Rate and timing of nitrogen fertilisation for canola production in the Western Cape of South Africa

by

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Thesis presented in partial fulfillment of the requirements for the degree
Master of Science in Agriculture
at
University of Stellenbosch

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March 2017

DECLARATION

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March 2017

Abstract

Canola (*Brassica napus*) is increasing in popularity as a cereal crop in the Western Cape. Nitrogen (N) is generally the most limiting nutrient to canola production. Nitrogen fertiliser guidelines for canola are currently adopted from international literature or adopted from guidelines for wheat, and should be refined for the local environmental conditions. The aim of this study is to determine the optimal rate of N fertilisation, and the distribution thereof in the Western Cape. Field experiments were conducted in 2015 at Langgewens and Altona (Swartland) and Roodebloem (southern Cape). The trial was laid out as a factorial arranged in a randomised block design, with six N rates (0, 20, 60, 90, 120 and 150 kg N ha^{-1}), of which each rate was applied in either one, two or three increments after planting, replicated in four blocks. Twenty kg N ha^{-1} was applied at planting. The rest was divided in equal increments either 30 days after planting (DAP), 30 and 60 DAP or 30, 60 and 90 DAP. Soil mineral N, leaf area index (LAI) and biomass was determined at 30, 60 and 90 DAP. Grain yield and thousand kernel mass (TKM) was recorded. Using these values obtained, agronomic N use efficiency (ANUE), water use efficiency (WUE) and profitability was determined by means of a sensitivity analysis. Treatments had no effect ($P>0.05$) on total soil mineral N content at any locality at any physiological stage with the exception of 90 DAP at Langgewens. Neither LAI nor biomass was affected by treatments ($P>0.05$) at any locality, at any physiological stage. Yield at Roodebloem was affected ($P<0.05$) by N fertilisation and treatments which had the highest yield were those who received 20 kg ha^{-1} at planting, and 70 or 100 kg ha^{-1} at 30 DAP respectively. These treatments did not differ ($P>0.05$) from treatments which received more than 60 kg N ha^{-1}, regardless of the distribution. At Langgewens and Altona, N fertilisation had no effect ($P>0.05$) on yield, while TKM was not affected by treatments at any locality. No differences ($P>0.05$) were observed for ANUE at Altona and Langgewens, while treatments had a significant effect on ANUE at Roodebloem. The treatment that received 20 kg N ha^{-1} at planting and 100 kg N ha^{-1} at 30 days after planting and no N later, had the highest WUE, but did not differ ($P>0.05$) from a number of treatments that received more than 90 kg N ha^{-1} at various time intervals. The WUE at Altona and Langgewens was not affected by treatments ($P>0.05$). At both Altona and Langgewens the highest gross income was obtained by treatment that received no N at all, while at Roodebloem the highest gross income was obtained by applying 90 kg N ha^{-1} for the entire duration of the growing season. Preliminary results indicate optimum N fertiliser rate of 90 to 120 kg N ha^{-1}, applied as 20 kg N ha^{-1} at planting and the remainder at 30 DAP at Roodebloem. No significant response to N applications was recorded in the Swartland. These results could be ascribed to drought conditions during 2015, which may have prohibited efficient uptake of N in the Swartland localities of Altona and Langgewens during critical periods.

The differences between treatments at Roodebloem in the southern Cape might be due to a combination of sufficient rainfall over the growing season, lower temperatures and sufficient N being available during early, rapid vegetative growth. This in turn enabled a higher LAI which allowed for higher biomass accumulation, and consequently higher translocation to seeds. It is recommend that this study be repeated before results could be used to develop fertiliser guidelines for canola production in South Africa.

Uittreksel

Kanola (*Brassica napus*) se gewildheid as graangewas in die Wes-Kaap is aan die toeneem. Stikstof (N) is oor die algemeen die mees beperkendste voedingstof vir kanolaproduksie. Stikstofriglyne vir kanolaproduksie word huidiglik afgelei vanaf internasionale literatuur of die riglyne vir koringproduksie, en moet vir die plaaslike omgewingstoestande verfyn word. Die doel van hierdie studie is om die optimale N bemestingspeil, asook die verspreiding daarvan in die Wes-Kaap te bepaal. Veldeksperimente is in 2015 op Altona en Langgewens (onderskeidelik hoë en matige produksiepotensiaal areas in die Swartland) en Roodebloem (Suid-Kaap) uitgevoer. Die eksperiment is uitgelê as 'n faktoriaal in 'n ewekansige blokontwerp uitgelê met ses N-peile (0, 20, 60, 90, 120 en 150 kg N ha^{-1}) wat in een, twee of drie stadiums na plant toegedien is, en in vier blokke herhaal. Twintig kg N ha^{-1} is toegedien tydens plant. Die res van die peil is dan verdeel in gelyke inkremente of óf 30 dae na plant (DNP), 30 en 60 DNP of 30,60 en 90 DNP. Grondminerale N, blaaroppervlakindeks (BOI) en biomassa is vasgestel op 30, 60 en 90 DNP. Graanopbrengs en duisend korrel massa (DKM) is na oes vasgestel. Hierdie waardes is gebruik om agronomiese N verbruiksdoeltreffendheid (ANVD), waterverbruiksdoeltreffendheid (WVD) en winsgewendheid deur middel van n sensitiwiteitsanalise, te bepaal. Behandelings het geen effek ($P>0.05$) op die totale grondminerale N op enige van die lokaliteite tydens enige van die fisiologiese stadiums gehad nie, met die uitsondering van 90 DNP op Langgewens. Behandelings het geen effek op BOI of biomassa ($P>0.05$) op enige lokaliteit, teen enige fisiologiese stadium gehad nie. Die opbrengs op Roodebloem is deur N behandelings beïnvloed, en die behandelings wat die hoogste opbrengs gehad het, het 20 kg N ha^{-1} tydens plant, en 70 of 100 kg ha^{-1} op 30 DNP onderskeidelik ontvang. Hierdie behandelings het nie verskil ($P> 0.05$) van behandelings wat meer as 60 kg N ha^{-1}, ongeag die verspreiding daarvan, ontvang het nie. Op Langgewens en Altona het behandelings geen effek ($P> 0.05$) op die opbrengs gehad nie, terwyl DKM nie deur die behandelings op enige van die lokaliteite beïnvloed was nie. Geen verskille ($P> 0.05$) is waargeneem in ANVD op Altona en Langgewens nie, terwyl behandelings 'n beduidende effek op ANVD op Roodebloem gehad het. Die behandeling wat 20 kg N ha^{-1} tydens plant en 100 kg N ha^{-1} op 30 dae na plant en geen N later ontvang het nie, het die hoogste WVD gehad, maar het nie verskil ($P> 0.05$) van 'n aantal ander behandelings wat meer as 90 kg N ha^{-1} ontvang op verskillende tydsintervalle nie. Die WVD by Altona en Langgewens is nie deur behandelings ($P> 0.05$) beïnvloed nie. Op beide Altona en Langgewens is die hoogste bruto inkomste deur die behandeling wat geen N ontvang verkry, terwyl op Roodebloem die hoogste bruto inkomste verkry is deur 90 kg N ha^{-1} vir die volle duur van die groeiseisoen toe te dien. Voorlopige resultate dui optimale N-peile van 90 tot 120 kg N ha^{-1}, toegedien as 20 kg N ha^{-1} tydens plant en die res op 30 DNP op Roodebloem. Geen beduidende effek op N bemesting is in

die Swartland waargeneem nie. Die resultate in die Swartland kan aan droogtetoestande gedurende 2015 toegeskryf word, wat die doeltreffende opname van N tydens kritieke periodes kon verhoed het. Die verskille tussen behandelings by Roodebloem in die Suid-Kaap kan toegeskryf word aan 'n kombinasie van voldoende reënval oor die groeiseisoen, laer temperature en voldoende N wat beskikbaar was vroeg in die seisoen tydens vegetatiewe groei. Dit het op sy beurt die plante in staat gestel om 'n hoër BOI te ontwikkel, wat hoër biomassa akkumulasie, en gevolglik hoër translokasie na sade tot gevolg gehad het. Dit word aanbeveel dat hierdie studie herhaal word voordat dit gebruik word om bemestingsriglyne vir kanolaproduksie in Suid-Afrika te ontwikkel.

Acknowledgements

My parents, Bertus and Marlene Coetzee, for giving me opportunities that was never yours to take, you are and will forever be my role models, guardians and friends.

Dr Pieter Swanepoel – Thank you for not only what you taught me about agriculture, but about life, passion and humanity. Your influence on my life will forever be visible.

Prof André Agenbag, your experience and inputs in this project and the sector is invaluable.

My friends and family for always lending an ear, allowing me to express my passion for agriculture and for guidance, proof reading and support.

A special thank you is expressed to Ronald Oosthuizen and his technical team for assistance and management of the trial.

The Protein Research Foundation for financial assistance.

My Heavenly Father, for allowing me the honour to be a trustee, a protector of the earth, and for all the above mentioned individuals, whose influence on my life can never be fully emphasised.

"I recognize the right and duty of this generation to develop and use the nature resources of our land: but I do not recognize the right to waste them, or to rob, through wasteful use, the generations that come after us."

Theodore Roosevelt

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Vir Johan van Huyssteen – hierdie is my klein bydrae tot jou groot passie vir die landbou

16 Augustus 1993 – 4 Januarie 2016

Chapter 1

Introduction

Canola (*Brassica* spp.) is a major oilseed crop with increasing importance in the southern Cape and Swartland regions of South Africa. The southern Cape is located about 150 km east of Cape Town and the major towns are Hermanus, Caledon, Bredasdorp, Swellendam and Heidelberg. The landscape is dominated by gently to moderately undulating hills enclosed by mountains to the north and the Indian Ocean to the south. The Swartland begins 50 km north of Cape Town and consists of the regions between the towns of Malmesbury in the south, Darling in the west, Piketberg in the north and Riebeek West and Riebeek-Kasteel in the east. These regions are highly suitable for production of canola due to its rainfall distribution and soil properties (Hardy and Wallace 2014). These areas generally receive the bulk of their rainfall from May to September. Most soils found in the area are characterised with a sandy loam texture and a high gravel content. These climate and edaphic characteristics contribute to canola being one of the only plant protein sources that can successfully be produced in the region.

Currently, commercial canola production in South Africa is confined to the Western Cape Province and has yet to be developed as a commercial crop elsewhere in South Africa. Trials evaluating canola production under irrigation is currently being undertaken in the central areas of South Africa. During 2015, 78 050 ha of canola was planted in the Western Cape. Canola is used to produce cooking oil and margarine in South Africa. In health conscious societies, canola oil is gaining popularity because of its high content of oleic and linolenic acids and by its favourable linoleate: linolenate ratio (Eskin and MacDonald 1991). After processing, the canola oilcake is valuable as a source of protein in animal feed rations (Weglarzy et al. 2013). Projections made by the Protein Research Foundations for 2020 using basis years, indicated a 3.1% increase in oilcake consumption in livestock feed programs. This projection increases to 3.2% by 2025 (Protein Research Foundation 2013).

Canola is not only regarded as an important oilseed crop locally, but also worldwide. It is second only to soybean as the most important source of vegetable oil in the world (Raymer 2002). In addition, *Brassica* spp. is important in crop rotation systems due to its possible long-term effects on other cereal crops in subsequent rotations (Hardy and Wallace 2014). Canola cultivated in rotation with winter cereals in Alberta, Canada, has shown a significant higher economic return in the winter crop cereals. This was primarily due to effective weed control possibilities during the canola seedling establishment phase (Blackshaw 1994.) Canola used as a break crop also reduces the disease pressure in wheat production systems (Mason and Brennan 1998; Lamprecht et al. 2006). This is one of the most important advantages of using canola in the crop rotation systems in the Western Cape (Lamprecht et al. 2006).

Canola has a relatively high requirement for nitrogen (N), and compared to other crops produced in the southern Cape and Swartland, has a low N use efficiency (NUE) (Sylvester-Bradley 2009). Nitrogen is also one of the highest input costs in canola production. The scope to enhance canola profitability by improving the NUE, is largely dependent on management strategies, based on fertiliser guidelines. Nitrogen fertiliser guidelines should differ between regions of dissimilar environmental conditions (Ozer 2003). Currently, appropriateness of N fertiliser guidelines for canola in South Africa is questioned. These guidelines are adopted from international literature or adopted from guidelines for wheat, and should be refined for the local environmental conditions.

