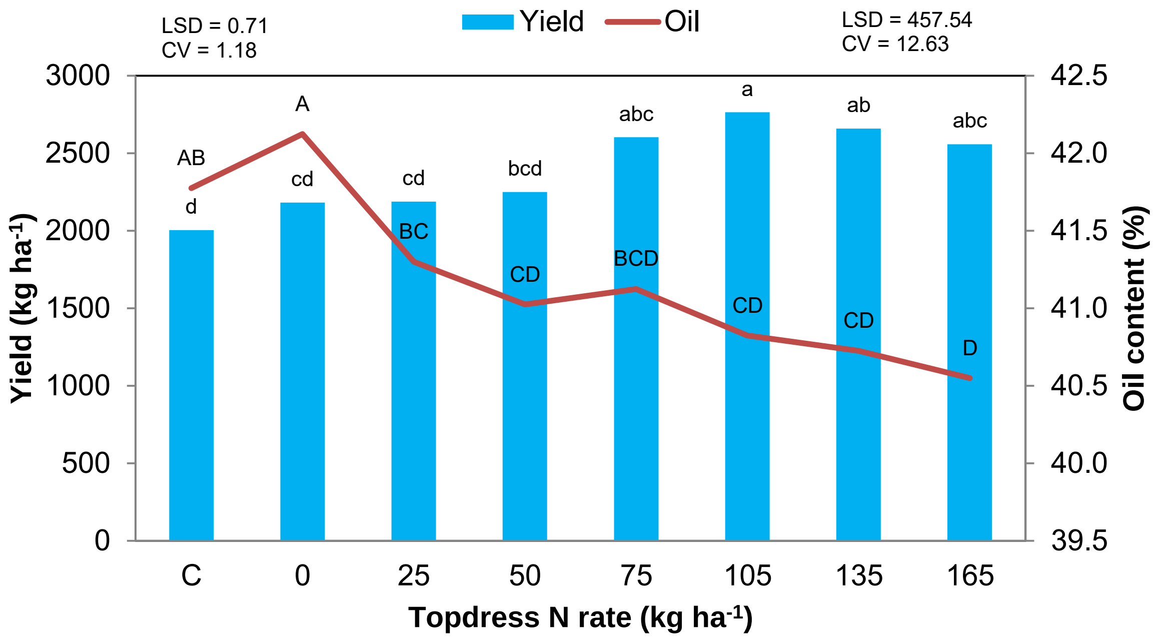

Figure 4.16 Influence of topdressed fertiliser N rate (kg ha^{-1}) on canola yield (kg ha^{-1}) and seed oil content (%) at Langgewens 2016. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different lowercase letters indicate significant differences between mean yields at a 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

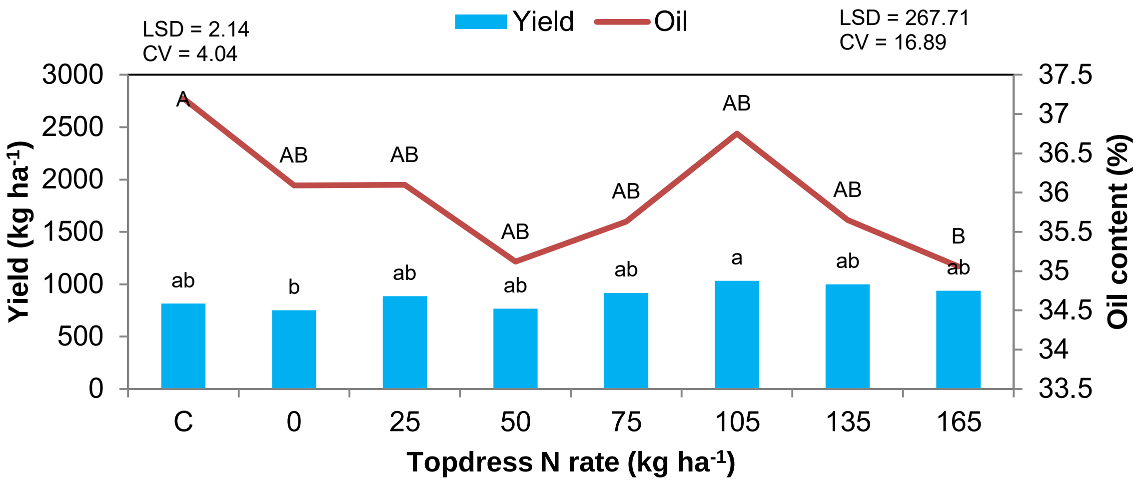

Figure 4.17 Influence of topdressed fertiliser N rate (kg ha^{-1}) on canola yield (kg ha^{-1}) and seed oil content (%) at Langgewens 2017. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different lowercase letters indicate significant differences between mean yields at a 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

4.3.4 *Nitrogen use efficiency (NUE)*

NUE significantly decreased ($p<0.05$) from 25 kg ha^{-1} to 75 kg ha^{-1}. No differences ($p>0.05$) were recorded on NUE between N treatments varying from 105 kg ha^{-1} to 165 kg ha^{-1} in 2016 (Figure 4.18). Similar results were recorded in 2017 as in 2016, namely that as N rate increased, NUE decreased ($p<0.05$). No differences ($p>0.05$) were recorded between the effect of total N rates varying from 135 kg ha^{-1} to 190 kg ha^{-1} in 2017.

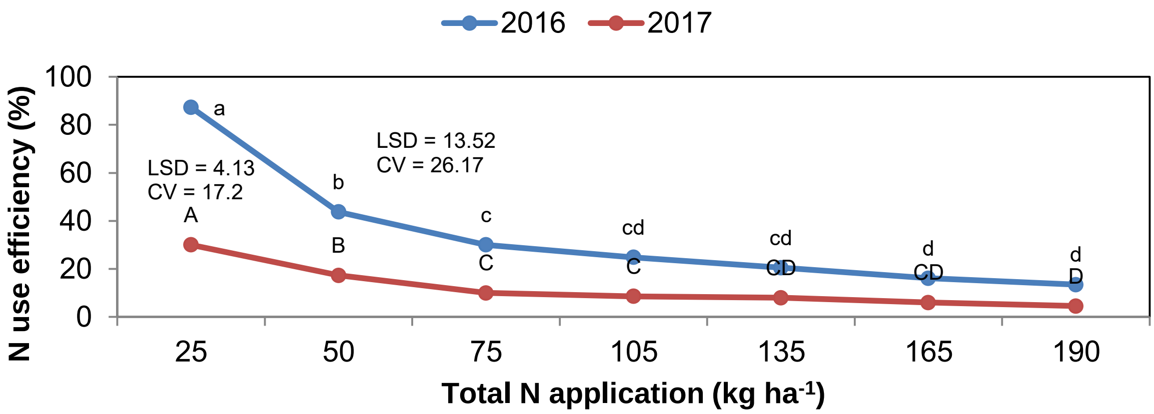

Figure 4.18 Nitrogen use efficiency (NUE) as affected by N topdress rate and distribution of N application at Langgewens 2016 and 2017. Lines with different letters indicate significant differences between mean oil content at a 5% level, with uppercase letters for 2017 and lowercase letters for 2016 results.

4.4 Porterville (Nuhoop)

4.4.1 *Soil mineral N concentration*

Pre-topdress soil mineral N concentration recorded no difference (p>0.05) between different top dress N rates applied (Figure 4.19). Post topdress soil mineral N concentration increased (p<0.05) as topdressed N rate increased. Topdress N rate of 165 kg ha^{-1} recorded higher (p<0.05) soil mineral N concentration compared to control and 0 kg ha^{-1} treatments. At harvest, soil mineral N concentration did not differ (p>0.05) between treatments, except for 165 kg ha^{-1} which was higher (p<0.05) than all other treatments.

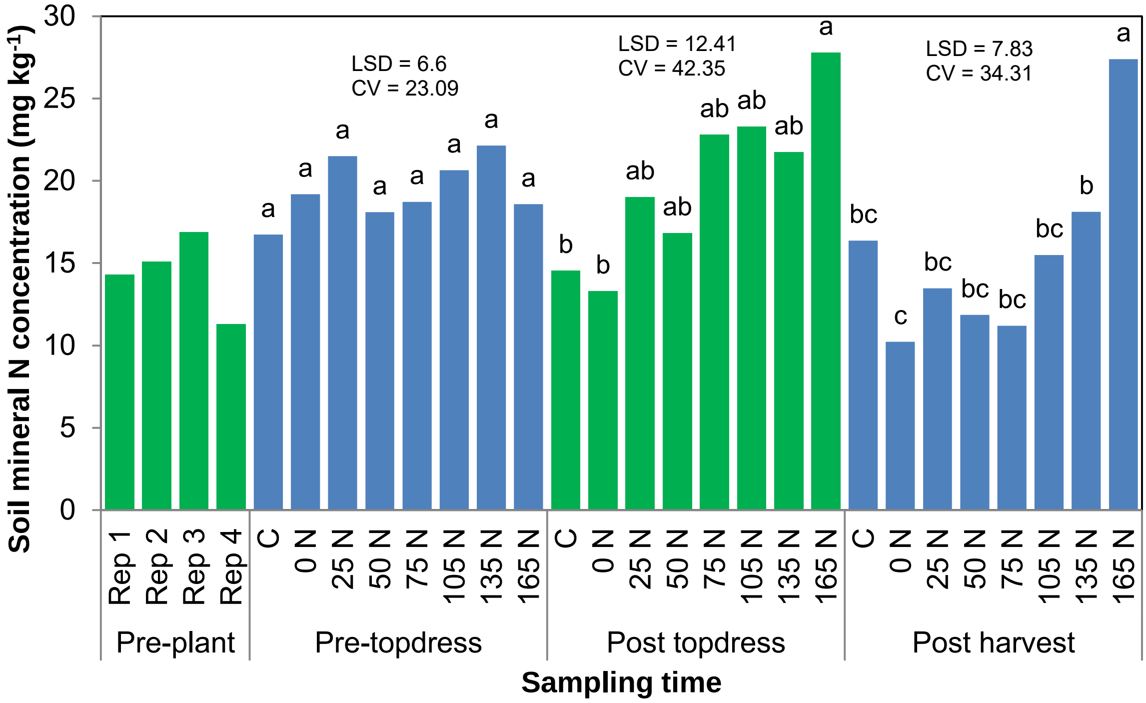

Figure 4.19 Soil mineral N concentration (mg kg^{-1}) in the 0-300 mm soil layer as influenced by topdress N rate (kg ha^{-1}) at pre- and post topdress N as well as residual mineral N at harvesting at Porterville 2017. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different letters within a sampling event indicate significant differences between soil mineral N concentrations at the 5% level.

Figure 4.20 summarises the effect of topdressed N rate on soil mineral N concentration at Porterville 2017.

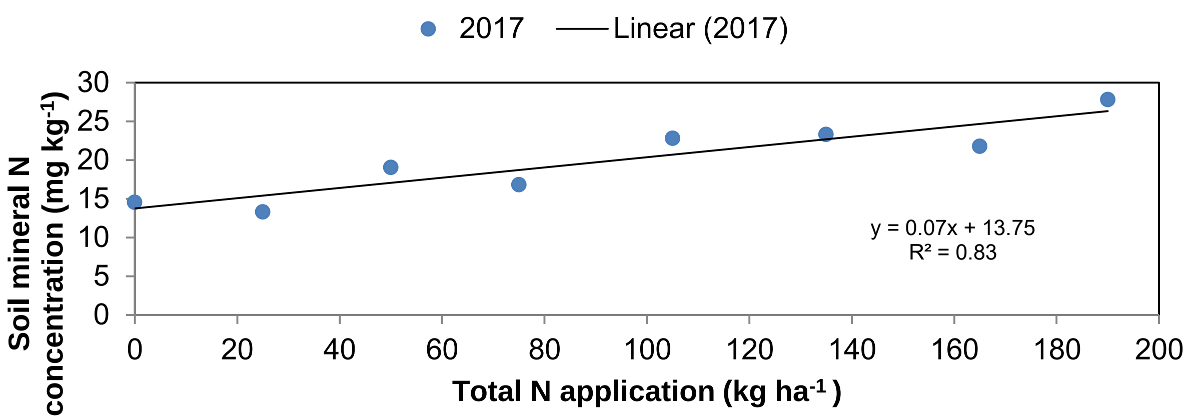

Figure 4.20 Pearson regression analysis between topdress N rate (kg ha^{-1}) and soil mineral N concentration post topdress (mg kg^{-1}) at a 300 mm depth at Porterville 2017.

4.4.2 *Plant parameters*

Plant population after establishment recorded inconsistent results varying between 38 and 49 plant m^{-2} (Table 4.2).Topdress N rate had no influence (p>0.05) on plant population at harvest. Biomass production increased (p<0.05) as topdress N rate increased.

Table 4.7 Influence of fertiliser N treatments (kg ha^{-1}) on seedling survival rate (m^{-2}) and biomass production (kg ha^{-1}) at Porterville 2017

Treatment	Plant population after establishment (m^{-2})	Plant population at harvest (m^{-2})	Biomass (kg ha^{-1})
C	41 ^{bc}	41 ^{a}	2167 ^{c}
0	40 ^{bc}	41 ^{a}	2916 ^{abc}
25	43 ^{abc}	38 ^{a}	2861 ^{bc}
50	38 ^{c}	40 ^{a}	3166 ^{abc}
75	49 ^{a}	40 ^{a}	3139 ^{abc}
105	39 ^{bc}	45 ^{a}	4139 ^{a}
135	41 ^{abc}	39 ^{a}	3194 ^{abc}
165	47 ^{ab}	43 ^{a}	3444 ^{ab}
CV (%)	13.2	20.6	26.7
LSD (0.05)	8.4	12.3	1226.7

Means without a common letter following the value in the same column differed significantly (P = 0.05).

4.4.3 *Yield and oil content*

Yield increased ($p<0.05$) as N rate increased at Porterville 2017. Maximum yield response was recorded at 50 kg ha^{-1} where further increase resulted in no difference ($p>0.05$) in yield (Figure 4.21). Oil content decreased ($p<0.05$) as topdressed N rate increased.