Furthermore, increased N application rates and the time of application may play significant roles in increasing canola production (Mason and Brennan 1998). Although N is known to enhance production in comparison to crops grown with no additional applied N (Allen and Morgan 1972), yields obtained for the amount of N applied, are lower than potential yields for the rate of N (Cheema et al. 2010), as judged by best farmer yields (Hocking et al. 1997). These lower yields are mainly due to imbalanced nutrient supply. As N fertiliser accounts for one of the highest input cost refined N management may have a substantial influence on the profitability of canola production. Research on the optimal rate of N application has been done in the Swartland and southern Cape, while little information is known about distribution of N application in these regions. The opportunity to further enhance production of canola by refining N topdressing management strategies in the Western Cape exists. Enhanced production requires research on management practices in the southern Cape and Swartland which will lead to improved production.

With the demand for canola expected to rise, this study aims to improve the management of application strategies to enhance the N use efficiency of canola in the Swartland and southern Cape by determining the optimal rate and timing of fertiliser N applications in the Swartland and southern Cape.

The hypothesis is stated as follows:

H_1H_0: Increasing rates of N application will lead to increased yields up to an optimum level.

H_1H_1: Increasing rates of N application will not lead to increased yields.

H_2H_0: Split application of N over more than one time of application will increase yield.

H_2H_1: Split application of N over more than one time of application will not increase yield.

Following the literature review in Chapter 2, the effect of different N rates and the time of application thereof on yield, thousand kernel mass (TKM), total soil mineral N, leaf area index (LAI) and biomass is addressed in Chapter 3. In Chapter 4 the effect of the different rates and time of application thereof on agronomic nitrogen use efficiency (ANUE), water use efficiency (WUE) and the economic feasibility of each treatment are addressed. In Chapter 5, conclusions and recommendations for this study is made.

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Chapter 2
Literature Review

2.1. Introduction

Canola produced in the southern Cape and Swartland is produced under similar climatic circumstances as western and southern Australia, due to their location on the same latitude and both having a Mediterranean-type climate. As in Australia, only *Brassica napus* cultivars adopted to short day length conditions are grown during the winter growing season. In South Africa, nitrogen (N) is often the most limiting nutrient for production of cool- and warm season grain crops. According to the Protein Research Foundation (2013), N fertiliser is the highest production cost in producing canola. Canola has a relatively high requirement for N (Holmes 1980; Grant 1993). It removes 40 kg ha^{-1} N from soil to produce one ton of grain, in comparison with wheat, which only removes 21 kg ha^{-1} N to produce one ton of grain (Protein Research Foundation 2013). This review aims to illustrate the need for a better understanding of time and rates of N fertilisation to enhance N use efficiency (NUE) and yield, in the Swartland and southern Cape production areas, to therefore maximize the profitability and ensure the sustainability of canola production in these production areas.

2.2. The nitrogen cycle

Plants absorb N in the form of nitrate (NO_3^-) and ammonium (NH_4^+), with NO_3^- being the preferred form. A large proportion of the N in the soil is naturally found in organic form and is not readily available for uptake by plants. The organic nitrogen should be transformed into inorganic N forms before it can be used by plants. Soil particles are charged negatively, and therefore NO_3^- is mobile in soils, making it susceptible for leaching. The availability of NO_3^- and NH_4^+ to plants is subject to mineralisation, nitrification, leaching, volatilization and denitrification. Mineralisation is the process of converting bound organic N to inorganic, plant available NH_4^+. Nitrification is the process of converting NH_4^+ to NO_3^- through the working of Nitrosomonas and Nitrobacter bacteria, after which it becomes available to plants (Yue et al. 2014).

A simplified N cycle is illustrated in Figure 2.1 on page 6.

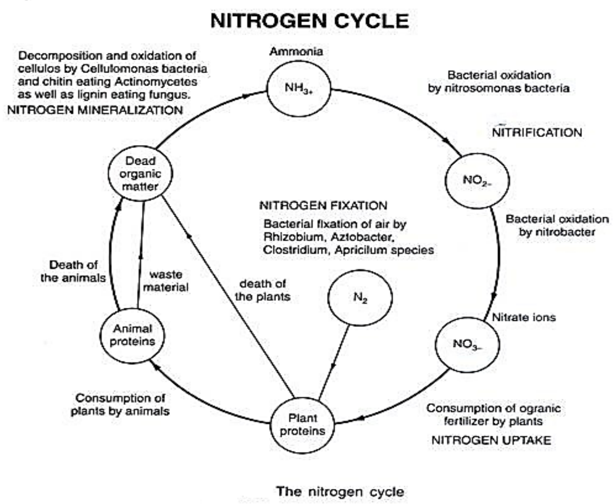

Figure 2.1: The soil nitrogen cycle, indicating the transformations of organic N into plant available forms of nitrogen (www.yourarticlelibrary, 2016.).

2.3. Physiological development of canola and nitrogen use

According to Harper and Berkenkamp (1975), *Brassica napus* have six growth stages, each stage with different requirements towards N uptake (Figure 2.2). Classification of these stages tends to be more complicated than conventional winter crops, primarily because of the indeterminate growth pattern of canola, causing growth stages to overlap.

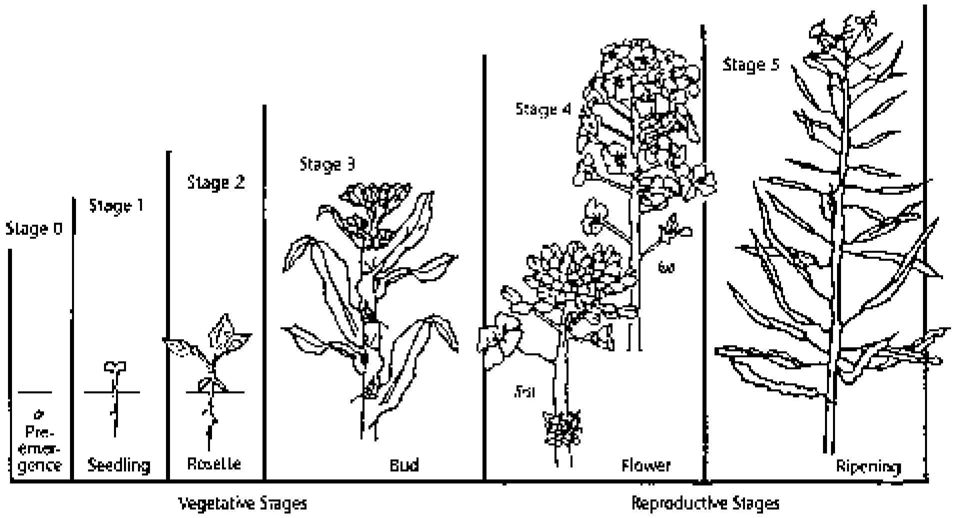

Figure 2.2: The six growing stages of *Brassica napus* as described by Harper and Berkenkamp (1975).

During pre-emergence, stage 0, N uptake is very low. The N needs for plant growth is partially met by reserves in the seed (Protein Research Foundation 2013). Due to the small size of the canola seed, it has a limited amount of resources to support the plant during establishment. Pre-sowing N or N at planting is therefore required to support establishment.

The establishment of the seedling, stage 1, requires only a small amount of N, as the seedlings growth is still sustained by the pre-sowing N or N at planting. Brandt et al. (2007) found that plant density decreased at higher fertiliser levels during planting, due to excessive inorganic N from fertiliser salts that may lead to fertiliser-induced burning of the seedling.

During stage 2, when the leaves are produced, leaf growth showed strong correlation to N fertiliser (Rood and Major 1984). Rapid leaf growth is needed to give the canola plant a competitive advantage towards weeds. In leaves, N is a component of chlorophyll, which is responsible for photosynthesis. Optimal availability is therefore crucial during leaf production, to ensure optimal leaf area and sufficient levels of chlorophyll for photosynthesis. Leaf area index (LAI) indicates the area of leaves produced. A LAI of 3.11 at start of flowering was found to be optimum (Cheema et al. 2001). Relatedly, the leaf area duration (LAD) indicates the area of the leave and the duration of the leaf. Scott et al. (1973) reported that LAD of oilseed rape was closely related to LAI and that LAI was increased by higher rates of N application. Nitrogen improves leaf area duration (LAD) after flowering and increases the amount of assimilates, leading to an increased seed yield (Wright et al. 1998).

Stage 2 and 3 overlaps. During stage 3, the budding stage, stem elongation and flower initiation takes place. This stage is also known as a stage of active root growth. Stage 3 shows similar N-uptake patterns as for stage 2 and is known for its rapid production of dry matter and nutrient needs (Cheema et al. 2010). A study done on the comparison of growth response and N uptake by Mason and Brennan (1998) indicated that rate of N uptake by canola was the highest between 6 and 8 weeks after seeding, the stages of leaf production and stem elongation. Similarly, the rate of dry matter production of canola was at its highest during week 8.

During the end of stage 3, flowers are also initiated. The canola plant undergoes a physiological change from vegetative growth to reproductive growth. Most of the plants dry matter has been formed by this stage. While N uptake is still increasing during this stage, the rate of uptake is slower than in stage 2 (Mason and Brennan 1998). The maintenance of the leaf surface will determine pod set, oil content and yield (Scott et al. 1973), thus the importance of sufficient levels of N. During anthesis, stage 4, canola plants produce pods from the existing flowers. The final number of seeds in the pods is fixed in this stage. During the final stage of the canola plants life cycle, ripening, the pods formed during flowering are the main sink of N. N is mobile within the plant (Grant 1993), and can therefore be mobilised from bearing branches and translocated to the developing pods (Zhang et al. 1991).

The yield of canola as a result of increasing N application will be influenced by the plants ability to mobilise N from senescing leaves and branches during this stage. While N uptake was the highest in stage two of the life cycle, 14% of total dry matter accumulates after the end of flowering (Hocking et al. 1997), largely due to the mobilisation of accumulated N.

2.4. Nitrogen use efficiency

2.4.1. Rate of nitrogen application

A study involving the time and rate of N application, conducted in Pakistan, indicated that the total dry matter, leaf area index (LAI), leaf area duration (LAD), seed and oil yield, and protein content were significantly affected by N application rate (Cheema et al. 2010).

Studies to determine the optimal rate of N to ensure the highest yield in canola has been done worldwide (Wright et al. 1998; Rathke et al. 2005; Cheema et al. 2010). Although various trials have been conducted to test the optimal rate of N for canola, special attention needs to be paid to these rates in the southern Cape and Swartland (Protein Research Foundation 2013). Fertiliser recommendations are site specific because crop response to fertiliser is driven by the availability of water. The rate of N applied has different impacts on dry matter, seed yield, oil concentrations, total N in the plant and N in the shoots (Hocking et al. 1997). Nitrogen increases the yield by stimulating more branches per plant, and therefore more flowers per plant (Ozer 2003). The higher amount of flowers stimulates the development of a higher amount of pods, leading to a higher seed yield.

Hocking et al. (1997) experimented with N applications rates of 0, 10, 25, 50, 75, 100 and 150kg N ha^{-1} in a trial in New South Wales, Australia. Before sowing, 25kg N ha^{-1} was applied. Dry matter yield was found to be lower a fertilization rate of 75 kg ha^{-1} than at 50 kg ha^{-1}, but higher than at 0 and 25 kg ha^{-1}. While a fertilisation rate of 75 kg N ha^{-1} proved to be effective, 50 kg N ha^{-1} was more efficient. Seed yield improved at higher rates of applied N. The higher number of seeds and pods obtained by higher rates of applied N ensured a higher yield than at lower rates of applied N.

Similarly, a study by Mason and Brennan (1998) made use of increasing rates of N application (0, 35, 69 and 138 kg N ha^{-1}). Results indicated higher protein concentrations in the grain, but lower oil concentrations with increasing rates of N application. This study corresponds with the findings of Hocking et al. (1997).

During 2008 and 2009, the impact of the rate and the timing of N application on the yield were tested in Pakistan. While the climatic circumstances differ from the production areas in the current study in the Swartland and southern Cape, the study confirmed that the rate of N application significantly increased seed yield and protein contents of canola (Cheema et al.

2010). Increasing N application led to a decrease in oil percentage, indicating an inverse relationship between oil percentage and protein content. This was in line with Ozer (2003). The increase in yield due to increasing applied N was due to a higher number of pods per plant, a result of a higher amount of flowers per plant.

2.4.2. Timing of nitrogen application

Time of N application will vary greatly, depending on environmental conditions. During the period of 2001 to 2003, a study involving the rates of N and the times of application were conducted (Cheema et al. 2010). It was found that the time of application played a significant role in both seasons of the conducted trial. This might be due to nutrients being available at optimum times when canola plants required it the most. The optimum time of fertiliser application will be dependent on the climate (Grant and Bailey 1993). The optimal recommendation found by Cheema et al. (2010) was 60kg ha^{-1} at sowing and 60 kg ha^{-1} at flowering. Nitrogen is mobile in soils, and, as discussed previously, heavy early winter rains in the southern Cape and Swartland on sandy loam soils may lead to N losses in the form of leaching. Applying additional N after heavy rains might therefore be more available to uptake than before rains, depending on the soil type. Powlson et al. (1992) found a linear relationship between fertiliser N and drainage in the rain season, while N applied in the drier season resulted in increased amounts of residual N in the soil after harvest. They also found that a loss of N fertiliser occurs soon after application, because plants did not have sufficient time to absorb it.

The foregoing review emphasises the need for a better understanding of rates of N application and specifically the timing of N application in the southern Cape and Swartland production areas, to enhance the NUE of canola. This in return may lead to better management strategies to produce canola more cost efficiently.

To produce more canola cost efficiently, a proper understanding of the NUE is essential. The NUE is defined as the final amount of grain produced per unit of the total amount of N available for the plant (Sylvester-Bradley and Kindred 2009). The total amount includes N applied and N available in the soil. A wide spectrum of additional parameters can be determined by using NUE, such as the agronomic use efficiency. Agronomic use efficiency (AUE), by definition, is the amount of grain produced per unit of fertiliser applied (Wright et al. 1998). This parameter is more practical, as it is difficult to determine the amount in the soil and the amount taken up by plants. The Harvest Index (HI) needs to be taken into account when determining NUE.

Oilseed rape is highly inefficient in using N, in comparison with other crops. Table 1 illustrates the NUE (kg DM kg^{-1} N) of various crops, along with parameters needed to obtain the NUE value. Winter oilseed rape has a lower NUE than winter crops (wheat, barley and oats) commonly grown in the Swartland and southern cape. While the NUE of canola are mainly determined by the cultivar (Svečnjaka and Rengel 2006), various environmental factors may influence the NUE. The response of canola to increasing rates of N varies due to environmental differences, including climate, soil moisture-and type, and residual fertility (Ozer 2003).

Table 2.1: The main arable crops grown in the UK, listed according to their average overall NUE, adapted from Sylvester-Bradley and Kindred (2009). NUE = Nitrogen use efficiency

Crop	Harvested (t ha^{-1})	N applied or fixed (kg ha^{-1})	N capture (kg N uptake kg^{-1} N available)	N conversion (kg DM kg^{-1} N uptake)	NUE (kg kg^{-1} N available)
Winter oats	5.1	109	0.67	40	27
Winter wheat: milling	6.2	209	0.65	33	22
Winter barley: malting	4.6	143	0.45	46	21
Oilseed rape: Winter	2.9	207	0.85	12	10

2.4.3. Environmental influence on nitrogen use efficiency

Mineralisation and nitrification are subject to various environmental factors that influence biological activity of these *nitrosomonas* and *nitrobacter* bacteria. Nitrification occurs very slowly at low temperatures, and the optimal temperature for soil microbial activity was found to be 25°C to 35°C (Yue et al. 2014). Higher temperatures lead to a decrease in mineralization rate, if soil moisture is insufficient. Canola prefers cool temperatures and the duration of growth stages will therefore be shortened by high temperatures (Protein Research Foundation 2013). Shorter development stages caused by high temperatures, will lead to lower yields and oil contents. Depending on the management system, higher temperatures will have a direct effect on the tempo of evaporation (Milly 1984), causing a decrease in available moisture, leading to a decrease in NUE.

The availability of soil water plays a major role in the final yield of canola. Moisture shortages during the stem elongation and pod fill stages will impact oil and seed yield. As discussed in the physiological stages of canola, active root growth takes place during stage 2 and 3, allowing roots to grow deeper and accessing more soil moisture to sustain growth. Under dry land conditions, soil moisture may limit yield (Grant and Bailey 1993). Results by (Tesfamariam et al. 2010) found that water stress during the vegetative period and flowering stage significantly reduced the LAI, and resulted in leaf senescence during the seed fill stage. During all stages of the canola plants development, water stress led to a decrease in total above ground biomass in comparison to the treatment with no water stress. During the flowering stage, water stress led to abscission of the seed pods. Canola was found to be most sensitive to water stress during the flowering stage and less sensitive during the vegetative stage (Tesfamariam et al. 2010). Additional N applications will only lead to higher yields to the level where soil moisture limits yield (Grant and Bailey 1993). The optimal soil moisture as factor affecting mineralization was found to be at 60% of soil water holding capacity (WHC). Higher WHC led to an increase in denitrification (Yue et al. 2014), due to a lack of oxygen which inhibits soil microbial activity (Wang et al. 2004). Denitrification is the process of reducing nitrates to a form unavailable to plants.

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Chapter 3

The effect of rate and distribution of nitrogen fertilisation on productivity of canola in the Western Cape

3.1. Abstract

Canola (*Brassica napus*) is increasing in popularity as a cereal crop in the Western Cape. Nitrogen (N) is generally the most limiting nutrient to canola production. Nitrogen fertiliser guidelines for canola are currently adopted from international literature or adopted from guidelines for wheat, and should be refined for the local environmental conditions. The aim of this study is to determine the optimal rate of N fertilisation, and the distribution thereof in the Western Cape. Field experiments were conducted in 2015 at Langgewens and Altona (moderate and high production potential zones in the Swartland) and Roodebloem (southern Cape). The trial was laid out as a factorial arranged in a randomised block design, with six N rates (0, 20, 60, 90, 120 and 150 kg N ha^{-1}), which was applied in one, two or three increments after planting, replicated in four blocks. Twenty kg N ha^{-1} was applied at planting. The rest was divided in equal increments either 30 days after planting (DAP), 30 and 60 DAP or 30, 60 and 90 DAP. Soil mineral N, leaf area index (LAI) and biomass was determined at 30, 60 and 90 DAP. Yield and thousand kernel mass (TKM) was recorded. Treatments had no effect (P>0.05) on total soil mineral N content at any locality at any physiological stage with the exception of 90 DAP at Langgewens. Neither LAI nor biomass was affected by treatments (P>0.05) at any locality, at any physiological stage. Yield at Roodebloem was affected (P<0.05) by N fertilisation and treatments which had the highest yield were those who received 20 kg ha^{-1} at planting, and 70 or 100 kg ha^{-1} at 30 DAP respectively. These treatments did not differ (P>0.05) from treatments which received more than 60 kg N ha^{-1}, regardless of the distribution. At Langgewens and Altona, N fertilisation had no effect (P>0.05) on yield, while TKM was not affected by treatments at any locality. The lack of significant differences observed, especially at Langgewens and Altona, could be ascribed to drought conditions during 2015, which may have prohibited efficient uptake of N during critical periods. Preliminary results indicate optimum levels of 90-120 kg N ha^{-1}, applied as 20 kg N ha^{-1} at planting and the remainder at 30 DAP at Roodebloem. No significant response to N applications was recorded in the Swartland. Due to lower N mineralisation potential of Swartland soils, higher optimum levels are expected in normal and high rainfall years, than in the southern Cape.

3.2. Introduction

Canola has been increasing in popularity as a cereal crop in the southern Cape and Swartland regions in South Africa from the 1990s. Canola oil is attractive to health conscious societies because of its high content of oleic and linolenic acids and by its favourable linoleate:linolenate ratio (Eskin and McDonald 1991). During 2015, 78 050 ha of canola was planted in the Western Cape. Projections made by the Protein Research Foundation (2015) and the Bureau for Food and Agricultural Policy (2015) indicate that canola consumption will continue to rise, not only due to the well-known health benefits, but also as a feeding ration in livestock feeding programs. Although trials are being conducted in the central production areas of South Africa under irrigation, canola production is currently limited to the Western Cape due to its unique terroir and climate. The rate of canola needed to ensure the demand caused by the increasing projected consumption is met, will therefore currently have to be produced in the Western Cape.

One method to enhance productivity of canola in these regions, is to refine nitrogen (N) fertiliser management. Nitrogen is generally the most liming nutrient (Grant 1993), and crop responses to N fertilisation is common (Ozer 2003). Furthermore, N is one of the most expensive inputs for canola production. Canola has a relatively high requirement for N and, compared to other crops produced in the southern Cape and Swartland, a low N use efficiency (NUE). The opportunity to further enhance production of canola by refining N fertiliser management strategies exists. Nitrogen fertiliser guidelines should differ between regions of dissimilar environmental conditions (Ozer 2003). Currently, N fertiliser guidelines for canola production in the Western Cape is determined from international literature or adopted from guidelines for wheat. Due to climatic differences within the canola production area, we expect that the optimal rate of N fertiliser and the distribution thereof will differ not only for local conditions, but also between different areas within the Western Cape. The aim of this study is to determine the optimal rate and the distribution of N fertiliser for optimal canola production.

3.3. Materials and methods

3.3.1. Trial preparation

3.3.1.1. Experimental sites

Field experiments were conducted at Langgewens Research Farm (33°16’42.33” S; 18°42’11.62” E), Altona (33°41'04.9"S; 18°37'09.2"E) and Roodebloem (34°13'11.1"S; 19°31'51.0"E) in the 2015 growing season. The three sites were strategically identified based on climate and soil characteristics, to represent a more extensive production area of the Western Cape.

Langgewens and Altona are situated in the Swartland, and Roodebloem in the southern Cape. Although both regions are characterised by a Mediterranean-type climate, their rainfall distribution differ. The Swartland receives approximately 80% of its total annual rainfall during the months of April to October, and the southern Cape cape 60 to 75%. The long-term average annual rainfall for Langgewens, Altona and Roodebloem is 397, 527 and 449 mm, respectively. The 2015 season was characterised by dry conditions in the Swartland, with rainfall lower than the long-term average of most months (Figure 3.1). Although Altona received sufficient rainfall from January through March, and higher than expected rainfall during June, rainfall was generally lower in the remaining months than the long-term average. Roodebloem received higher than average rainfall in June, July and September, while the rainfall during the remainder of the year was below the long-term average (Western Cape Department of Agriculture 2015).

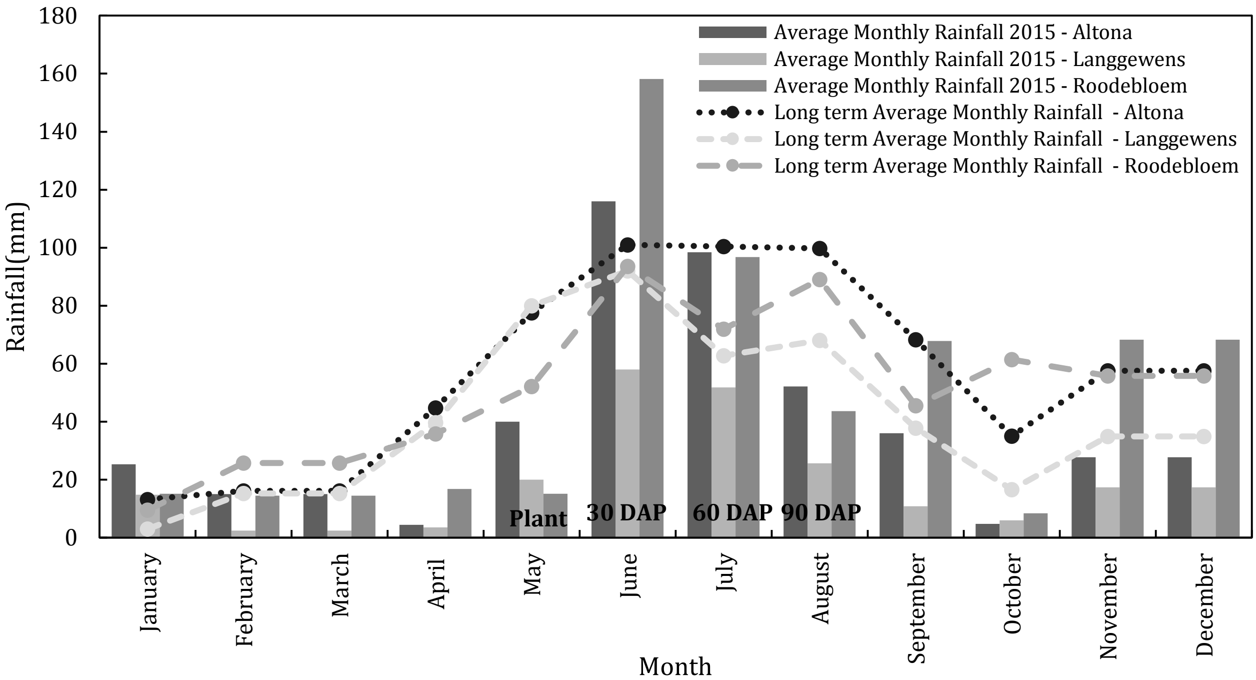

Figure 3.1: Average long-term and monthly rainfall for 2015 for Altona, Roodebloem and Langgewens. 'Plant' indicates when the canola was planted, while 30, 60 and 90 DAP indicates the number of days after planting, when N fertiliser was applied.