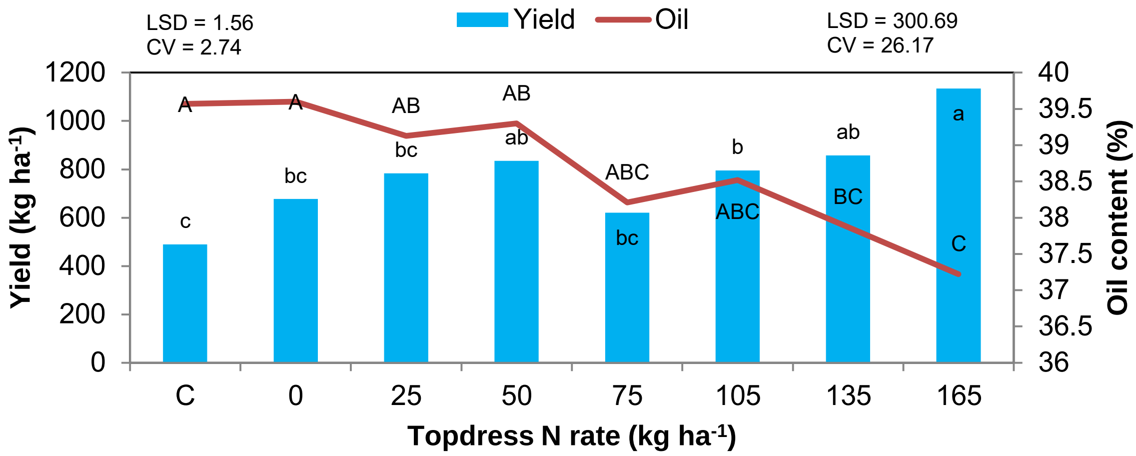

Figure 4.21 Influence of topdressed fertiliser N rate (kg ha^{-1}) on canola yield (kg ha^{-1}) and seed oil content (%) at Langgewens 2016. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different lowercase letters indicate significant differences between mean yields at a 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

4.4.4 *Nitrogen use efficiency (NUE)*

NUE decreased ($p<0.05$) as N rate increased from 0 kg ha^{-1} to 105 kg ha^{-1}. Further increase of N rate from 105 kg ha^{-1} to 165 kg ha^{-1} resulted in no differences ($p>0.05$) in NUE (Figure 4.22).

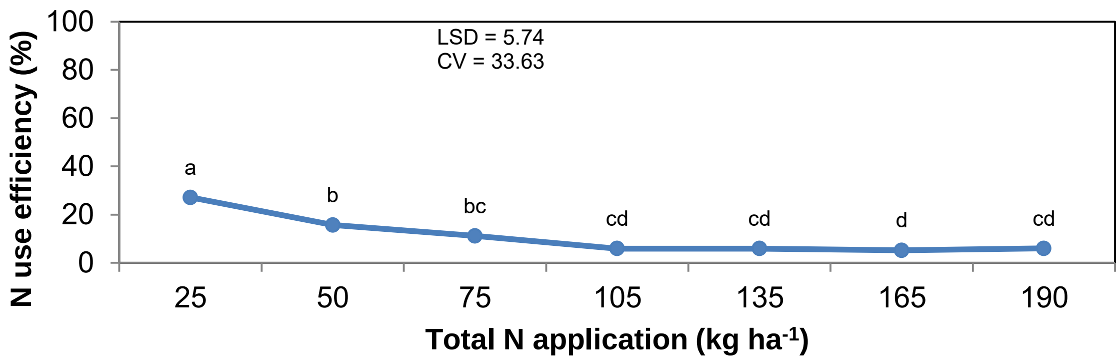

Figure 4.22 Nitrogen use efficiency (NUE) as affected by N topdress rate and distribution of N application at Porterville 2017. Line with different letters indicates significant differences between mean oil content at a 5% level.

4.5 Darling (Klipvlei)

4.5.1 *Soil mineral N concentration*

No differences (p>0.05) in soil mineral N concentration were recorded at pre-planting, pre-topdress or at harvesting (Figure 4.23). Post topdress soil mineral N concentration recorded an increase (p<0.05) in soil mineral N concentration as topdressed N rate was increased. Soil mineral N concentration was higher (p<0.05) at 135 kg ha^{-1} and 165 kg N ha^{-1} compared to topdress N rates between 0 kg ha^{-1} and 75 kg ha^{-1}.

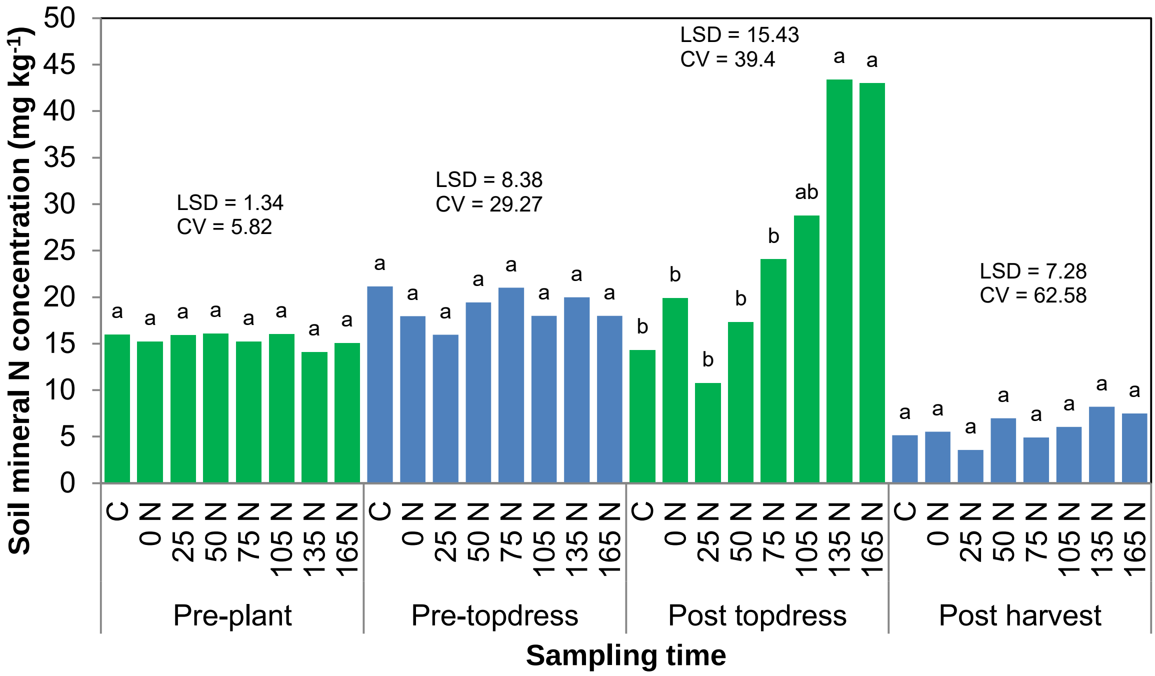

Figure 4.23 Soil mineral N concentration (mg kg^{-1}) in the 0-300 mm soil layer as influenced by topdress N rate (kg ha^{-1}) at pre-planting, pre- and post topdress N as well as residual mineral N at harvesting at Darling 2016. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different letters within a sampling event indicate significant differences between soil mineral N concentrations at the 5% level.

Figure 4.24 summarises the effect of topdressed N rate on soil mineral N concentration at Darling 2016.

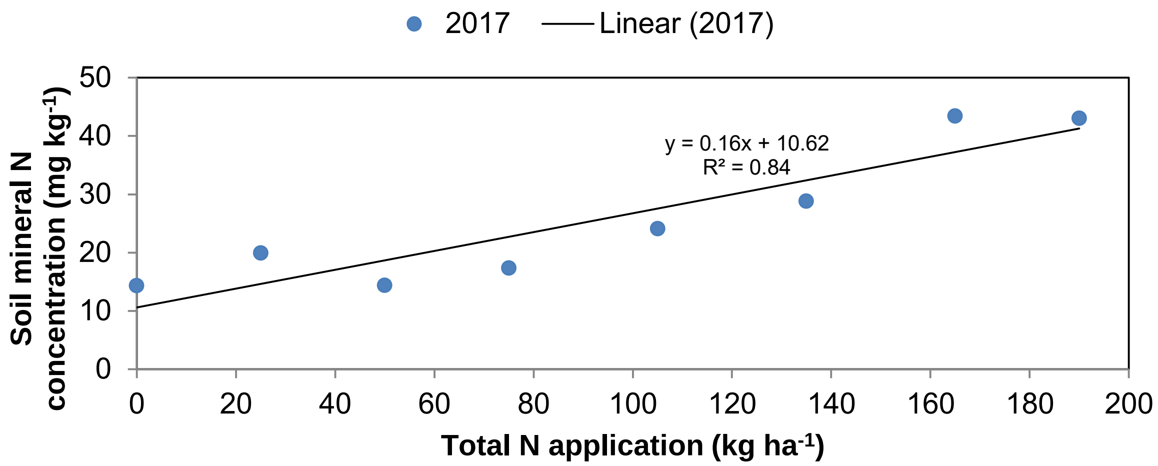

Figure 4.24 Pearson regression analysis between topdress N rate (kg ha^{-1}) and soil mineral N concentration post topdress (mg kg^{-1}) at a 300 mm depth at Darling 2016.

4.5.2 *Plant parameters*

Nitrogen topdress rate did not influence canola biomass production during 2016 at Darling (Table 4.8).

Table 4.8 Influence of fertiliser N treatments (kg ha^{-1}) on biomass production (kg ha^{-1}) at Darling 2016

Treatment	Biomass (kg ha^{-1})
C	5813 ^{a}
0	5944 ^{a}
25	7056 ^{a}
50	7417 ^{a}
75	4813 ^{a}
105	6500 ^{a}
135	6459 ^{a}
165	7354 ^{a}
CV (%)	32.3
LSD (0.05)	3259.0

Means without a common letter following the value in the same column differed significantly (P = 0.05).

4.5.3 *Yield and Oil content*

Canola yield increased ($p<0.05$) as topdressed N was increased to 105 kg ha^{-1}, except for the 75 kg ha^{-1} treatment (Figure 4.25). Topdressed N rates above 105 kg ha^{-1} did not increase ($p>0.05$) yield. Canola oil content decreased ($p<0.05$) as N rate increased.

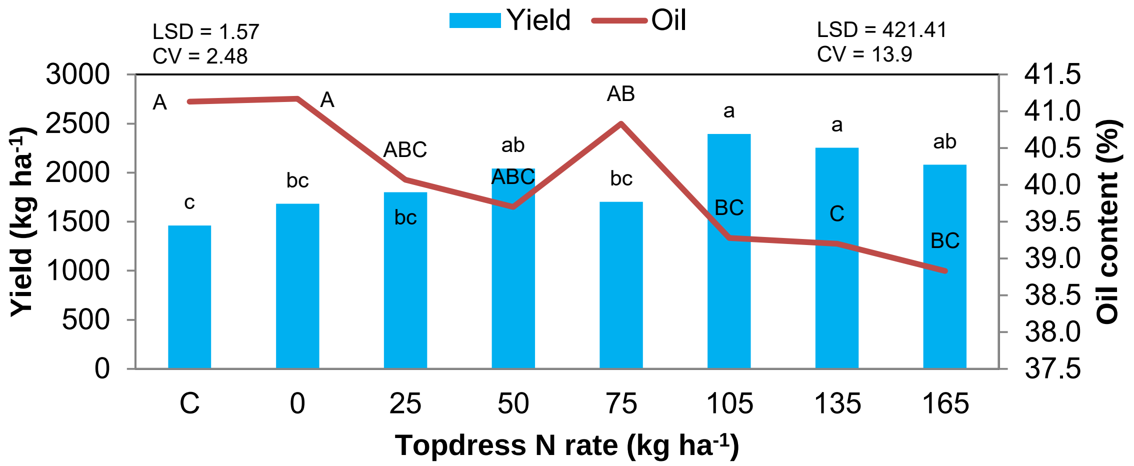

Figure 4.25 Influence of topdressed N rate (kg ha^{-1}) on canola yield (kg ha^{-1}) and oil content (%) at Darling 2016. C = control, 0N, 25N, 50N, 75N, 105N, 135N and 165N = kg N ha^{-1} topdressed. Bars with different lowercase letters indicate significant differences between mean yields at a 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

4.5.4 *Nitrogen use efficiency (NUE)*

NUE decreased ($p<0.05$) as N topdressed rate increased at Darling (Figure 4.26). No difference in NUE was recorded between 105 kg ha^{-1} and 190 kg ha^{-1}.

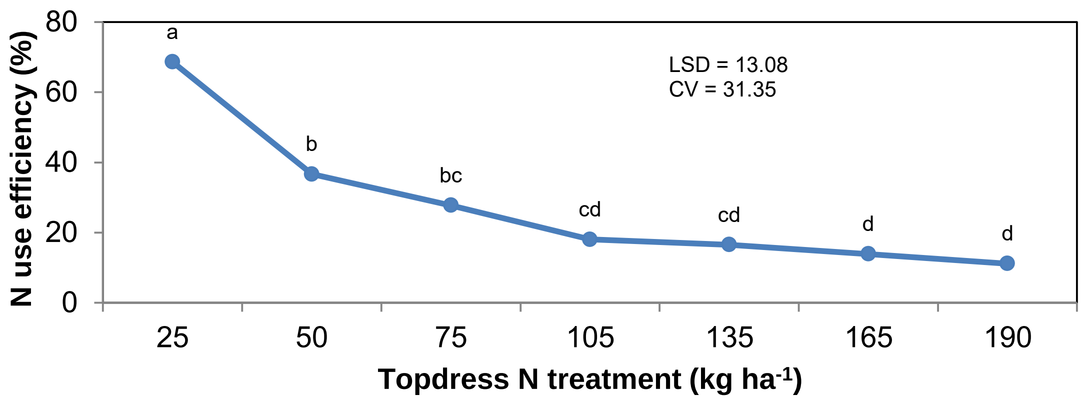

Figure 4.26 Nitrogen use efficiency (NUE) as affected by N topdress rate and distribution of N application at Darling 2016. Line with different letters indicates significant differences between mean oil content at a 5% level.