The average maximum daily temperatures in summer were generally similar or slightly lower than the long-term average daily maximum temperatures (Figures 3.2 and 3.3). The average minimum daily temperature was higher during August and September than the long-term average (Western Cape Department of Agriculture 2015).

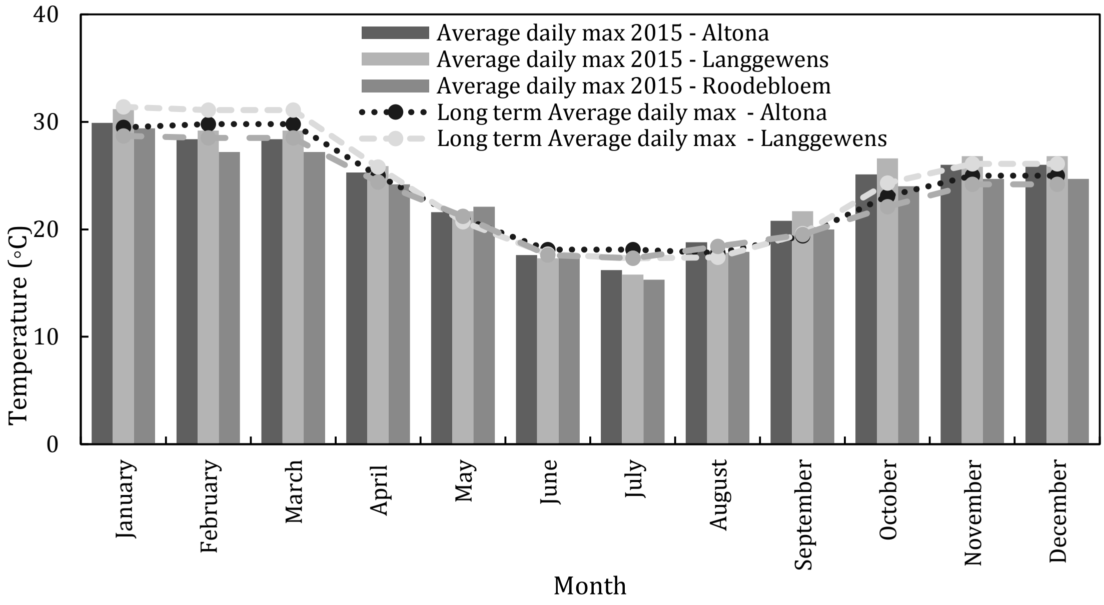

Figure 3.2: Average long-term and mean daily maximum temperatures for 2015 for Altona, Roodebloem and Langgewens.

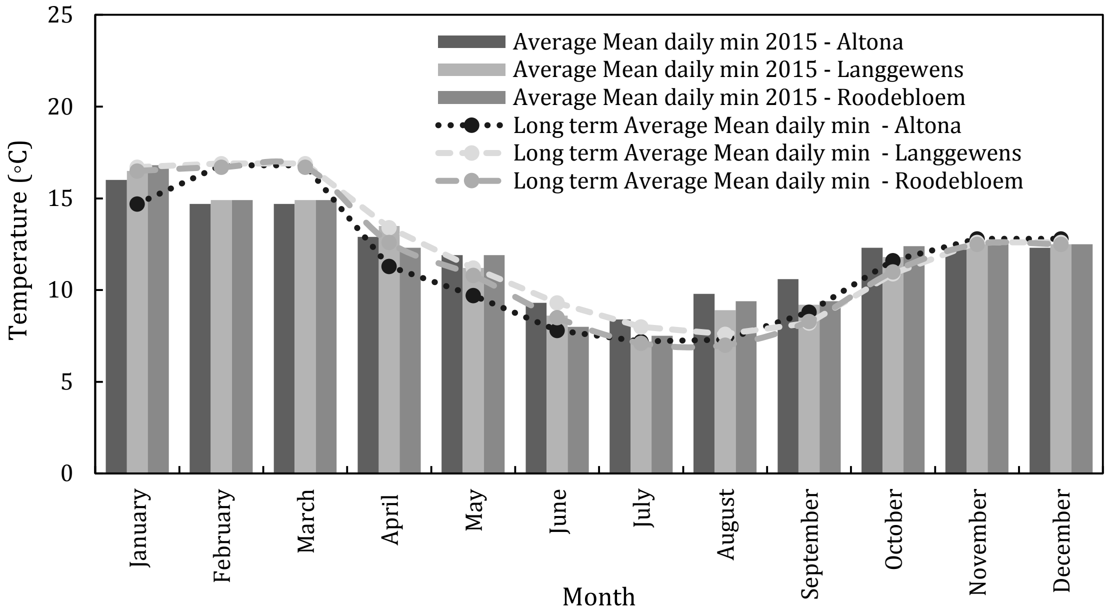

Figure 3.3: Average long-term and mean daily minimum temperatures for 2015 for Altona, Roodebloem and Langgewens.

Soil fertility status was determined prior to execution of the trial. Soil fertility indicators were satisfactory for canola production, except for sulphur (S) and boron (B). To prevent suboptimal production, gypsum was applied prior to planting at 30 kg S ha^{-1} to alleviate suboptimal S content in soil, and a foliar application for B was applied during the leaf production phase. The soil carbon (C) content in the 0 – 150 mm soil layer for Langgewens was 0.64%, Altona 1.27%

and Roodebloem 0.86%. Soils of all sites were shallow (250 – 300 mm) sandy loams with a high gravel content (>40%). Annual medics (*Medicago* spp.) were planted in the previous season on the trial sites at Altona and Langgewens, while wheat (*Triticum aestivum*) was planted at Roodebloem during the previous growing season.

3.3.1.2. Treatments and layout

The experiment was laid out as a factorial arranged in a randomised block design, with 14 N treatments replicated in four blocks. Treatments comprised of four N rates, which was applied in one, two or three increments after planting, and two control treatments. The total rate of N applied per season were 60, 90, 120 and 150 kg N ha^{-1}. For each of these, 20 kg N was applied at planting. The rest were then divided in equal increments either 30 days after planting (DAP), 30 and 60 DAP or 30, 60 and 90 DAP (Table 1). An experimental unit therefore comprised two factors: N-rate and DAP effect (N distribution). The first control received no N, while the second control received only 20 kg N ha^{-1} during planting. For interpretation, treatments will be expressed in the form of the rate of N (kg ha^{-1}) applied at each increment, viz, in order from left to right, fertiliser rate at planting (placed with seed), 30 days after planting, 60 DAP and 90 DAP. As an example, treatment 20-40-0-0 indicates that 20 kg N ha^{-1} was applied at planting, 40 kg N ha^{-1} at 30 DAP, 0 kg N ha^{-1} at 60 DAP and 0 kg N ha^{-1} at 90 DAP. At earlier stages of sampling, for example at 30 DAP, the figures will only be included to up to the specific point in time, for instance 20-0 at 30 DAP or 20-0-0 at 60 DAP. Plots comprised 1.36 m x 5 m. Half of the plot was dedicated for destructive sampling of plants, and the other half were kept for determining yield.

Table 3.1: Summary of nitrogen fertiliser treatments applied at Altona, Langgewens and Roodebloem. The N fertiliser rate (kg ha^{-1}) is shown which was applied at different increments, viz, in order from left to right, fertiliser rate at planting (placed with seed) 30 days after planting (DAP), 60 DAP and 90 DAP.

Experimental Unit	**N-rate (kg ha^{-1})**	**At planting**	**30 DAP**	**60 DAP**	**90 DAP**
0-0-0-0	0	0	0	0	0
20-0-0-0	20	20	0	0	0
20-40-0-0	60	20	40	0	0
20-20-20-0	60	20	20	20	0
20-13-13-13	60	20	13.3	13.3	13.3
20-70-0-0	90	20	70	0	0
20-35-35-0	90	20	35	35	0
20-23-23-23	90	20	23.3	23.3	23.3
20-100-0-0	120	20	100	0	0
20-50-50-0	120	20	50	50	0
20-33-33-33	120	20	33.3	33.3	33.3
20-130-0-0	150	20	130	0	0
20-65-65-0	150	20	65	65	0
20-43-43-43	150	20	43.3	43.3	43.3

3.3.1.3. Seedbed preparation and trial management

Soil was lightly scarified (<150mm deep) using a harrow to prepare a proper seedbed. A conventional small-plot planter was used to plant canola (cv Hyola 555 TT) at a seeding rate of 3 kg ha^{-1}. Roodebloem, Altona and Langgewens were planted on 6, 7 and 12 April 2015, respectively. Trifloralin was sprayed as pre-emergent herbicide to control weeds, especially ryegrass. Duraspin was used to control insects. Nitrogen was applied in the form of limestone ammonium nitrate (28% N).

3.3.2. Sampling and analyses

3.3.2.1. Total soil mineral N

For all three localities, two composited soil samples were taken per plot to a depth of 150 mm, prior to planting and at 30, 60 and 90 DAP, prior to application of N fertiliser. Samples were kept cool on ice bricks during transportation. Samples were dried at 70°C for three days and passed through a 2 mm sieve. Samples were analysed for nitrate and ammonium content, using the salicylic acid (Cataldo et al. 1975) and indophenol-blue (Keeney et al. 1982) methods, respectively. The ammonium and nitrate content were used to calculate the total mineral N content in the soil. Nitrogen mineralisation for all three localities was determined through aerobic incubation at 20°C and at 75% of field water capacity for 7, 14, 28 and 42 days.

3.3.2.2. Plant density, aboveground biomass and leaf area index (LAI)

Plant density was determined at 30 DAP by counting the number of plants in a 0.5 m^2 quadrant (Table 2). Langgewens had a lower plant density than Altona and Roodebloem, which may be as a result of drier soil conditions. Roodebloem, which had sufficient rainfall prior to planting, had the highest plant density of the three localities. Even though the guidelines for South Africa recommend a plant density of 50 to 80 plants m^{-2}, Angadi et al. (2003) found that seed yield only declined with plant densities lower than 40 plants m^{-2}. Only treatments 20-13-13-13 and 20-70-0-0 at Langgewens had plant densities lower than this threshold and should therefore be interpreted with caution.

Table 3.2: Summary of plant densities at Altona, Langgewens and Roodebloem. The N fertiliser rate (kg ha^{-1}) is shown which was applied at different increments, viz, in order from left to right, fertiliser rate at planting (placed with seed) 30 days after planting (DAP), 60 DAP and 90 DAP.

	Plant density (plants m^{-2})		
Treatment	**Altona**	**Langgewens**	**Roodebloem**
0-0-0-0	63	43	88
20-0-0-0	72	43	88
20-40-0-0	67	43	78
20-20-20-0	85	42	78
20-13-13-13	70	37	88
20-70-0-0	70	37	91
20-35-35-0	77	42	86
20-23-23-23	67	47	85
20-100-0-0	71	49	95
20-50-50-0	76	40	89
20-33-33-33	76	43	87
20-130-0-0	75	43	96
20-65-65-0	73	44	89
20-43-43-43	64	40	80

Ten plants were sampled per plot at 30, 60 and 90 DAP to determine aboveground biomass production. Plants were dried for 72 h at 70^{0}C. Leaf area was measured with a LICOR leaf area meter and LAI was subsequently calculated.

3.3.3. Statistical analysis

A one-way analysis of variance (ANOVA) was used to test for differences between treatments for all parameters. Means were separated using the Fisher's least significant difference (LSD) test at a 5% level. Where applicable, a 10% significance level was used to identify trends. In cases where residuals were not normally distributed, the Kruskal-Wallis test was used as a non-parametric test to confirm the results of the ANOVA. In cases where Levene's test for homogeneity of variances indicated heterogeneous variances, the LSD test was replaced with the Games-Howell multiple comparison procedure. The VEPAC package of STATISTICA was used for statistical analyses.

3.4. Results

3.4.1. Langgewens Research Farm

3.4.1.1. Total soil mineral N

Total soil mineral N content prior to planting was 34.1, 60.4 and 32.3 mg N kg^{-1} at soil depths of 0-150, 150-300 and 300-450 mm, respectively (results not shown). For the first seven days, approximately 5 to 12 mg N kg^{-1} soil was released through mineralisation, depending on the soil depth (Figure 3.4). If the first 14 days was taken into account, more N was fixed into organic matter (microbial organisms) than what was released. After 28 days of incubation, the most N was released in the 0 – 150 and 150 – 300 mm layers. When soil was incubated for 42 days, N was released only in the 0 – 150 mm depth layer, and fixed in the deeper layers.

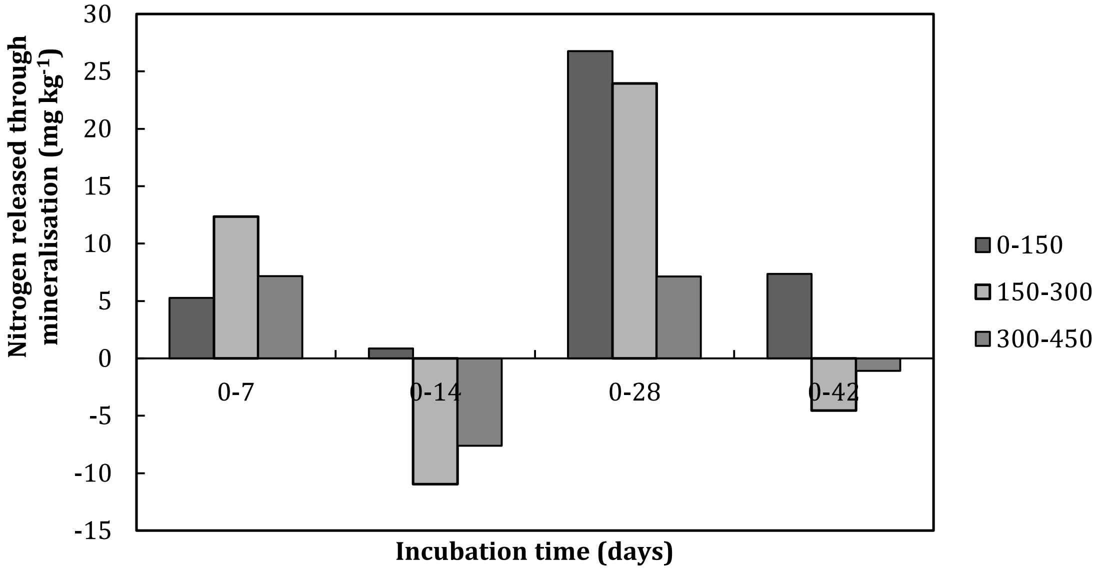

Figure 3.4: Total soil mineral nitrogen released at soil depths of 0-150, 150-300 and 300-450 mm at Langgewens Research Farm after 7, 14, 28 and 42 days of incubation at 20°C and at 75% of field water capacity.

At 30 DAP the total mineral N in soil was measured to assess the influence of N fertilisation during the planting procedure on the total soil mineral N content. Treatment 0-0, where no N was applied whatsoever, had a total soil mineral N content of 25.9 mg kg^{-1}. Treatment 20-0 (20 and zero kg N ha^{-1} at planting and 30 DAP, respectively) had a total soil mineral N content 43.5 mg kg^{-1} (SD = 14.76), and did not differ ($P>0.05$) from treatment 0-0 (results not shown). Therefore, placing 20 kg N ha^{-1} with seed during planting made no difference ($P>0.05$) to the mineral N content of soil 30 days later.

Prior to applying fertiliser at 60 DAP, total soil mineral N content did not differ ($P>0.05$) between treatments (Figure 3.5).

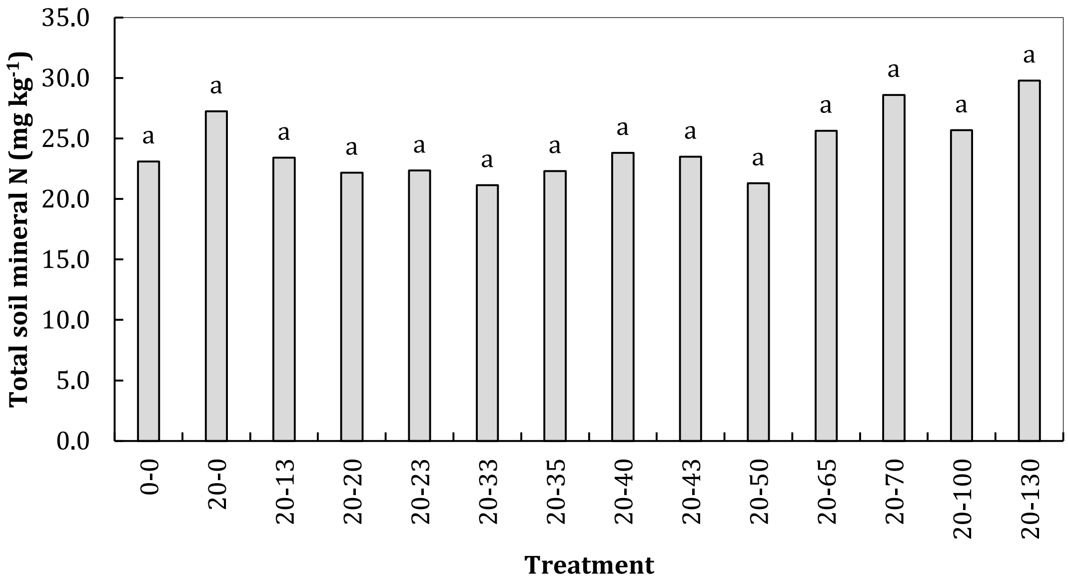

Figure 3.5: Total soil mineral N content (mg N kg^{-1} soil) as affected by rate and time of N application on Langgewens Research Farm. Figures on x-axes indicate the N fertiliser rate (kg ha^{-1}) at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed) and 30 days after planting. P= 0.404.

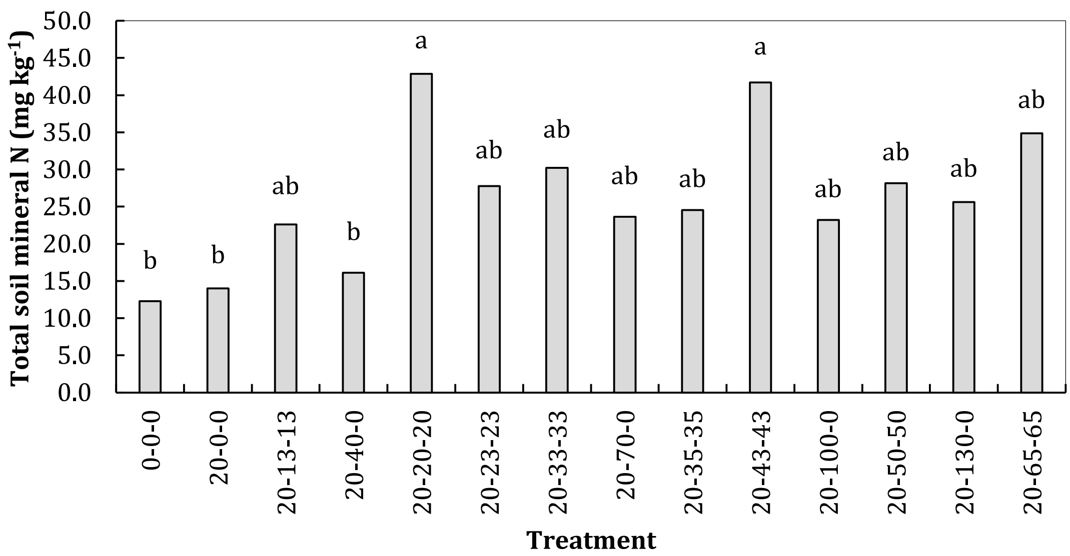

Figure 3.6: Total soil mineral N content as affected by rate and time of N application on Langgewens Research Farm. Figures on x-axes indicate the amount of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed), 30 and 60 days after planting. P=0.005

At 90 DAP, prior to fertilisation, the effect of fertiliser treatments applied up to 60 DAP on total soil mineral N content was assessed (Figure 3.6). Treatments 20-20-20 and 20-43-43 had the highest (P<0.05) total soil mineral N content, but only differed from treatments 0-0-0, 20-0-0 and 20-40-0. Therefore, N applied at a rate higher than 46 kg N ha^{-1}, and at two intervals (30 and 60 DAP), resulted in a higher (P<0.05) total soil mineral N content.

3.4.1.2. Leaf area index (LAI) and aboveground biomass

The LAI of the control treatment 0-0 at 30 DAP was 0.60 m^2 m^{-2}, and the second control, which received 20 kg N at planting, had an LAI of 0.78 m^2 m^{-2} (SD = 0.23), but they were not different (P>0.05). At 60 DAP and 90 DAP, no treatment effect (P>0.05) on LAI were detected (Figures 3.7 and 3.8, respectively). The LAI did not change much from 60 to 90 DAP, as the LAI at 60 DAP was as high as 2.9 m^2 m^{-2} and at 90 DAP it was 2.7 m^2 m^{-2}.

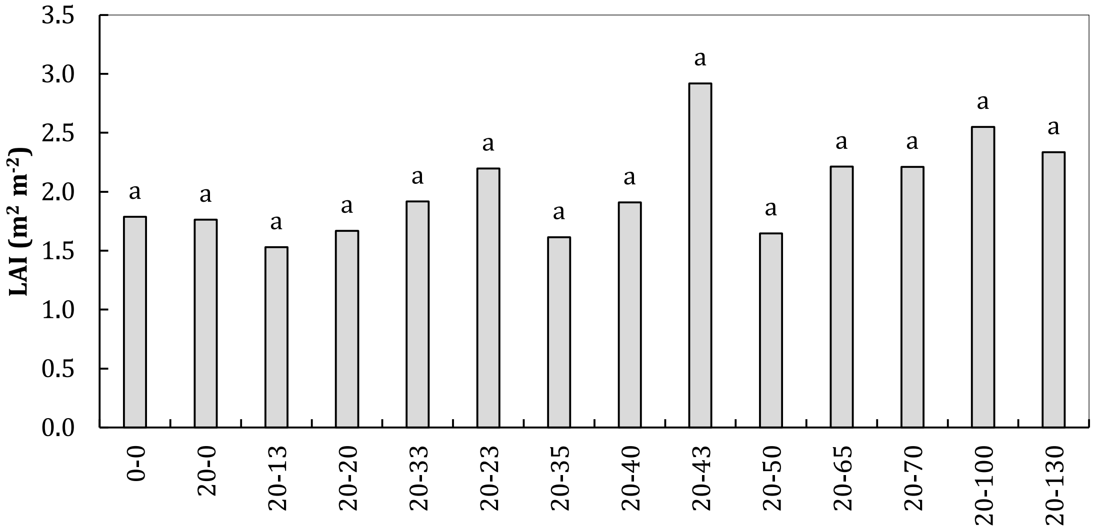

Figure 3.7: LAI as affected by rate and time of N fertiliser application on Langgewens Research Farm at 60 days after planting (DAP). Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed) and 30 DAP. P=0.691; Soil Water Content = 5.86% ± 0.37.

For biomass production at 30 DAP, the control treatment which received no N at planting, produced 8.67 kg ha^{-1} and control treatment 0-20 (20 kg ha^{-1}) produced 11.27 kg ha^{-1} (SD = 2.58) and did not differ from each other (P>0.05) (results not shown). Treatments did not affect biomass production at 60 DAP (P>0.05), which ranged from 73 to 105 kg ha^{-1} (Figure 3.9). The results on LAI and biomass might be an indication of sufficient N fixed by the annual medics in the previous season, and a lack of moisture, due to low rainfall, to sustain initial growth. At 90 DAP, biomass ranged between 448 and 783 kg ha^{-1}. It was not affected by the treatments (P>0.05), which again were most probably due to the very low rainfall experienced at Langgewens during 2015 (Figure 3.10).