4.6 Discussion

4.6.1 *Soil mineral N concentration*

In general, 2016 pre-plant soil mineral N content (NO_3^- + NH_4^+) ranged from 15 mg kg^{-1} to 40 mg kg^{-1} between sites. Tygerhoek recorded a soil mineral N concentration of approximately 40 mg kg^{-1}, Riversdale and Langgewens approximately 25 mg kg^{-1} and Darling 15 mg kg^{-1}. In 2017 Tygerhoek, Riversdale and Langgewens recorded similar pre-plant soil mineral N concentration of approximately 27 mg kg^{-1}, while Porterville recorded a soil mineral N concentration of ~ 15 mg kg^{-1}. Considering that 40 kg N ha^{-1} is needed to produce 1 ton of canola grain (Canola Working Group of the Western Cape 2001), pre-plant soil mineral N concentration at all sites was not sufficient to produce canola yield of 2 to 3 ton ha^{-1}. Grant and Bailey (1993) also reported that if soil NO_3^--N is below 50 mg kg^{-1}, canola will respond to applied fertiliser N. Thus, for the current study, a response to additional N fertiliser was expected at all sites. Additional N is needed to meet N demand of high yield canola during the growing season. Sites in the southern Cape (Riversdale and Tygerhoek) tended to have higher soil mineral N concentration at the beginning of the season compared to sites in the Swartland (Langgewens, Porterville and Darling). This was, however, expected due to higher summer rainfall (together with high soil temperature) and soil organic C content in southern Cape sites compared to Swartland sites, which increased N mineralisation and resulted in higher soil mineral N concentration for canola growth (Kolberg et al.1999; Raun and Johnson 1999).

Pre-topdress soil mineral N concentration did not differ ($p>0.05$) between control (0 kg ha^{-1} at plant) and N rate treatments that received 25 kg N ha^{-1} at planting (0 kg ha^{-1} topdress) at all sites, except for Tygerhoek 2016. In both years, April and May was very dry which resulted to low soil moisture two to four weeks following planting. Low soil moisture during this period may have reduced N mineralisation, which could be the reason for low soil mineral N concentration response to N application at planting. These results are similar to those results obtained by Coetzee (2017), who reported no difference in soil mineral N concentration 30 days after planting between control treatments and treatments receiving 20 kg N ha^{-1} at planting due to drought conditions. Thus when planting in low soil moisture and no rain is expected 2 to 4 weeks following planting, reducing N fertiliser rate during planting should be considered to increase N management efficiency.

Post topdress soil mineral N concentration increased ($p<0.05$) as topdressed N rate increased at all sites in 2016 and 2017. These results are in agreement with Maali and Agenbag (2003) who reported that N fertilisation increased total N content in the top 300 mm of soil. In 2016, a definite response was recorded in soil mineral N concentration following high topdress N rates (105 kg ha^{-1} to 165 kg ha^{-1}). High topdress N rates increased ($p<0.05$) soil mineral N concentration at Riversdale and Tygerhoek to c. 100 mg kg^{-1}, Langgewens to c. 60 mg kg^{-1} and Darling to c. 45 mg kg^{-1}. Similar results were reported by Coetzee (2017) who also found a high concentration of total soil mineral N after high rates of N was applied to the soil. The accumulation of soil mineral N as a result of these high N topdress rates may be due to the combination of sufficient available soil water, increased net N mineralisation after N fertilisation due to reduced N immobilisation (Dijkstra et al. 2005) and the decline of N recovery of canola at high N topdress rates (Rathke et al. 2006, Cameron et al. 2013). This was, however, not the case in 2017. High N rates did not result in a spike of soil mineral N concentration. Low soil mineral N concentration response to N topdressings recorded in 2017 may be due to drought conditions. Low soil moisture and low rainfall may have reduced N fertiliser dilution and N mineralisation potential. Similar results were found by Maali and Agenbag (2003) who reported large differences between years in soil mineral N concentration response to N fertilisation due to differences in distribution and total rainfall.

At harvest, soil mineral N concentration at all sites dropped to similar soil mineral N between treatments (± 15 mg kg^{-1}), indicating that N was either utilised by the crop or lost to the environment. Considering that biomass production and seed yield was not increased ($p>0.05$) at high soil mineral N concentration at each specific site in 2016 and 2017, it could be indication of oversupply of N. This is in agreement with Goulding et al. (2000) who reported high N losses through leaching when N fertiliser rate was increased above optimum for crop N demand. Low crop response recorded at high soil mineral N concentration may also be due to dry conditions which reduce overall fertiliser N efficiency through volatilisation, reduced N mineralisation and impaired N transport to roots (Jensen et al.1997, Bouwman et al. 2002), especially during 2017. Furthermore canola's reduced fertiliser N recovery efficiency as N supply increases could also have an effect (Sidlauskas and Bernotas 2003). It would thus be ideal to avoid excessive soil mineral N as this do not increase yield, but results in oversupply of N which is negative to the environment and reduces profit.

4.6.2 *Plant parameters*

In 2016 and 2017 plant population varied between sites ranging from an average of 20 plants m^{-2} to 45 plants m^{-2} which is acceptable according to results reported by French et al. (2016). French et al. (2016) reported ideal plant population of 20 to 25 plants m^{-2} in low rainfall (<300 mm) areas and 30 to 40 plants m^{-2} in high rainfall areas (450 to 550 mm). Differences in plant population recorded (20 to 45 plants m^{-2}) did, however, not affect yield. Bernardi and Banks (1993) reported no difference in yield in plant densities ranging from 20 plants m^{-2} to 60 plants m^{-2}. Furthermore Potter et al. (2001) reported that in low rainfall areas yield increased as plant populations were increased to between 20 and 25 m^{-2}, where as a further increase in plant population did not affect yield. Contrasting results have, however, been reported by Shirtliffe (2009) who found that canola plant populations need to be 50 plants m^{-2} to maintain yield potential. Out of an agronomic point of view it may therefore be ideal to establish 40-50 plants m^{-2} to compensate for some possible plant mortality due to post-seeding stresses (e.g. drought, wind, insects, water or weed competition).

In 2016, topdressed N rate did not influence ($p>0.05$), or recorded inconsistent results, for plant population after establishment and at harvest at all sites. Similar results were recorded in 2017 for plant population after establishment and at harvest as in 2016 at all sites, except Langgewens. These results are in agreement with studies by Van Zyl (2007) and Harker and Hartman (2016) who reported that N treatments had no influence on plant population. Langgewens recorded higher plant population after establishment for the control treatment, compared to treatments that received N. This may be due to N applied in dry soil during planting in the N rate treatment plots which could have scorched seedlings and reduced emergence rate. This is in agreement to studies by Grant and Bailey (1993) who reported a reduction in emergence of canola with seed placed N at low soil moisture.

Except for Riversdale in 2016 and Porterville in 2017 where increased ($p<0.05$) biomass production following N application was recorded, no difference ($p>0.05$) in biomass production for different topdress N rates were recorded at other sites in 2016 and 2017. Biomass production that did not respond to increasing topdress N rates are in contrast to several studies (Ozer et al. 1999, Sidlauskas and Bernotas 2003 and Taheri et al. 2012), who reported an increase in biomass production as N supply increased. In 2016, no response recorded for biomass production to increasing topdress N rates might have been due to sufficient soil mineral N concentration, especially at control and low topdress N rate treatments, for biomass growth. High topdress N rates might have increased soil mineral N content to excessive levels were canola could not utilise N for biomass due to canola's poor N mobilisation in tissues in high N supply environments (Svečnjak and Rengel 2006). In 2017, dry conditions that delayed establishment (reduced vegetative growth stage), may have influenced biomass production. Low soil moisture could have limited N uptake of canola, which could have reduced biomass production. These results are in agreement with Coetzee (2017) who also reported no difference in biomass production as N rate increased during a dry growing season.

4.6.3 *Yield*

In 2016, similar canola yield responses to topdress N treatments were recorded at all localities. Yield increased ($p<0.05$) as N topdress rate increased to approximately 50 kg N ha^{-1}, followed by no further response as N topdress rates increased from 105 to 165 kg ha^{-1}.

Maximum yield response did, however, differ between sites. Differences in yield response recorded between sites were expected due to differences in soil- and climatic conditions between sites which influence canola yield potential.

Riversdale and Tygerhoek recorded similar results where increasing topdress N rate above 25 kg ha^{-1} did not increase yield ($p>0.05$). Highest yield was recorded at Riversdale and Tygerhoek at approximately 2.1 ton ha^{-1}. At Langgewens and Darling, increasing the N topdress rate above 75 kg ha^{-1} and 50 kg ha^{-1} respectively, did not increase yield ($p>0.05$). Langgewens recorded highest yield at 2.6 ton ha^{-1} while Darling recorded highest yield at 2 ton ha^{-1}. These results are similar to those reported by Hocking et al. (1997) who reported that a total of 75 kg ha^{-1} resulted in best canola yield response (3.5 ton ha^{-1}), and a further increase of total N rate up to 150 kg ha^{-1}, did not significantly increase yield.

In general, very low yields were recorded in 2017 at all sites compared to 2016. Canola yield varied between 0.7 ton ha^{-1} to 1.3 ton ha^{-1}. This was mainly due to the very dry conditions throughout the Western Cape. These dry conditions contributed to low yield response for increasing N rates, especially at Langgewens. At Langgewens N topdressing did not influence yield ($p>0.05$). Riversdale and Tygerhoek did not respond to N fertilisation at all, and maximum yield was obtained at a topdress rate of 0 kg N ha^{-1}. At Porterville, maximum yield was recorded at 50 kg ha^{-1}. This is in agreement with Ma and Herath (2016) who reported that N treatments did not increase canola yield due to extended drought conditions. Grant and Bailey (1993) reported that under dryland conditions N can only increase yield to the limits imposed by soil moisture supply. Soil moisture plays a primary role in N transport to roots and low soil moisture may result to impaired N-transport, which may be the case for the poor response to N topdressings in this study during 2017 (FERTASA 2016). These results are in agreement with those found by Jensen et al. (1997) who reported that dryness reduced availability of N by lower effectiveness of N fertiliser due to reduced mineralisation of soil organic N as well as impaired N-transport to roots.

Several studies have also showed contrasting results to topdress N fertilisation across seasons, varying from 50 kg ha^{-1} (Ma and Herath 2016) to 250 kg ha^{-1} (Yusuf and Bullock 1993). These differences emphases the distinct effect that environmental and soil conditions can have on N management. Thus, it is very important to adapt N management according to rainfall and soil mineral N concentration.

Over the two years, Riversdale and Tygerhoek (southern Cape) generally tended to reach maximum yield response at lower N rates compared to Langgewens, Porterville and Darling in the Swartland. Abovementioned results showed that optimal topdress N rate at rosette stage (4 to 5 leaf stage) at Riversdale and Tygerhoek tended to be between 25 kg ha^{-1} to 50 kg ha^{-1}. Sites in the Swartland tended to reach maximum response at topdress N rates varying from 50 to 75 kg ha^{-1}. The tendency of less additional topdress N fertiliser needed in the southern Cape than in the Swartland may be due to higher soil mineral N concentration for canola growth due to higher N mineralisation potential as explained earlier.

4.6.4 *Oil content*

All sites recorded a similar trend in oil content. Oil content tended to gradually decrease ($p<0.05$) as yield and topdressed N rate increased in 2016 and 2017. These results are similar to those reported by Rathke et al. (2006), Karamanos et al. (2007) and Ghanbari-Malidarreh (2010). Reduction of oil content under high N fertilisation rates are due to increased protein content production at the expense of oil production (Grant and Bailey 1993; Behrens et al. 2002; Rathke et al. 2005). Although lower oil content was noted at high N topdress rates, oil content remained above the quality standard of 40% (Hocking et al. 1997) in 2016 at all sites, except at Darling. Allah et al. (2015) reported that sulphur (S) availability had a significant increasing effect on canola oil content. Darling was the only site that had a suboptimal exchangeable S content in soil (4.6 mg kg^{-1}), which may have resulted in oil content to drop below 40%. In 2017, oil content were lower compared to 2016 and was, in most cases, below the ideal 40% content, especially at high N rates. This may be due to the dry 2017 growing season, which could have had an effect on seed oil production. Several studies reported on a decline in oil content in seed under dry growing conditions, especially when drought occurs during the flowering stage (Walton et al. 1999, Tesfamariam et al. 2010 and Ma and Herath 2016).

4.6.5 *Nitrogen Use Efficiency (NUE)*

Nitrogen use efficiency decreased ($p<0.05$) as N top dressed rate increased at all sites in 2016 and 2017. Nitrogen use efficiency drastically decreased when total N application was increased above 25 kg ha^{-1}. These results were in agreement with studies by Hocking et al. (1997), Fageria and Baligar (2005) and Gan et al. (2008), where a general trend of decreasing NUE with increasing N fertiliser rate was reported. Canola has high capacity to take up NO_3^- from soil, but only 50 to 60% of applied N fertiliser is recovered in seed (Schjoerring et al.1995, Malagoli et al. 2005). The reduction in NUE of canola is mainly due to poor N mobilisation to reproductive tissue and partly due to N rich leaf fall during a time when there is a high N demand for seed production (Hocking et al. 1999 and Svečnjak and Rengel 2006). Thus, low NUE efficiency in most cases is due to sink strength limitations rather than unavailability of N.

In 2016, NUE decreased from approximately 80% at lowest total N fertilisation rate of 25 kg ha^{-1} to approximately 10% at 190 kg ha^{-1} at all sites. Similar results were recorded in 2017 as in 2016 except for a low NUE of 30% to 50% at lowest total N application of 25 kg ha^{-1} at all sites. This general reduction of NUE during a dry growing season is in agreement with results from studies by Taylor et al (1991) and Ma and Herath (2016). Taylor et al. (1991) reported that drought stress interacts with N nutrition and reduces NUE.

Nitrogen use efficiency can be a useful tool to assess if N management practices are efficient or result in N losses which have a negative impact on the environment. European NUE guidelines were consulted as a comparative measure, as local guidelines for desirable NUE levels are not available. According to the European Nitrogen Export Panel (2015), a NUE in the 50% to 90% range is desirable. Only the N treatment that received 25 kg N ha^{-1} at plant with no additional N topdressing (0 kg ha^{-1}) recorded a desirable NUE. Riversdale and Tygerhoek reached maximum yield response at total N application of 50 kg ha^{-1} which recorded a NUE of approximately 40%. At the Swartland sites, a maximum yield response at total N application of 75 kg ha^{-1} to 100 kg ha^{-1} recorded low NUE of approximately 10%. It can thus be concluded that topdress N rate at Swartland sites should not be increased above 100 kg ha^{-1} due to very low NUE which could have a negative impact on the environment and reduce profitability. For the southern Cape sites, increasing topdress N rate above 50 kg ha^{-1} resulted in very low NUE and potential N losses.

Chapter 5: The effect of topdress N rate plus foliar N at stem elongation on canola seed yield and oil content.

5.1 Riversdale

5.1.1 *Yield*

In 2016, additional foliar N application recorded higher yield ($p<0.05$) at control and 0 kg ha^{-1} treatments, but no response ($p>0.05$) was detected for any other treatment (Figure 5.1). In 2017 similar results were recorded as in 2016, except for higher ($p<0.05$) yield also recorded at 165 kg ha^{-1} (Figure 5.2).

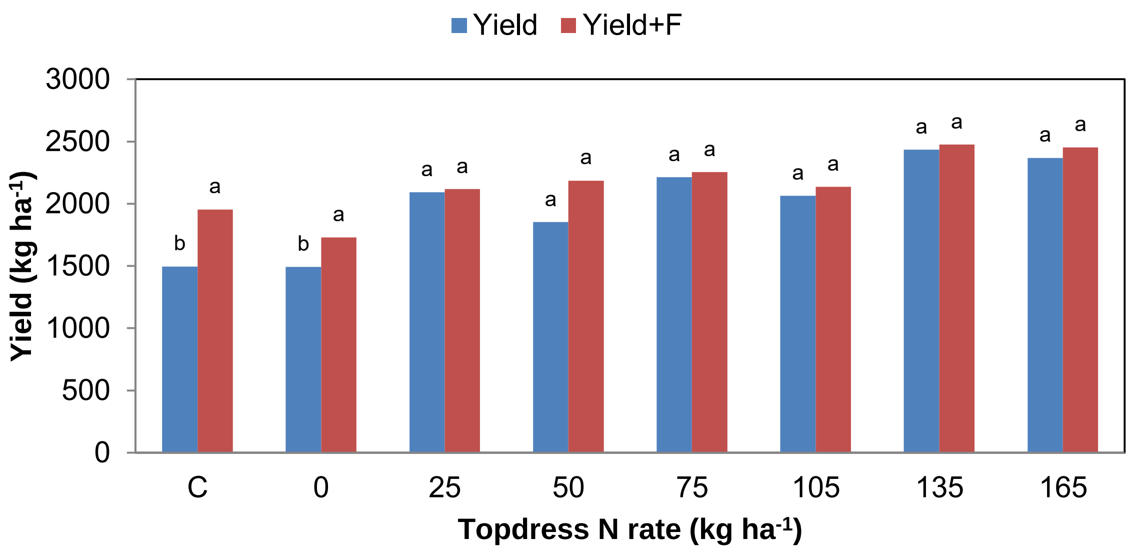

Figure 5.1 Influence of additional foliar N application at stem elongation on canola yield (kg ha^{-1}) at Riversdale 2016. Bars with different letters indicate significant differences between mean yields at the 5% level.

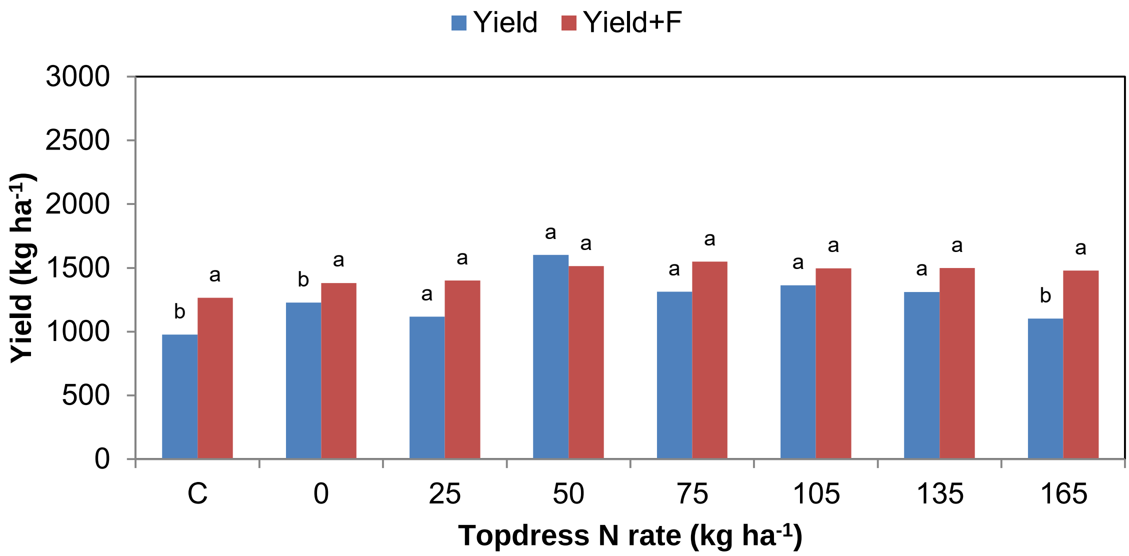

Figure 5.2 Influence of additional foliar N application at stem elongation on canola yield (kg ha^{-1}) at Riversdale 2017. Bars with different letters indicate significant differences between mean yields at the 5% level.

5.1.2 *Oil content*

In 2016, oil content was higher ($p<0.05$) at 25 kg ha^{-1} and 75 kg ha^{-1} treatments without foliar application compared to treatments receiving additional foliar N application (Table 5.1). No differences ($p>0.05$) were recorded between rest of treatments. In 2017 no differences ($p>0.05$) were recorded between treatments with or without additional foliar N application.

Table 5.1 Influence of additional foliar N application at stem elongation on oil content at Riversdale 2016 and 2017

				2016				
Treatment	**C**	**0**	**25**	**50**	**75**	**105**	**135**	**165**
Oil (%)	*	46.1 a	45.3 a	45.7 a	44.3 a	44.1 a	42.2 a	41.5 a
Oil + F (%)	*	45.6 b	43.9 b	44.6 a	43.1 b	42.6 a	42.2 a	41.4 a
CV (%)	*	0.6	0.7	0.7	0.5	1.3	1.6	0.3
LSD (0.05)	*	0.4	1.1	1.1	0.8	2.0	2.3	0.5
				2017				
Oil (%)	41.0 a	40.4 a	39.9 a	*	38.8 a	38.3 a	37.6 a	37.5 a
Oil + F (%)	40.5 a	39.8 a	39.5 a	*	38.5 a	37.3 a	37.5 a	37.2 a
CV (%)	1.6	1.0	2.8	*	2.4	4.1	2.2	2.0
LSD (0.05)	2.31	0.7	2.0	*	3.3	5.4	2.9	2.7

*Data was not acceptable for statistical analysis

Means without a common letter following the value in the same column differed significantly (P = 0.05) in a specific year.

5.2 Tygerhoek

5.2.1 *Yield*

In 2016 inconsistent yield results were recorded between treatments with and without foliar N application. Foliar N application at control treatment resulted to yield increase ($p<0.05$). No differences ($p>0.05$) were recorded in yield at 0 kg ha^{-1}, 25 kg ha^{-1}, 50 kg ha^{-1}, 75 kg ha^{-1} and 135 kg ha^{-1}. At 105 kg ha^{-1} and 165 kg ha^{-1} yield were lower ($p<0.05$) with foliar N application (Figure 5.3). During 2017, no differences ($p>0.05$) in yield were recorded between all treatments with or without foliar N application (Figure 5.4).

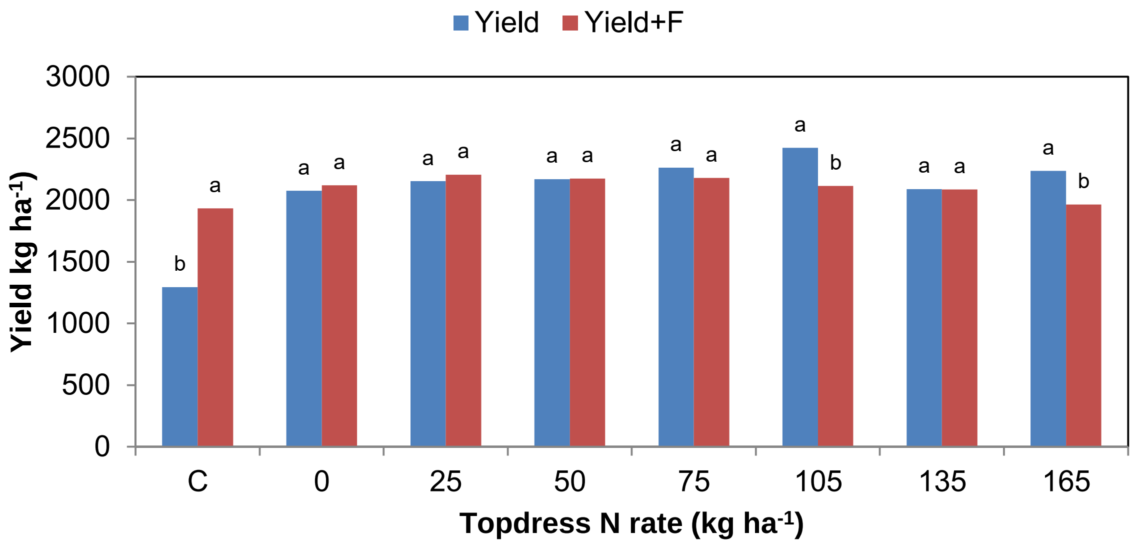

Figure 5.3 Influence of additional foliar N application at stem elongation on canola yield (kg ha^{-1}) at Tygerhoek 2016. Bars with different letters indicate significant differences between mean yields at the 5% level.

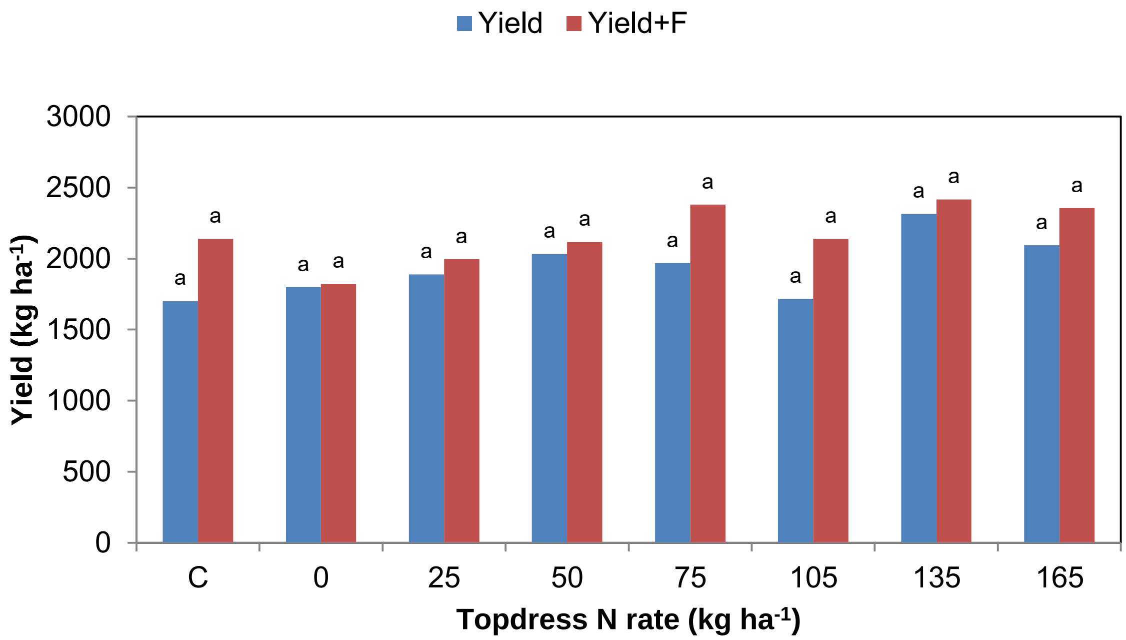

Figure 5.4 Influence of additional foliar N application at stem elongation on canola yield (kg ha^{-1}) at Tygerhoek 2017. Bars with different letters indicate significant differences between mean yields at the 5% level.

5.2.2 *Oil content*

In 2016 and 2017 no differences (p>0.05) were recorded in oil content between treatments with or without foliar N application, except for treatment 75 kg ha^{-1} in 2016. Higher (p<0.05) oil content was recorded at 75 kg ha^{-1} without foliar N application compared to 75 kg ha^{-1} with foliar N application (Table 5.2).