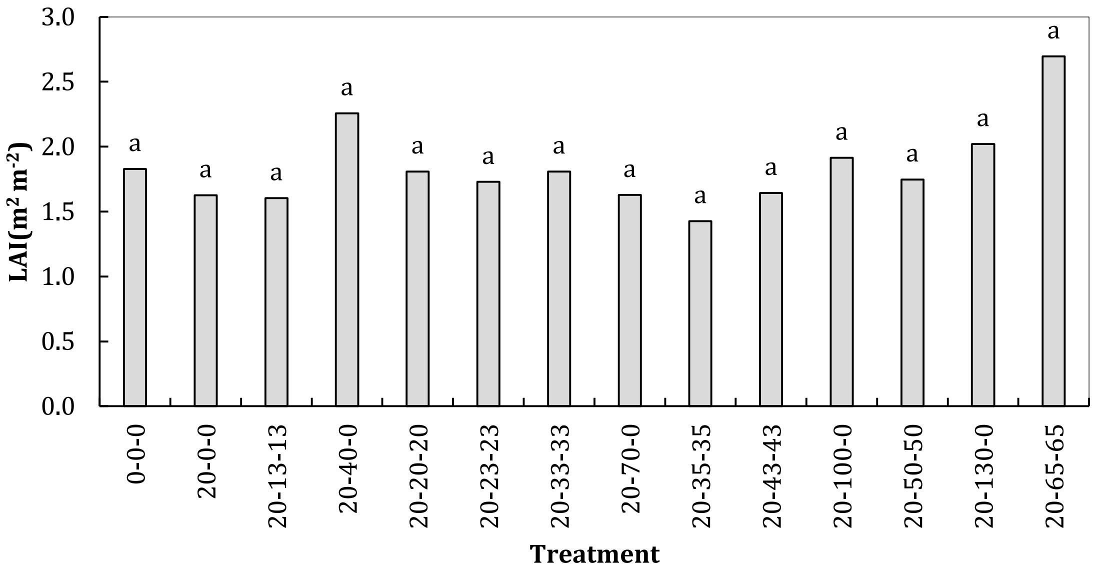

Figure 3.8: LAI as affected by rate and time of N application on Langgewens Research Farm at 60 days after planting. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed), 30 and 60 days after planting. P=0.174; Soil Water Content = 4.29% ± 0.38.

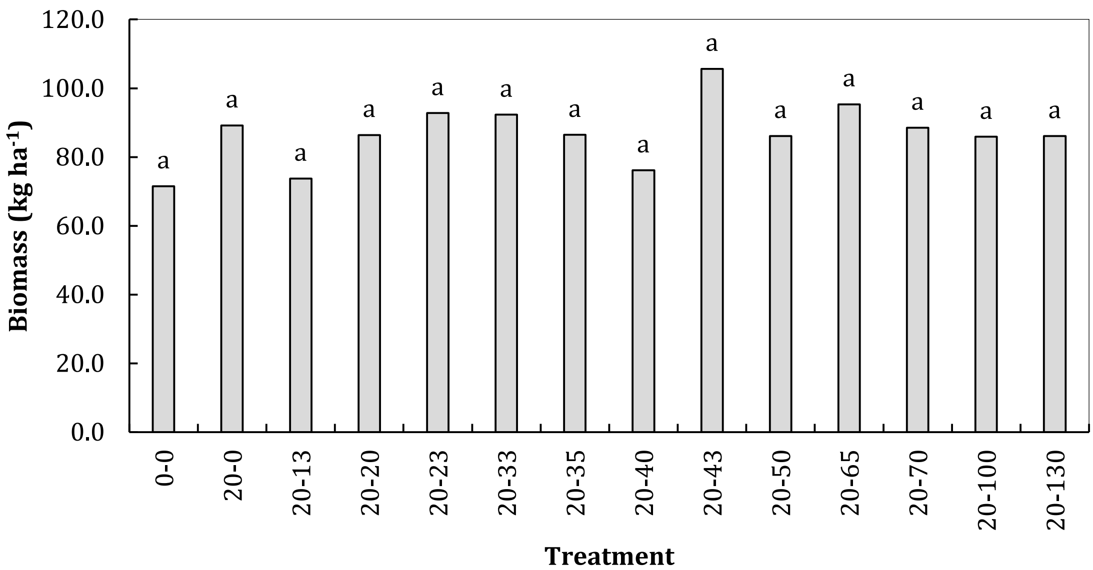

Figure 3.9: Aboveground biomass production as affected by rate and time of N application on Langgewens Research Farm at 60 days after planting (DAP). Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed) and 30 DAP. P=0.662; Soil Water Content = 5.86% ± 0.37.

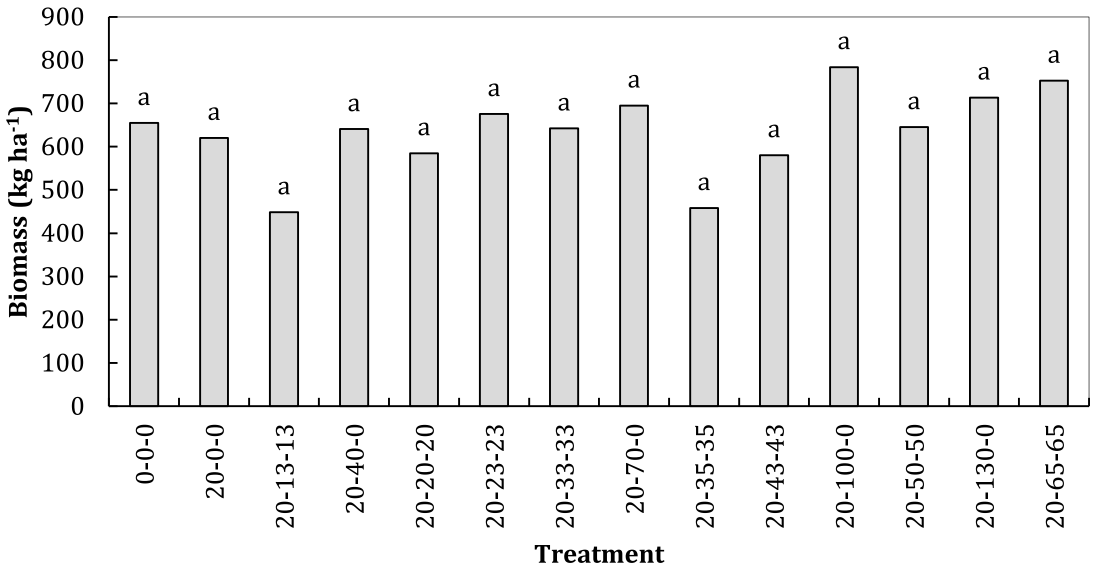

Figure 3.10: Aboveground biomass as affected by rate and of N application at 60 DAP on Langgewens research farm measured at 90 days after planting. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed) 30 and 60 days after planting. P=0.480; Soil Water Content = 4.29% ± 0.38.

3.4.1.3. Yield and thousand kernel mass (TKM)

Treatments of N fertiliser rate or distribution of N did not affect grain yield or TKM (P>0.05) at Langgewens during 2015. No difference (P>0.05) was found between control treatment 0-0-0-0 and the other treatments (Figures 3.11 and 3.12). The mean yield across all treatments was 1.68 Mg ha^{-1} (SD = 0.24) and mean TKM was 2.21 g (SD = 0.06). The low grain yield and TKM clearly showed the detrimental effect of the low rainfall on the growth and yield of canola on this locality.

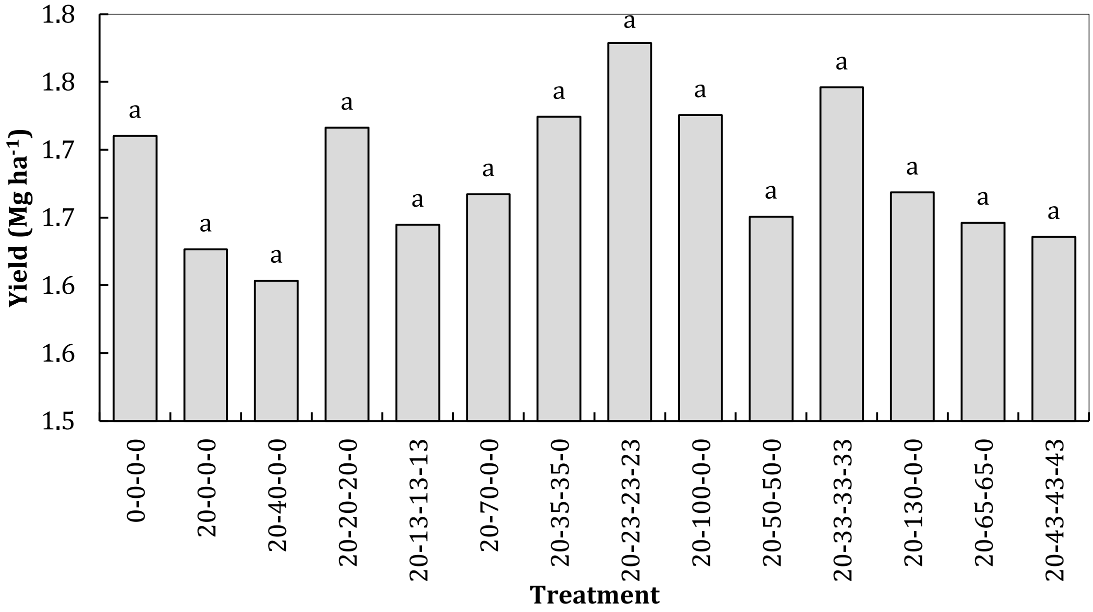

Figure 3.11: Canola yield (Mg ha^{-1}) as affected by rate and time of N application on Langgwens Research Farm. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting. P=1.000

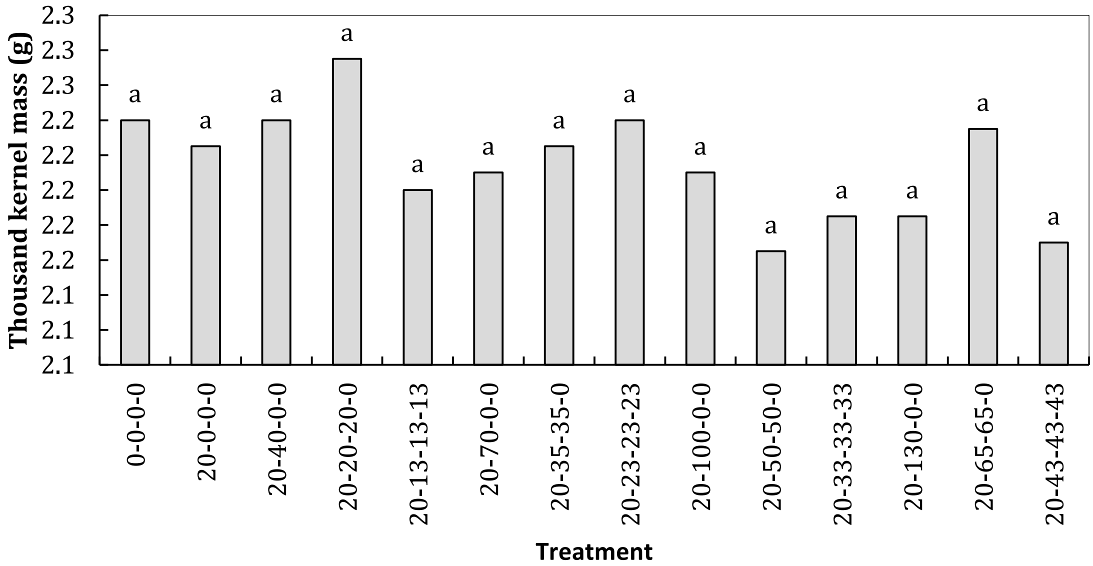

Figure 3.12: Thousand kernel mass as affected by rate and time of N application on Langgwens Research Farm. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting. P=0.390

3.4.2. Altona

3.4.2.1. Total soil mineral N

The initial soil N content at 0-150 and 150-300 mm soil depth layers were 24.75 and 13.42 mg N kg^{-1}, respectively (results not shown). At a soil depth of 300-450 mm the soil N content was 10.18 mg kg $^{-1}$. At soil depths of 0-150 and 300-450 mm, the total soil mineral N initially declined for 14 days of incubation, after which it increased towards 28 days (Figure 3.13). That was followed by a decline in the total soil mineral content towards 42 days of incubation. However, after 14 days of incubation, soil from a depth of 150-300 mm, had an unexpected very high total N content.