Table 5.2 Influence of additional foliar N application at stem elongation on oil content at Tygerhoek 2016 and 2017

				2016				
Treatment	**C**	**0**	**25**	**50**	**75**	**105**	**135**	**165**
Oil (%)	42.3 [a]	42.6 [a]	42.5 [a]	42.1 [a]	41.9 [a]	41.9 [a]	41.9 [a]	40.8 [a]
Oil + F (%)	41.8 [a]	42.2 [a]	42.1 [a]	41.6 [a]	41.6 [b]	41.4 [a]	41.3 [a]	41.7 [a]
CV (%)	0.5	0.8	0.6	0.9	0.4	1.2	1.1	0.8
LSD (0.05)	0.8	0.8	0.8	0.9	0.3	1.6	1.0	1.2
				2017				
Oil (%)	40.2 [a]	41.0 [a]	40.3 [a]	40.5 [a]	40.5 [a]	39.9 [a]	39.2 [a]	39.0 [a]
Oil + F (%)	40.2 [a]	40.7 [a]	39.7 [a]	40.0 [a]	39.8 [a]	39.5 [a]	38.8 [a]	38.8 [a]
CV (%)	1.2	1.0	2.3	0.4	0.5	2.2	0.8	1.5
LSD (0.05)	1.7	1.4	3.1	0.6	0.7	3.0	0.7	1.3

Means without a common letter following the value in the same column differed significantly (P = 0.05) in a specific year.

5.3 Langgewens

5.3.1 *Yield*

In 2016 no differences (p>0.05) were recorded in yield between all treatments with or without foliar N application (Figure 5.5). In 2017, inconsistent results were recorded in yield (Figure 5.6). At 25 kg ha^{-1}, 50 kg ha^{-1} and 135 kg ha^{-1} higher (p<0.05) yields were recorded with additional foliar N application. The rest of the treatments recorded no yield difference (p>0.05) for additional foliar N application.

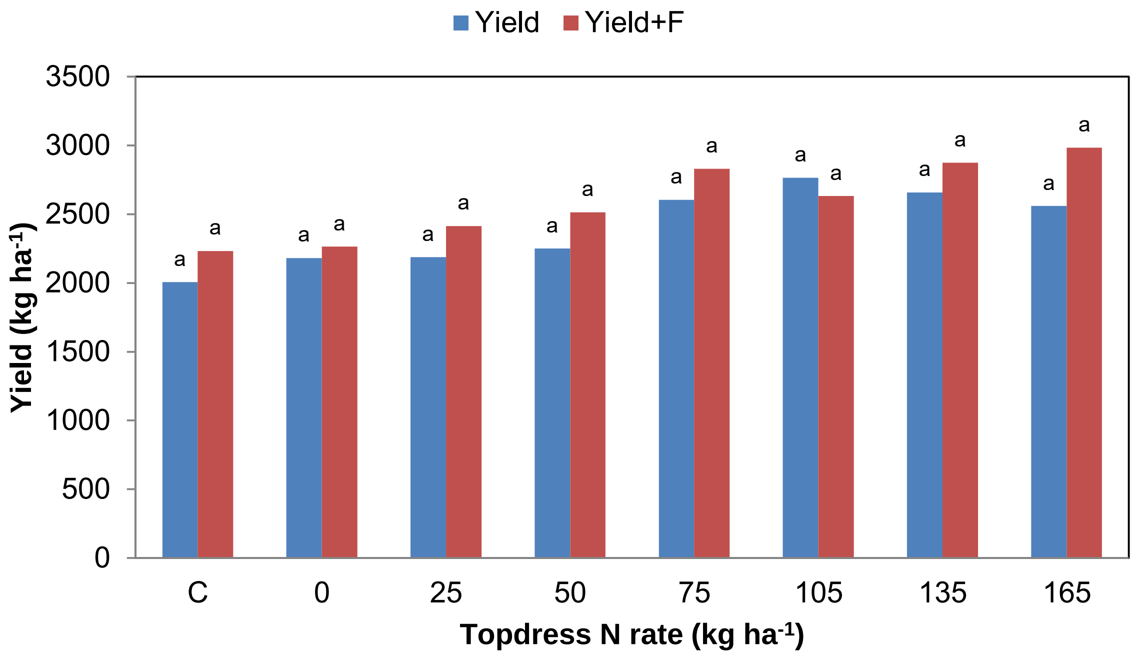

Figure 5.5 Influence of additional foliar N application at stem elongation on canola yield (kg ha^{-1}) at Langgewens 2016. Bars with different letters indicate significant differences between mean yields at the 5% level.

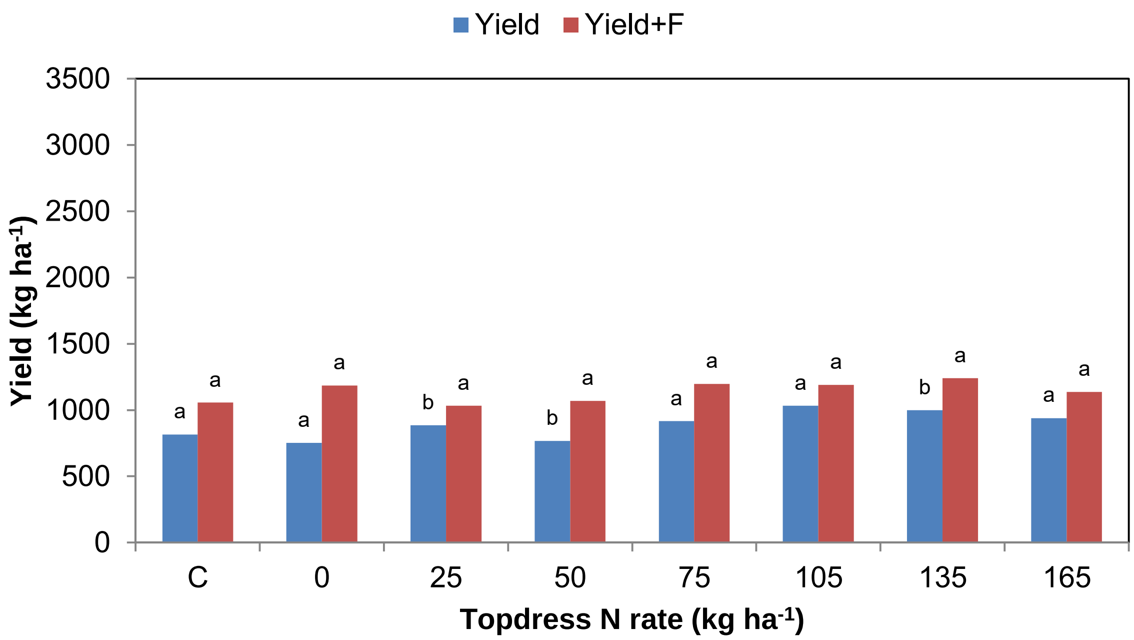

Figure 5.6 Influence of additional foliar N application at stem elongation on canola yield (kg ha^{-1}) at Langgewens 2017. Bars with different letters indicate significant differences between mean yields at the 5% level.

5.3.2 *Oil content*

No difference (p>0.05) was recorded in oil content between treatments with or without additional foliar N application in 2016 and 2017 at Langgewens (Table 5.3).

Table 5.3 Influence of additional foliar N application at stem elongation on oil content at Langgewens 2016 and 2017

				2016				
Treatment	**C**	**0**	**25**	**50**	**75**	**105**	**135**	**165**
Oil (%)	41.8 [a]	42.1 [a]	41.3 [a]	41.0 [a]	41.1 [a]	40.8 [a]	40.7 [a]	40.6 [a]
Oil + F (%)	41.7 [a]	41.8 [a]	41.2 [a]	41.2 [a]	41.1 [a]	40.9 [a]	41.0 [a]	40.8 [a]
CV (%)	0.3	0.9	1.6	1.0	0.6	0.9	1.0	0.8
LSD (0.05)	0.3	0.8	1.5	0.9	0.6	0.8	1.0	0.7
				2017				
Oil (%)	37.6 [a]	37.0 [a]	36.3 [a]	36.2 [a]	36.1 [a]	36.7 [a]	35.6 [a]	35.1 [a]
Oil + F (%)	37.2 [a]	36.1 [a]	36.1 [a]	35.1 [a]	35.6 [a]	35.6 [a]	35.6 [a]	34.5 [a]
CV (%)	0.5	5.5	3.2	6.5	2.6	1.4	1.4	2.4
LSD (0.05)	0.4	4.5	2.6	5.2	2.1	1.1	1.2	1.9

Means without a common letter following the value in the same column differed significantly (P = 0.05) in a specific year.

5.4 Porterville

5.4.1 *Yield*

No differences (p<0.05) in yield were recorded for an additional foliar N application at all treatments evaluated at Porterville 2017 (Figure 5.7).

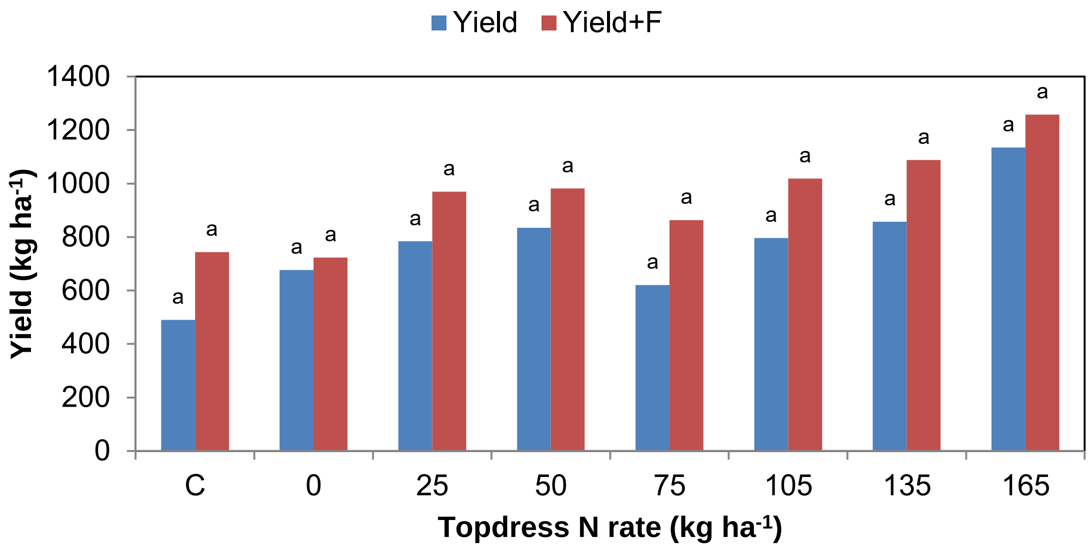

Figure 5.7 Influence of additional foliar N application at stem elongation on canola yield (kg ha^{-1}) at Porterville 2017. Bars with different letters indicate significant differences between mean yields at the 5% level.

5.4.2 *Oil content*

Porterville recorded no differences (p>0.05) in oil content between treatments with or without foliar N application (Table 5.4).

Table 5.4 Influence of additional foliar N application at stem elongation on oil content at Porterville 2017

				2017				
Treatment	**C**	**0**	**25**	**50**	**75**	**105**	**135**	**165**
Oil (%)	39.6 [a]	39.6 [a]	39.1 [a]	39.3 [a]	38.2 [a]	38.5 [a]	37.9 [a]	38.0 [a]
Oil + F (%)	39.6 [a]	38.7 [a]	39.0 [a]	39.2 [a]	37.5 [a]	37.6 [a]	37.1 [a]	37.2 [a]
CV (%)	2.2	2.0	2.5	1.8	2.5	3.3	2.4	1.3
LSD (0.05)	2.0	1.8	2.2	1.6	2.1	2.8	2.0	1.1

Means without a common letter following the value in the same column differed significantly (P = 0.05).

5.5 Darling

5.5.1 *Yield*

No differences (p>0.05) were recorded in yield of all treatments with or without additional foliar N application at Darling (Figure 5.8).

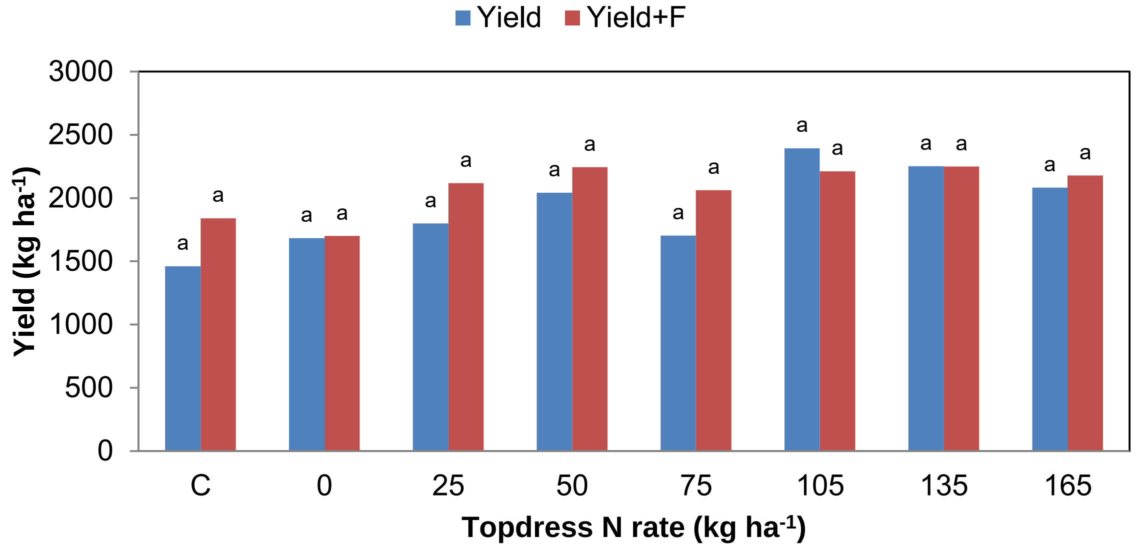

Figure 5.8 Influence of additional foliar N application at stem elongation on canola yield (kg ha^{-1}) at Darling 2016. Bars with different letters indicate significant differences between mean yields at the 5% level.

5.5.2 *Oil content*

No differences (p>0.05) were recorded in oil content between treatments with or without foliar N application at Darling 2016 (Table 5.5).