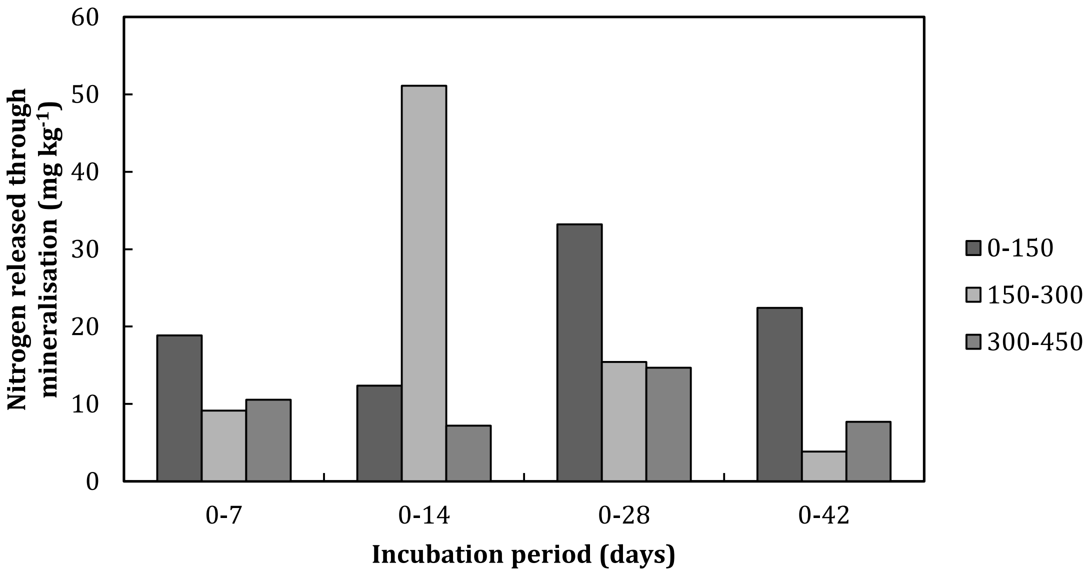

Figure 3.13: Total soil mineral nitrogen at soil depth layers of 0-150, 150-300 and 300-450 mm at Altona after seven, 14, 28 and 42 days of incubation at 20°C and at 75% of field water capacity.

Total soil mineral N content was determined at 30 DAP. Although the control treatment which received no N at planting (0-0-0-0), had a total soil mineral N content of 58.38 mg kg^{-1} compared to 63.87 mg kg^{-1} (SD= 14.44) for control treatment which received 20 kg N ha^{-1} at planting (20-0-0-0), but treatments did not differ ($P>0.05$). Similarly, the total mineral N content of the soil at 60 and 90 DAP also showed no differences ($P>0.05$) (Figures 3.14 and 3.15). The variation between treatments at 60 DAP was large (SD=10.37) and total soil mineral N ranged from 22.04 mg kg^{-1} for treatment 20-0 to 39.06 mg kg^{-1} for treatment 20-65. Standard deviation between treatments at 90 DAP were 5.88.

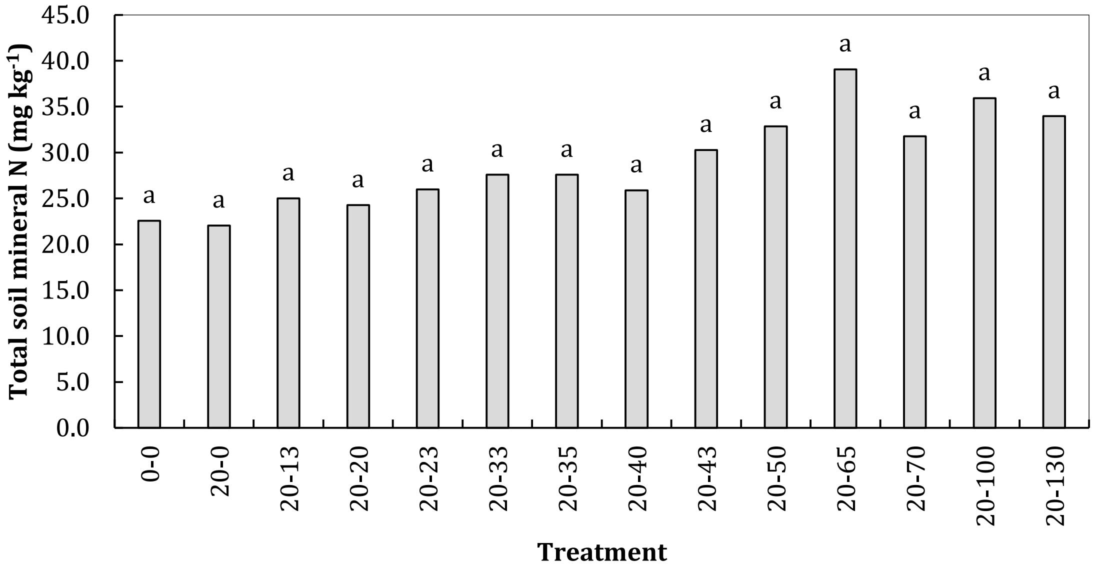

Figure 3.14: Total soil mineral N content as affected by rate and time of N application on Altona. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed) and 30 days after planting. P=0.471; Soil Water Content=11.75%±0.46

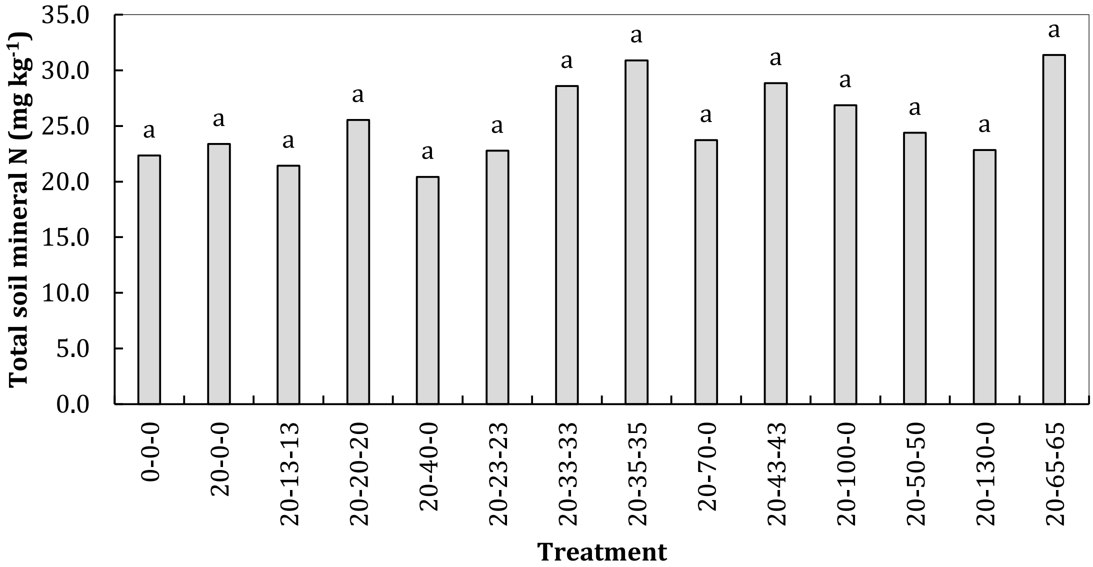

Figure 6: Total soil mineral N content as affected by rate and time of N application on Altona. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed), 30 and 60 days after planting. P=0.106; Soil Water Content=8.36%±0.23

3.4.2.2. Leaf area index (LAI) and aboveground biomass

At 30 DAP, LAI for treatments did not differ (P>0.05). Control treatment one, which did not receive any N at all had an LAI of 0.71 $m^2 m^{-2}$, while control treatment two, which received 20 kg N ha^{-1} at planting, recorded an LAI of 0.64 $m^2 m^{-2}$ (SD of 0.0.14). The LAI at 60 DAP ranged from 4.44 $m^2 m^{-2}$ for treatment 20-43 to 6.84 $m^2 m^{-2}$ for treatment 20-40, but because of a large variation between treatments (SD = 1.61) there were no significant treatment effect (Figure 3.16). At 90 DAP, the LAI showed a decline when compared to 60 DAP and differences were again not observed (P>0.05) (Figure 3.17).

Aboveground biomass did not differ (P>0.05) between treatments at 30 DAP (results not shown), 60 DAP (Figure 3.18) or 90 DAP (Figure 3.19). At 30 DAP control treatment one (0-0-0-0) had a biomass of 11.35 kg ha^{-1}, and control treatment two (20-0-0-0) a biomass of 9.95 kg ha^{-1} (SD= 2.21). This increased to 650 and 726 kg ha^{-1} for the two respective control treatments after 90 DAP. However, no differences (P>0.05) were observed for either 60 or 90 DAP.

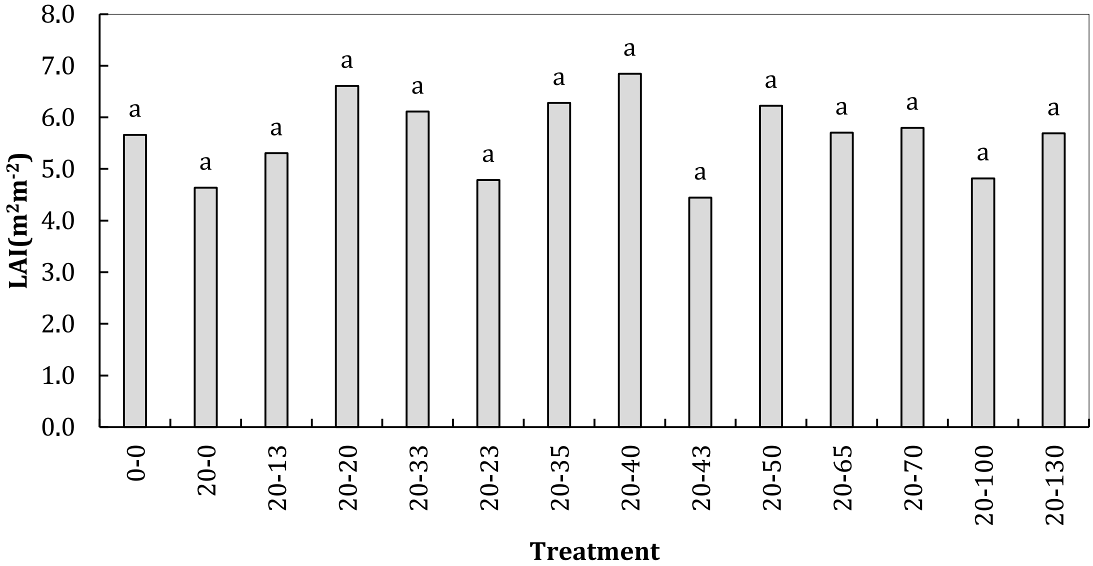

Figure 3.16: LAI as affected by rate and time of N application on Altona at 60 days after planting. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed) and 30 days after planting. P=0.621; Soil Water Content=11.74%±0.45

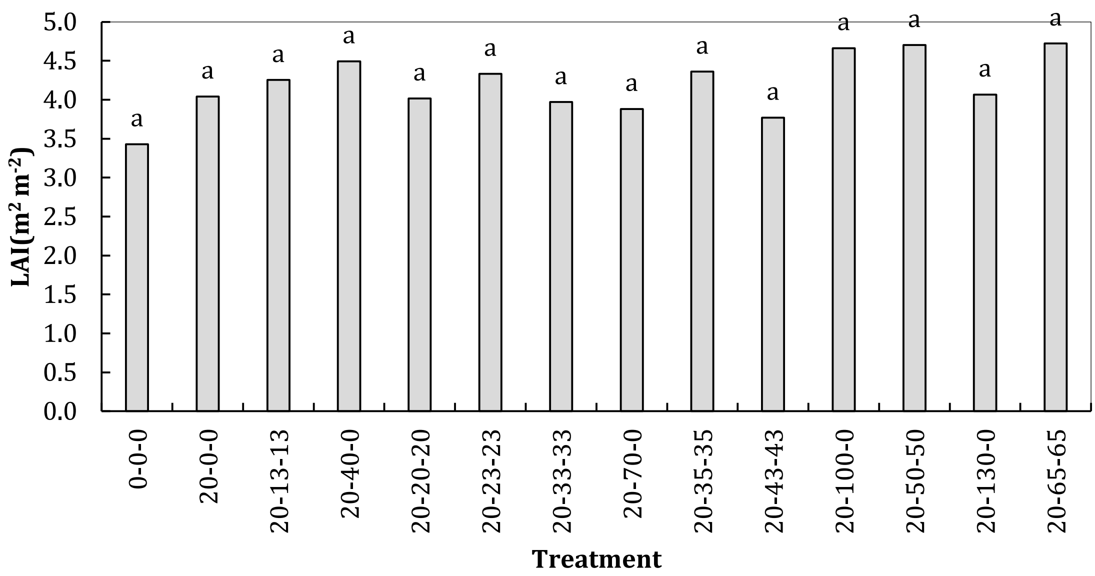

Figure 3.17: LAI as affected by rate and time of N application on Altona at 90 days after planting. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed), 30 and 60 days after planting. P=0.958; Soil Water Content=8.36%±0.23