Table 5.5 Influence of additional foliar N application at stem elongation on oil content at Darling 2016

				2016				
Treatment	**C**	**0**	**25**	**50**	**75**	**105**	**135**	**165**
Oil (%)	41.1 ^{a}	41.2 ^{a}	40.7 ^{a}	39.7 ^{a}	40.8 ^{a}	39.3 ^{a}	39.2 ^{a}	38.83 ^{a}
Oil + F (%)	41.2 ^{a}	40.5 ^{a}	41.4 ^{a}	39.7 ^{a}	40.2 ^{a}	39.0 ^{a}	39.7 ^{a}	39.3 ^{a}
CV (%)	1.1	0.6	4.0	1.0	2.6	0.3	1.2	1.3
LSD (0.05)	1.0	0.9	5.7	0.9	3.5	0.4	1.0	1.1

Means without a common letter following the value in the same column differed significantly (P = 0.05).

5.6 Discussion

5.6.1 *Yield*

Foliar N application is an alternative fertilisation strategy to increase N fertilisation effectiveness (Gooding and Davies, 1992; Sait 2003). This is due to reduced N losses through N leaching and denitrification with foliar N application compared to soil applied N fertiliser. Not much research has, however, been done on effects of foliar N application on canola yield and oil content. It was therefore difficult to compare and analyse results due to the paucity of information. Most of the work reported for crop responses to foliar fertilisation has been done on wheat and soybean.

Foliar N application coincided with stem elongation growth stage due to the high N demand canola has during this phase. Several studies have reported an increase in yield for split N topdressing during the stem elongation phase (Sidlauskas and Bernotas 2003, Barlog and Grzebisz, 2004, Rathke et al. 2006 and Ghanbari-Malidarreh 2010). Contrasting results have been reported by Hocking et al. (1997) and Cheema et al. (2001), who reported no yield response to N topdressing at later growth stages following N at planting. These studies were, however, based on surface broadcast granular N fertiliser and not foliar N application.

In 2016, applying additional N as a foliar spray at stem elongation resulted in no increase ($p>0.05$) in canola yield at all sites evaluated. No yield response recorded may be due to sufficient soil mineral N content for canola production, especially at high topdress N rates. Plant yield response to foliar application is generally not positive when nutrient supply or soil nutrient content is sufficient (Fageria et al. 2009; Fernández and Eichart 2009). Furthermore, canola's low NUE at high N supply could also have limited yield response to foliar N topdressing. In 2017, similar results were recorded as in 2016, except for some minor inconsistencies. The control and 0 kg ha^{-1} N rate treatment recorded higher ($p<0.05$) yield with additional foliar N application at Riversdale 2017. Horst et al. (2003) reported that under low soil N conditions, N uptake at stem elongation is highly correlated to yield. Thus the combination of low soil mineral N content and impaired N transport to roots due to low soil moisture at control and 0 kg ha^{-1} could have resulted in yield response recorded.

5.6.2 *Oil content*

At all sites evaluated in 2016 and 2017, additional N applied as a foliar spray at stem elongation did not influence ($p<0.05$) oil content between al treatments. These results were expected since no yield response was recorded for foliar N sprays. Several studies have reported that canola N uptake or content is highly correlated to yield (Hocking et al. 1997, Jackson 2000 and Gan et al. 2008). It has also been reported that seed oil content has an inverse relationship with canola N uptake or content (Rathke et al. 2006 and Karamanos et al. 2007). Thus no yield response to foliar N topdressing resulted in no significant additional N uptake by canola and therefore also no influence on oil content.

Chapter 6: The effect of N source fertiliser on plant parameters, canola seed yield and oil content

6.1 Riversdale

6.1.1 *Plant parameters*

The N sources evaluated in this study did not influence (p>0.05) plant population after establishment, plant population at harvest or biomass production in 2016 and 2017 (Table 6.1 and Table 6.2). Plant population after establishment was not recorded during 2017 due unequal seedling emergence.

Table 6.1 The influence of fertiliser N source on plant population after establishment (m^{-2}), plant population at harvest (m^{-2}) and biomass prduction (kg ha^{-1}) at Riversdale 2016

Treatment	Plant population after establishment (m^{-2})	Plant population at harvest (m^{-2})	Biomass (kg ha^{-1})
UREA	35 [a]	39 [a]	6963 [a]
UREA + I	39 [a]	35 [a]	6926 [a]
AMS	35 [a]	36 [a]	7852 [a]
LAN	37 [a]	31 [a]	7000 [a]
LAN + S	38 [a]	36 [a]	7889 [a]
CV (%)	29.5	15.3	13.8
LSD (0.05)	20.5	10.2	1902.1

Means without a common letter following the value in the same column differed significantly (P = 0.05).

Table 6.2 The influence of fertiliser N source on plant population at harvest (m^{-2}) and biomass production (kg ha^{-1}) at Riversdale 2017

Treatment	plant population at harvest (m^{-2})	Biomass (kg ha^{-1})
UREA	38 [a]	7873 [a]
UREA + I	28 [a]	6095 [a]
AMS	42 [a]	7175 [a]
LAN	42 [a]	7524 [a]
LAN + S	38 [a]	8635 [a]
CV (%)	27.3	19.2
LSD (0.05)	24.8	2980.3

Means without a common letter following the value in the same column differed significantly (P = 0.05).

6.1.2 *Yield and oil content*

Yield of canola was not influenced (p>0.05) by N sources evaluated in 2016 and 2017. No differences (p>0.05) were recorded in oil content between N sources evaluated. In 2017 urea recorded higher (p<0.05) oil content than LAN and urea + inhibitor (Figure 6.2).

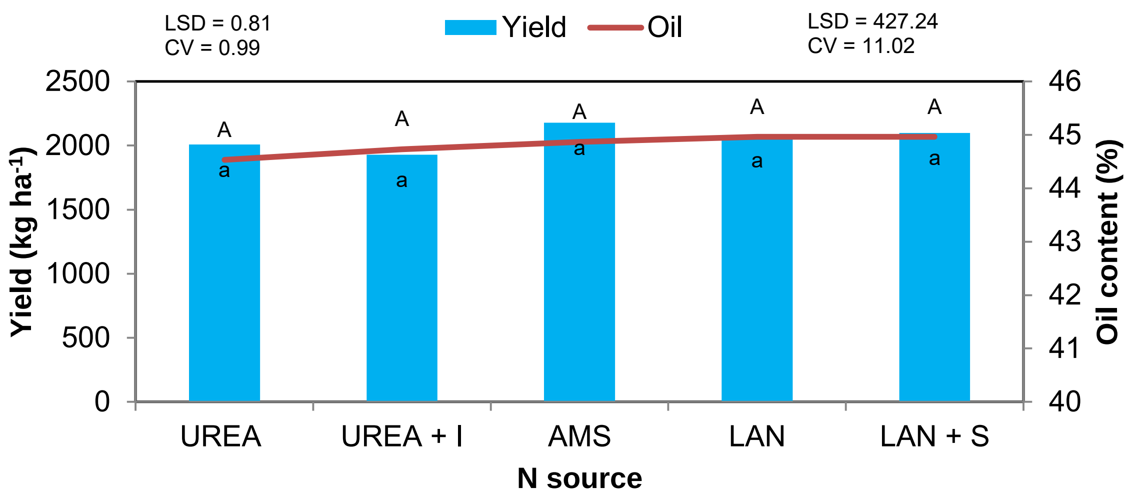

Figure 6.1 Influence of topdressed N source on canola yield (kg ha^{-1}) and oil content (%) at Riversdale during 2016. Bars with different lowercase letters indicate significant differences between mean yields at the 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

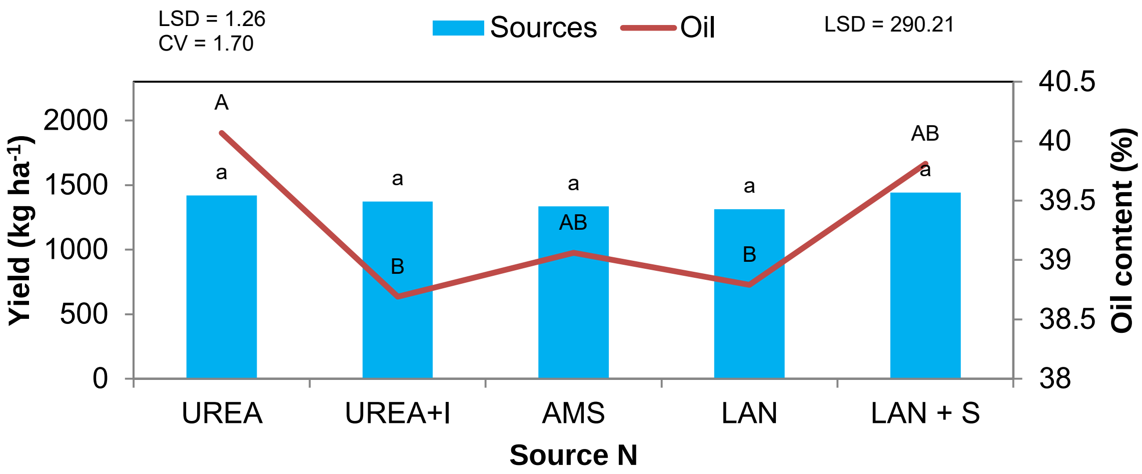

Figure 6.2 Influence of topdressed N source on canola yield (kg ha^{-1}) and oil content (%) at Riversdale during 2017. Bars with different lowercase letters indicate significant differences between mean yields at the 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

6.2 Tygerhoek

6.2.1 *Plant parameters*

No differences (p>0.05) were recorded in either plant population after establishment, plant population at harvest or biomass production between different N sources evaluated in 2016 and 2017 (Table 6.3 and Table 6.4). Biomass production was not determined for 2017 due to high plant size variation which is not suitable to determine biomass production.

Table 6.3 Influence of fertiliser N source on plant population after establishment (m^{-2}), plant population at harvest (m^{-2}) and biomass production (kg ha^{-1}) at Tygerhoek 2016

Treatment	Plant population after establishment (m^{-2})	Plant population at harvest (m^{-2})	Biomass (kg ha^{-1})
UREA	20.75 ^{a}	19.50 ^{a}	8021 ^{a}
UREA + I	30.25 ^{a}	27.75 ^{a}	7667 ^{a}
AMS	22.00 ^{a}	21.50 ^{a}	9042 ^{a}
LAN	18.50 ^{a}	17.75 ^{a}	7104 ^{a}
LAN + S	32.75 ^{a}	20.25 ^{a}	7854 ^{a}
CV (%)	40.6	30.4	30.0
LSD (0.05)	15.5	10.0	3673.9

Means without a common letter following the value in the same column differed significantly (P = 0.05).

Table 6.4 Influence of fertiliser N source on plant population after establishment (m^{-2}) and plant population at harvest (m^{-2}) at Tygerhoek 2017

Treatment	Plant population after establishment (m^{-2})	Plant population at harvest (m^{-2})
UREA	53 [a]	33 [a]
UREA + I	62 [a]	28 [a]
AMS	60 [a]	33 [a]
LAN	52 [a]	37 [a]
LAN + S	58 [a]	33 [a]
CV (%)	22.5	23.9
LSD (0.05)	19.7	12.0

Means without a common letter following the value in the same column differed significantly (P = 0.05).

6.2.2 *Yield and oil content*

No differences (p>0.05) were recorded in yield and oil content between different N sources evaluated at Tygerhoek 2016 (Figure 6.3). In 2017, no differences (p>0.05) were recorded in yield between N sources evaluated (Figure 6.4). Urea + inhibitor did however record higher (p<0.05) oil content than LAN and LAN + S.

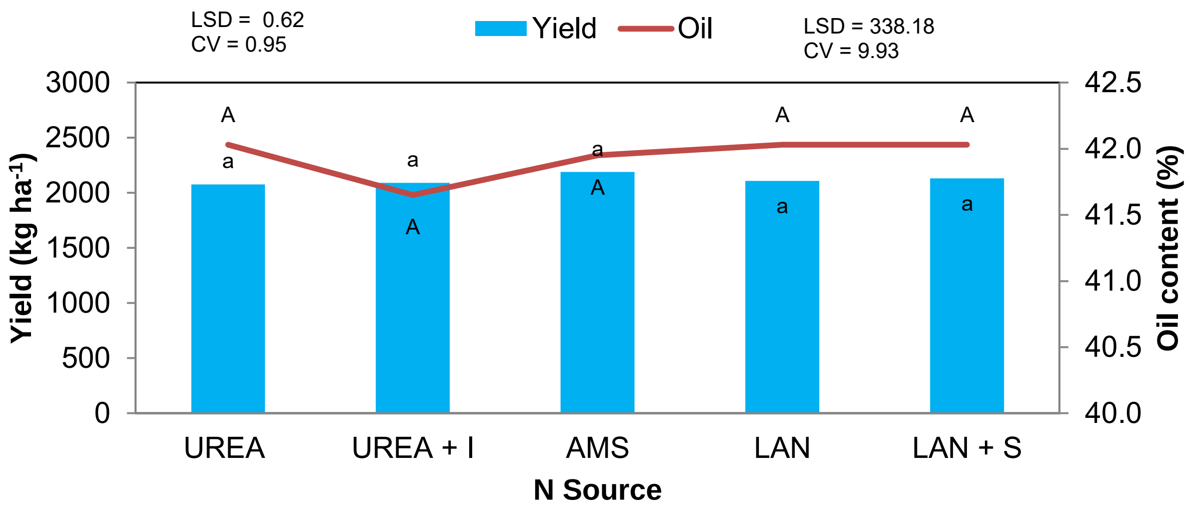

Figure 6.3 Influence of topdressed N source on canola yield (kg ha^{-1}) and oil content (%) at Tygerhoek during 2016. Bars with different lowercase letters indicate significant differences between mean yields at the 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

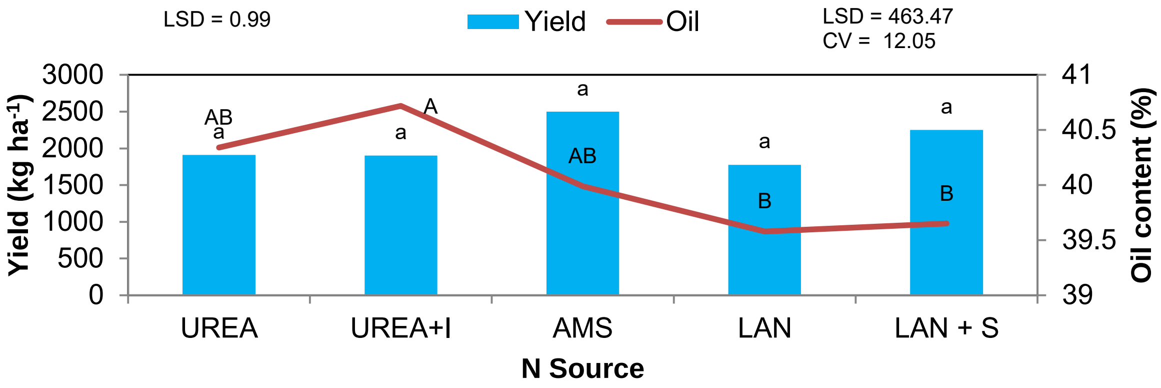

Figure 6.4 Influence of topdressed N source on canola yield (kg ha^{-1}) and oil content (%) at Tygerhoek during 2017. Bars with different lowercase letters indicate significant differences between mean yields at the 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

6.3 Langgewens

6.3.1 *Plant parameters*

No differences ($p>0.05$) were recorded in plant population after establishment and biomass production between N sources evaluated in 2016 (Table 6.5). In 2017, similar results were recorded as in 2016, namely that no differences ($p>0.05$) were recorded in plant population after establishment and plant population at harvest. There was however differences ($p<0.05$) recorded in biomass production between N source treatments in 2017. Urea recorded higher ($p<0.05$) biomass production compared to LAN and urea + inhibitor (Table 6.6).

Table 6.5 Influence of fertiliser N source on plant population after establishment (m^{-2}) and biomass production ($kg\ ha^{-1}$) at Langgewens 2016

Treatment	Plant population after establishment (m^{-2})	Biomass ($kg\ ha^{-1}$)
UREA	38 [a]	6667 [a]
UREA + I	37 [a]	8306 [a]
AMS	33 [a]	8083 [a]
LAN	33 [a]	8278 [a]
LAN + S	32 [a]	6667 [a]
CV (%)	22.7	16.4
LSD (0.05)	12.1	1920.8

Means without a common letter following the value in the same column differed significantly (P = 0.05).

Table 6.6 Influence of fertiliser N source on plant population after establishment (m^{-2}), plant population at harvest (m^{-2}) and biomass production ($kg\ ha^{-1}$) at Langgewens 2017

Treatment	Plant population after establishment (m^{-2})	Plant population at harvest (m^{-2})	Biomass ($kg\ ha^{-1}$)
UREA	51 [a]	36 [a]	5056 [a]
UREA + I	48 [a]	35 [a]	3889 [b]
AMS	54 [a]	38 [a]	4722 [ab]
LAN	49 [a]	35 [a]	3972 [b]
LAN + S	51 [a]	33 [a]	4139 [ab]
CV (%)	11.2	26.8	13.4
LSD (0.05)	8.7	14.6	943.0

Means without a common letter following the value in the same column differed significantly (P = 0.05).

6.3.2 *Yield and oil content*

The topdressed N sources evaluated did not influence ($p>0.05$) yield, but urea + I did however record lower ($p<0.05$) oil content compared to other N sources evaluated (Figure 6.5). In 2017 LAN recorded lower ($p<0.05$) yield than LAN + S and urea + inhibitor, but did not differ ($p>0.05$) from AMS and urea (Figure 6.6). Urea recorded higher ($p<0.05$) oil content than AMS but did not differ ($p>0.05$) from rest of N source treatments.

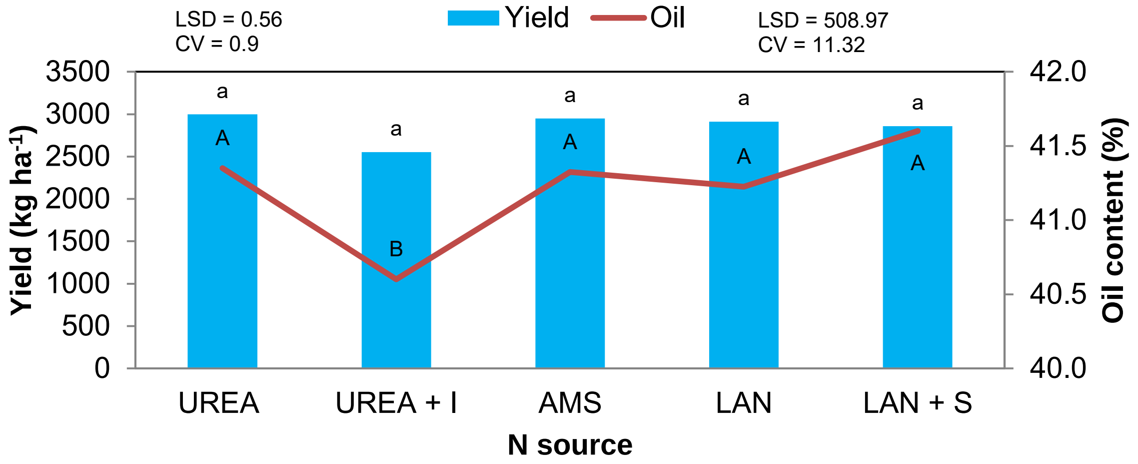

Figure 6.5 Influence of topdressed N source on canola yield (kg ha-1) and oil content (%) at Langgewens during 2016. Bars with different lowercase letters indicate significant differences between mean yields at the 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

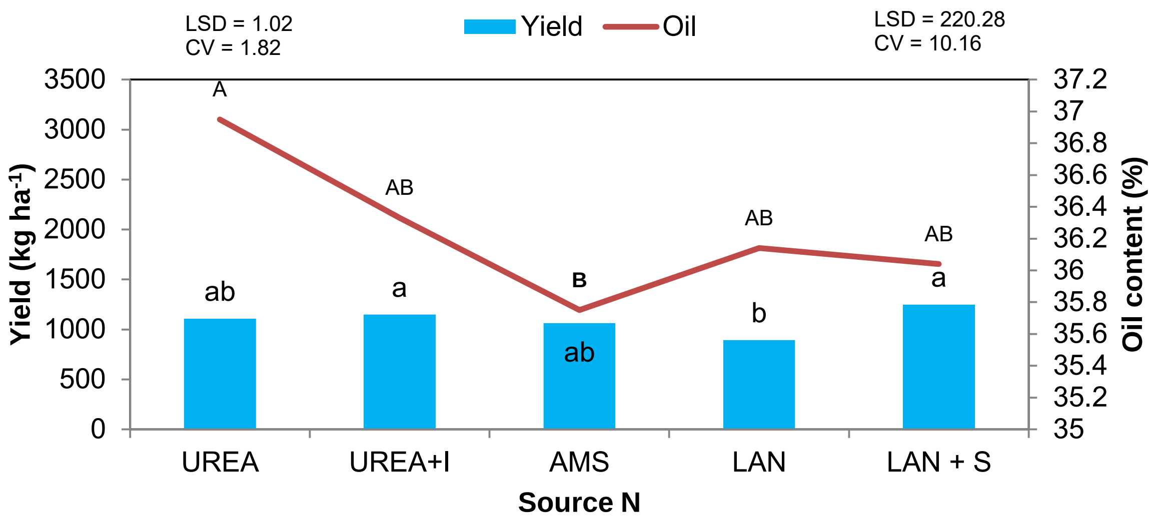

Figure 6.6 Influence of top-dressed N source on canola yield (kg ha^{-1}) and oil content (%) at Langgewens during 2017. Bars with different lowercase letters indicate significant differences between mean yields at the 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

6.4 Porterville

6.4.1 *Plant parameters*

No difference (p>0.05) was recorded in plant population after establishment, plant population at harvest and biomass production between N sources evaluated at Porterville 2017 (Table 6.7).

Table 6.7 Influence of fertiliser N source on plant population after establishment (m^{-2}), plant population at harvest (m^{-2}) and biomass production (kg ha^{-1}) at Porterville 2017

Treatment	Plant population after establishment (m^{-2})	Plant population at harvest (m^{-2})	Biomass (kg ha^{-1})
UREA	39 [a]	33 [a]	3611 [a]
UREA + I	37 [a]	40 [a]	3972 [a]
AMS	35 [a]	35 [a]	3167 [a]
LAN	38 [a]	41 [a]	3611 [a]
LAN + S	37 [a]	37 [a]	3389 [a]
CV (%)	14.0	22.1	26.7
LSD (0.05)	8.0	13.0	1460.4

Means without a common letter following the value in the same column differed significantly (P = 0.05).

6.4.2 *Yield and oil content*

No differences (p>0.05) in yield were recorded between N sources evaluated at Porterville 2017 (Figure 6.7). Only difference recorded in oil content was urea and LAN which recorded higher (p<0.05) oil content than urea + inhibitor and LAN + S.

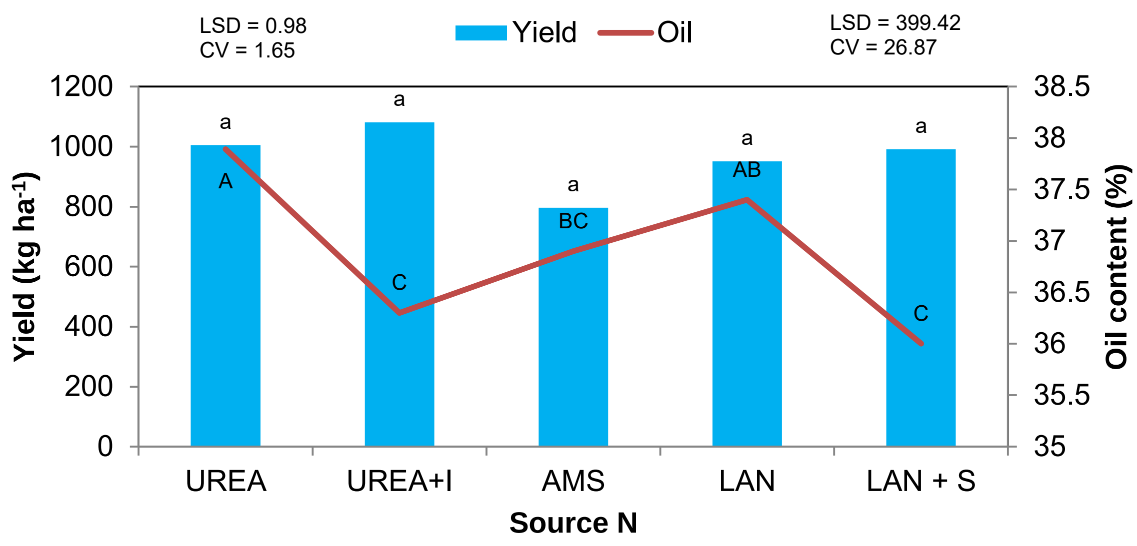

Figure 6.7 Influence of topdressed N source on canola yield (kg ha^{-1}) and oil content (%) at Porterville during 2017. Bars with different lowercase letters indicate significant differences between mean yields at the 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

6.5 Darling

6.5.1 *Plant parameters*

Plant population after establishment was not collected due to dry conditions after planting which resulted in unequal seedling emergence. Biomass production did not differ ($p>0.05$) between the different N sources evaluated at Darling 2016 (Table 6.8)

Table 6.8 Influence of fertiliser N source on biomass production (kg ha^{-1}) at Darling 2016

Treatment	**Biomass (kg ha^{-1})**
UREA	8889 [a]
UREA + I	8694 [a]
AMS	8917 [a]
LAN	8028 [a]
LAN + S	7833 [a]
CV (%)	28.2
LSD (0.05)	4364

Means without a common letter following the value in the same column differed significantly (P = 0.05).

6.5.2 ***Yield and oil content***

No differences (p>0.05) were recorded on yield and oil content between the different N sources evaluated at Darling (Figure 6.8).

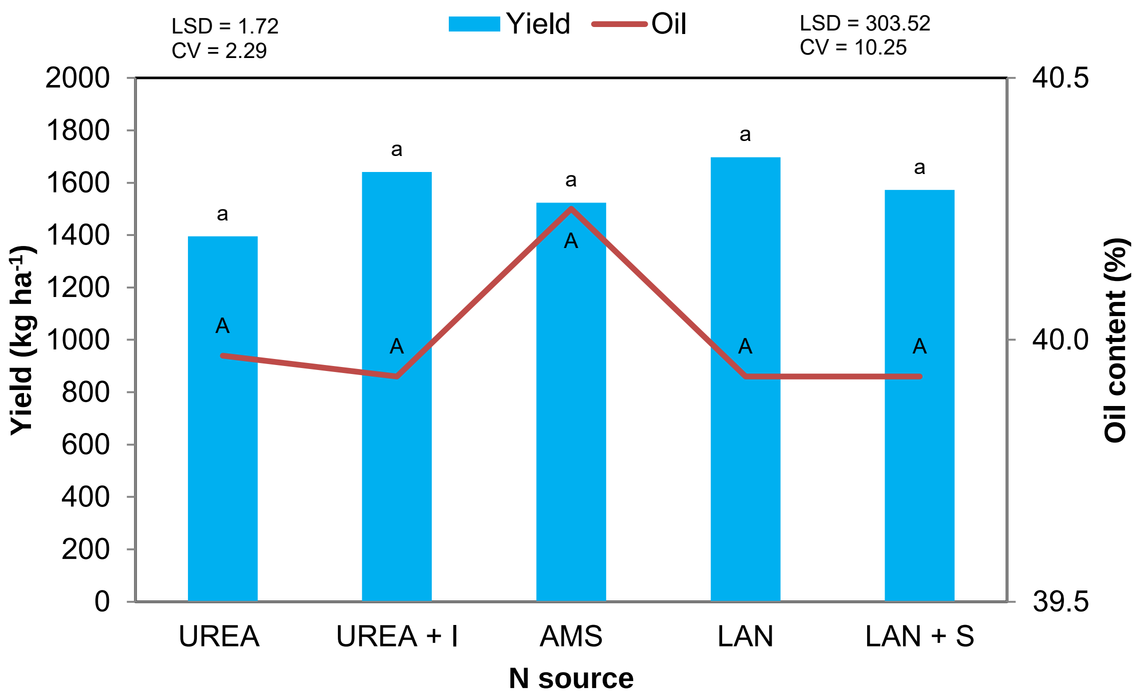

Figure 6.8 Influence of topdressed N source on canola yield (kg ha^{-1}) and oil content (%) at Darling during 2016. Bars with different lowercase letters indicate significant differences between mean yields at the 5% level. Points on the line with different uppercase letters indicate significant differences between mean oil content at a 5% level.

6.6 Discussion

6.6.1 *Plant parameters*

Plant population was not affected by nitrogen source treatments. These results were expected because all N source treatments received the same rate of N at planting (25 kg ha^{-1}) and the same fertiliser NPK mixture. Plant population varied between sites from 20 to 60 plants m^{-2}, which is adequate for canola production according to studies by Bernardi and Banks (1993) and French et al. (2016).

In 2016 and 2017 there were also no difference in plant population at harvest ($p>0.05$) between N sources evaluated at all sites. These results were in agreement to Barlog and Grzebisz (2004) and Kaefer et al. (2015) who reported no difference in plant population between different N sources.

Except for Langgewens 2017, no difference was recorded in biomass production ($p>0.05$) between different N sources evaluated. Taken into account that biomass production is correlated to N uptake (Sidlauskas and Bernotas 2003 and Taheri et al. 2012), N availability tended to be similar between N sources. Jones and Olson-Rutz (2016) and Grant and Bailey (1993) also found no significant difference in N efficiency between different N sources under field conditions.

Barlog and Grzebisz (2004) did, however, report differences in biomass production between N sources, as what was found at Langgewens in 2017. Urea recorded higher ($p<0.05$) biomass production compared to urea + inhibitor and LAN. Biomass production was influenced by N source due to influence on crop growth rate (Barlog and Grzebisz 2004). Urea has a higher release rate of N to soil compared to LAN and urea + inhibitor (Sait 2003). This is due to higher salt index of urea compared to LAN and the inhibitor effect which reduces N release of urea + inhibitor. Thus more readily available N through urea fertiliser compared to LAN and urea + inhibitor during favourable growing conditions could have increased crop growth rate which resulted in higher biomass production. It was expected that higher biomass production with urea would result in higher yield due to increased photosynthesis capacity. This was however not the case, as no differecne ($p>0.05$) was recorded in yield between urea, LAN and urea + inhibitor.

6.6.2 *Yield*

Nitrogen sources differ in terms of effect on crop physiology and response to environmental conditions which affected yield (Grant and Bailey 1993). Ozturk (2010) reported higher canola yield under sulphur deficient soil conditions after ammonium sulphate fertilisation compared to urea or an ammonium-nitrate source. Barlog and Grzebisz (2004) reported higher yield under ammonium nitrate fertiliser compared to NPK, calcium ammonium nitrate or calcium nitrate fertilisers. Plots fertilised with ammonium nitrate reached maximum physiological growth rate at an earlier stage which translated into higher yields. Under dry conditions urea application has a high risk for N loss through volatilisation which could limit yield (Kinsey 2006; Zimmer and Zimmer-Durand 2011). Addition of inhibitors (NBPT) to urea fertiliser application reduced volatilisation between 28% to 88% (Bishop and Manning 2008).

In 2016, results at all sites showed that yields were not influenced by topdressed N source (Urea, Urea + inhibitor, AMS, LAN+S, LAN). These results are similar to those reported by Behrens et al. (2002) and Kaefer et al. (2015) who found no differences in yield between different N sources. In 2017, no difference ($p>0.05$) in yield was recorded at Porterville, Tygerhoek and Riversdale. Langgewens did, however, record a difference ($p>0.05$) in yield. Urea + inhibitor and LAN + S recorded higher ($p<0.05$) yield than LAN, but it did not differ ($p>0.05$) from AMS and urea. LAN resulting in a lower ($p<0.05$) yield compared to urea + inhibitor and LAN + S may be due to low biomass production. Low biomass production results in reduced photosynthesis capacity, N metabolism and carbon fixation which correlate to lower yield ($p<0.05$).

Except for Langgewens in 2017, the different N sources tested in the study did not influence ($p>0.05$) yield. This might be due to optimum soil N conditions and optimum N rates during fertiliser applications which meant that each N source was utilised in a similar way by canola. Studies by Jones and Olson-Rutz (2016) reported no substantial difference in N availability and yield between N sources. Thus it could be concluded that N source should be selected based on cost, ease of application, leaf burn potential and reduced potential loss to volatilisation or leaching.

6.6.3 *Oil content*

In 2016, oil content did not differ ($p>0.05$) between N sources evaluated. These results were expected due to no difference ($p>0.05$) in yield recorded between N sources. Similar yields correlated to similar N uptake between N source plots which constitutes to similar oil content production. Kaefer et al. (2015) reported similar results where oil content was not influenced by different N sources. Oil content was, however, at an ideal quality level of 40% or more in 2016. In 2017, oil production recorded inconsistent results between sites and were in general lower compared to 2016. Riversdale, Langgewens and Porterville recorded an oil content below 40%. Low oil content of crop related to N source results are similar as those reported for oil content of N topdress treatments in 2017. Oil content did not differ ($p>0.05$) between N sources with or without additional S in 2017. Thus low oil content and inconsistent results recorded in general, may be due to dry conditions during flowering when oil production is most sensitive to water stress. Studies by Walton et al. (1999) and Tesfamariam et al. (2010) and Ma and Herath (2016) reported a reduction in oil content due to severe dry conditions such as experienced at the sites during 2017.

Chapter 7: Conclusion and Recommendations

7.1 Synopsis

Since the introduction of canola in the Western Cape, there has been a gradual increase in canola production among producers (SAGIS 2017). Canola is crucial in crop rotation systems with cereals as it creates opportunities to control weeds and increase wheat yield potential (Makhuvha and Hoffman 2015). Canola profitability is, however, under pressure, particularly when compared to wheat. Most producers therefore base their production systems on wheat and many producers are sceptical about planting canola. As canola has been introduced fairly recently into the production systems, a lack of knowledge regarding agronomic management of the crop exists. A better understanding of the ecophysiology and phenology of canola would lead to better management practices and reduce the economic risks involved with canola production.

There is a scarcity of research regarding N management of canola under conservation agriculture (CA) practices in the Western Cape. Following CA practices for an extended period of time, a change in certain physical, chemical and biological soil properties results, among which a change in soil N dynamics is prominent (Grahmann et al. 2014). It is important to take these changes in soil N dynamics into consideration when determining fertiliser N rates (Otto 2007). Current canola N recommendations are however, adopted from international literature or adjusted from N fertiliser guidelines for wheat. These guidelines in most cases do not take soil N and specific N demand of canola into account which could result in over or under fertilisation and eventually reduce profitability. Thus low profitability and inefficient fertiliser N use warrants new N management guidelines which are developed for canola under CA systems in different production areas. The aim of this study was therefore to determine the effect of different topdress N rates, foliar N application at stem elongation and sources of N have on plant parameters, canola seed yield, seed oil content and N use efficiency, whilst monitoring the effect of different topdress N rates on the soil mineral N concentration at plant, pre-topdress, post topdress and at harvest. The study was divided into three sections, each with its own objective:

1) The first objective was to determine the effect of different topdress N rates at rosette stage (4 to 5 leaf stage) on plant parameters, canola yield, oil content and N use efficiency, while monitoring the response of N application on soil mineral N content.

2) The second objective was to determine the effect of an additional foliar N application in the form of urea ammonium nitrate (UAN) at stem elongation stage on canola yield and oil content.

3) The third objective was to determine the effect of different N sources on plant parameters, canola yield and oil content.

7.1.1 *Objective 1: Determining the effect of different topdress N rates on soil mineral N concentration, plant parameters, canola yield, oil content and N use efficiency of canola*

Although increasing topdress N rate resulted in increased ($p<0.05$) soil mineral N concentration, the crop was not able to utilise excessive soil mineral N at high topdress N rates (105 kg ha^{-1} to 165 kg ha^{-1}). At harvest, soil mineral N concentration was similar between different topdress N rates. Thus these high topdress N rates of 105 kg ha^{-1} to 165 kg ha^{-1} resulted in over fertilisation. Weather conditions had definite impact on soil mineral N concentration response to N fertilisation and should be accounted for during determining of fertiliser N rates. Dry periods following planting resulted to low soil mineral N concertation response to N application at planting. Soil mineral N concentration in response to N topdressings was also very low during 2017 possibly due to the dry conditions.

Topdress N rate did not influence plant population at harvest. Contrary to what was expected, biomass production was also, in most cases, not influenced ($p>0.05$) by topdress N rate. Biomass production may not have responded to the topdress N due to dry periods experienced during the growing season.

Increasing topdress N rate increased ($p<0.05$) canola yield, but maximum yield response was reached at lower topdress N rates than expected. Optimal topdress N rate was 25 kg ha^{-1} at Riversdale and Tygerhoek in the southern Cape. This topdress N rate is lower than current N topdressing guidelines of 45 kg ha^{-1} for Riversdale and 68 kg ha^{-1} for Tygerhoek ascribed by FERTASA (2016) and fertiliser experts in the Western Cape. Langgewens, Porterville and Darling in the Swartland recorded an optimal topdress N rate of 50 to 75 kg ha^{-1}. This topdress N rate range are similar to current N guidelines ascribed by FERTASA (2016) and fertiliser experts in the Western Cape for the respective production areas.

Southern Cape sites recorded N use efficiencies (NUE) of 40% at optimal topdress N rate which was slightly lower than ideal NUE levels (EU Nitrogen Expert Panel 2015). Swartland sites recorded low NUE of 10% to 15% at optimal N topdress rates. It would thus be recommended not to increase topdress N rate above 50 kg ha^{-1} to 75 kg ha^{-1} due to the possibility of over fertilisation. Oil content generally decreased ($p<0.05$) as N rate increased at all sites in 2016 and 2017. The dry conditions during 2017 had a definite impact on reduction of oil content production. Final recommendations will however, only be finalised on completion of the research project after four years of data capturing.

7.1.2 *Objective 2: Determining the effect of topdress N rate plus foliar N at stem elongation on canola yield and oil content*

Applying an additional foliar N application of 20 kg N ha^{-1} (UAN) at stem elongation did not ($p>0.05$) increase yield in 2016 and 2017 at most of the sites. There was, however, a higher yield ($p<0.05$) recorded for the control and 0 kg ha^{-1} treatments at Riversdale and Tygerhoek. Foliar N application may thus be beneficial during N deficient conditions. Foliar N application did not influence oil content, which was expected.

7.1.3 *Objective 3: Determining the effect of N source on plant parameters, canola yield and oil content*

In general, N sources did not affect ($p<0.05$) the different variables evaluated. In 2016 and 2017, N sources did not affect plant population at harvest and biomass production at most sites. Nitrogen sources did also not affect yield, except at Langgewens 2017. Oil content was also not influenced by N source during 2016, while inconsistent results were recorded for oil content in 2017. These inconsistent oil content results observed for 2017 may be due to the dry conditions.

7.2 General conclusion

After doing a complete analysis of the canola N requirement under CA practices in different production areas of the Western Cape, it was apparent that N fertiliser recommendations have to be adjusted for certain areas. Current N recommendations may result in over fertilisation and reduced profitability at sites in the southern Cape. Current N recommendation at the Swartland sites caused low NUE and further increase in topdress N rates would most likely result in pollution of the environment. It is very important to take weather conditions into account when determining topdress N rate. Foliar N application at stem elongation did not affect yield and oil content at optimal soil N conditions. Nitrogen source did not affect variables evaluated and selection should be based on cost.

7.3 Limitations of research

The number of research sites and extensive area that was covered in this study made it difficult to monitor crops frequently during the growing season for potential crop growth limitations. These limiting factors include optimal timing of weed spraying, N topdressings and harvesting. During 2017, weed spraying at Porterville and Langgewens was slightly delayed when weeds were already well established. This might have limited N fertiliser response due to N uptake by weeds.

The dry period experienced during planting in 2016 and 2017 limited seedling emergence and N fertiliser response. Uneven emergence could have caused yield limitations and made it difficult to determine optimum time for collecting plant population data. Low rainfall and low soil moisture following N topdressings during 2017 may have caused yield response limitations as well as delayed N release to soil which could have affected post topdress soil mineral N concentration results. It is recommended that post topdress soil sampling should thus only be taken following substantial rainfall after N topdressing.

7.4 Recommendation for future research

Both years evaluated during this study was relatively dry, therefore it is uncertain how the effect of N fertilisation would have been in a wet season. It is thus recommended that this study should continue (as planned) for a further year or two to include the effect of a wet season before reliable N guidelines can be finalised.

Future research into investigating methods of increasing overall NUE of canola, especially at high topdress N rates are recommended. This may be achieved by determining limitations associated with N assimilation at high N supply and resolving these limitations. Determining and monitoring the effect weather conditions have on soil mineral N might also give insight and increase knowledge base on how to adjust N fertiliser during severe weather conditions which could improve N management efficiency.

It is recommended that alternative fertiliser strategies such as foliar N fertilisation should be compared to the conventional broadcasted granular N fertilisation. To our knowledge, there are no studies on N foliar fertilisation of canola, most of these studies have been done on wheat and soybeans (Fageria et al. 2009). It could thus reveal interesting results which might increase efficiency of N management of canola production.

Furthermore it is recommended to do a cost-benefit and sensitivity analyses of these results to evaluate gross and profit margins and compare it to current N guidelines which are based on canola production under conventional practices. This may yield interesting result in terms of how CA has changed profitability due to lower N fertiliser recommendations.

Chapter 8: References

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