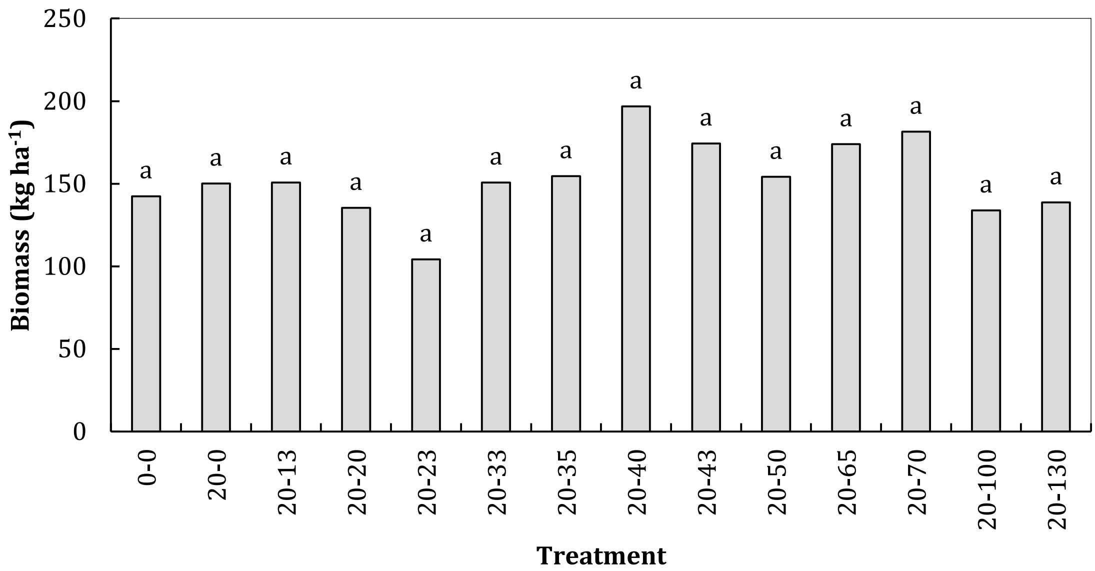

Figure 3.18: Aboveground biomass production as affected by rate and time of N application on Altona at 60 days after planting. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed) and 30 days after planting. P=0.647; Soil Water Content= 11.75%±0.46

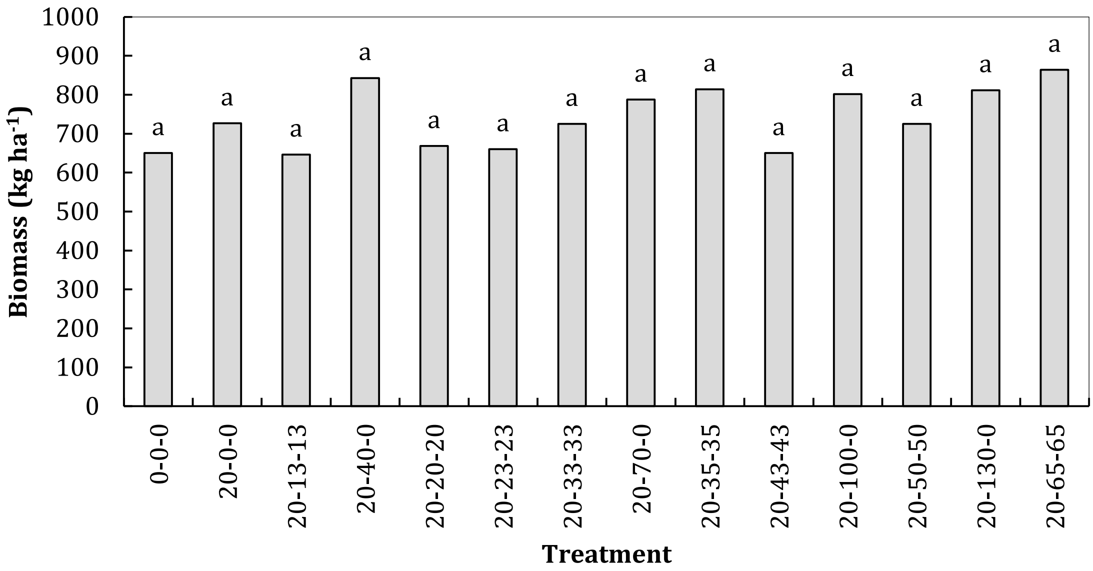

Figure 3.19: Aboveground biomass production as affected by rate and time of N application on Altona at 60 days after planting. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed), 30 and 60 days after planting. P=0.910; Soil Water Content=8.36%±0.23.

3.4.2.3. Yield and thousand kernel mass (TKM)

Nitrogen fertiliser treatments did not affect (P>0.05) yield or TKM at Altona (Figures 3.20 and 3.21, respectively). The mean grain yield was 3.29 Mg ha^{-1} (SD=0.30), while the mean TKM was 2.69 g (SD=0.09).

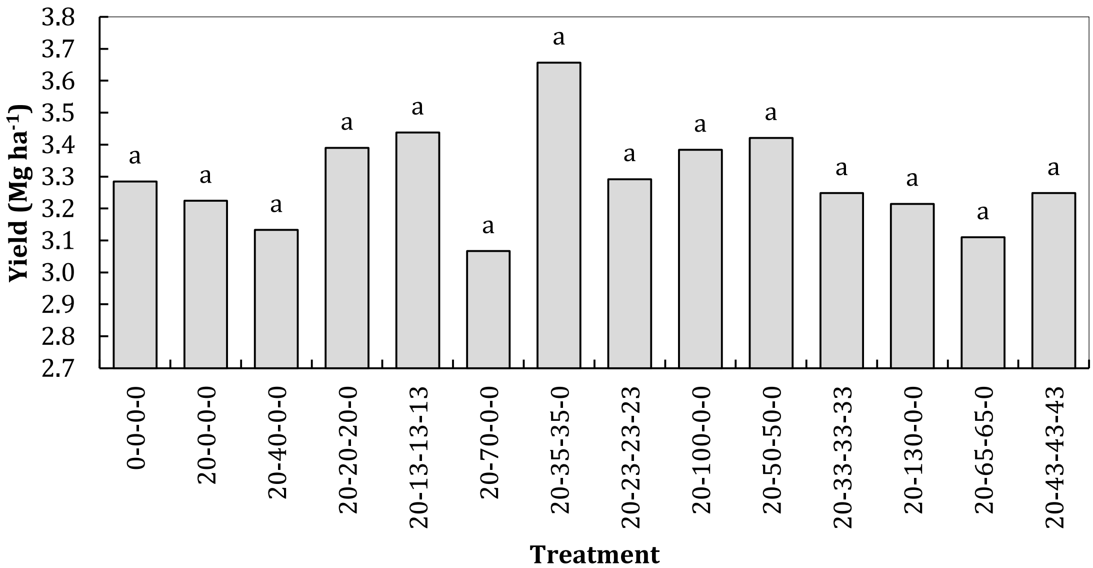

Figure 3.20: Canola yield (Mg ha^{-1}) as affected by rate and time of N application on Altona. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting. P=0.440

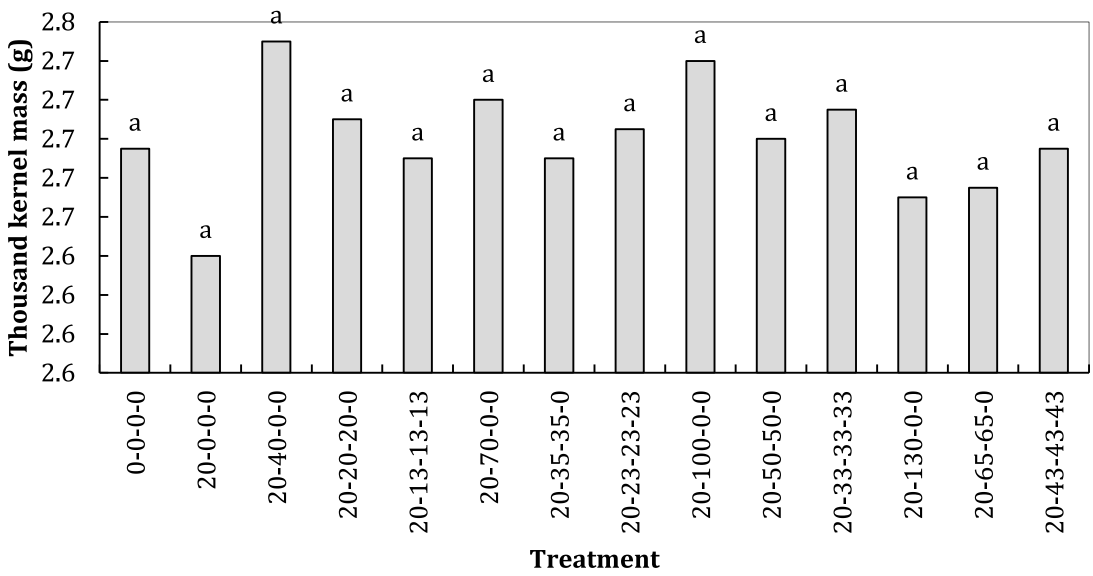

Figure 3.21: Thousand kernel mass as affected by rate and time of N application on Altona. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting. P=0.990

3.4.3. Roodebloem

3.4.3.1. Total soil mineral N

The total mineral N content of soil collected at Roodebloem before planting was 47.43 mg N kg^{-1} at a soil depth of 0-150 mm, 47.14 mg kg^{-1} at 150-300 mm and 30.12 mg kg^{-1} at 300-450 mm (results not shown). The mineralisation rate at Roodebloem (Figure 3.22) was negative up to 14 days of incubation, even though the mineralisation rate increased over the incubation period.

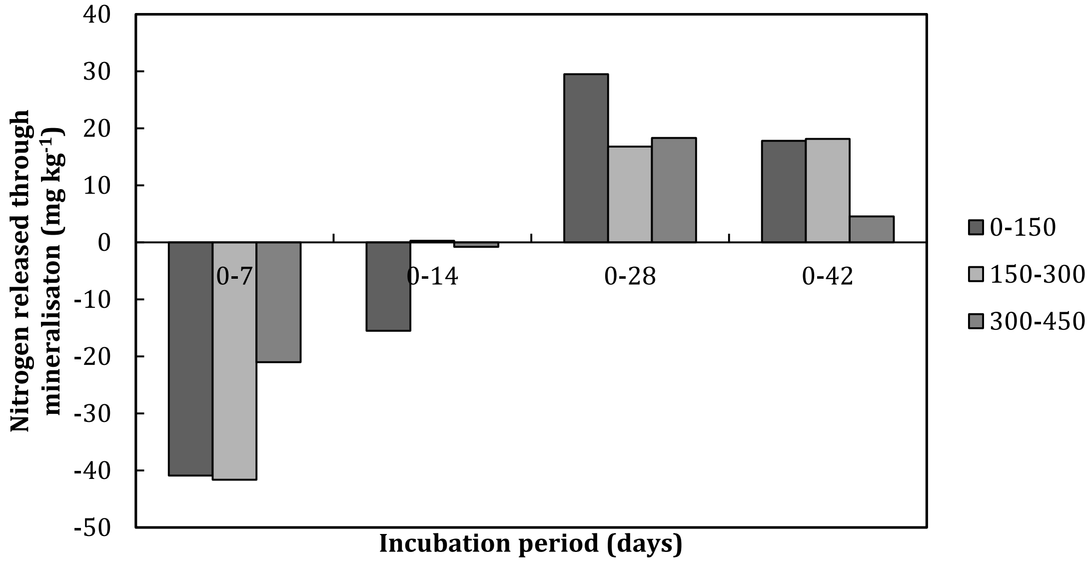

Figure 3.22: Total soil mineral nitrogen released at soil depths of 0-150, 150-300 and 300-450 mm at Roodebloem after 7, 14, 28 and 42 days of incubation at 20°C and at 75% of field water capacity.

Total soil mineral N content did not differ (P>0.05) at 30 DAP, although control treatment one, which did not receive any N fertiliser, had a total soil mineral N content of 58.33 mg kg^{-1} compared to control treatment two, which received 20 kg N at planting, and had a total soil mineral N content of 39.76 mg kg^{-1} (SD=22.80). The total soil mineral N content was high for all treatments at 60 DAP. Although differences were not observed (P<0.05), it showed a slight and gradual increase with increasing N fertiliser rate (Figure 3.23). No differences (P>0.05) in the total soil mineral N content between treatments were found at 90 DAP (Figure 3.24), but showed a similar tendency than at 60 DAP.

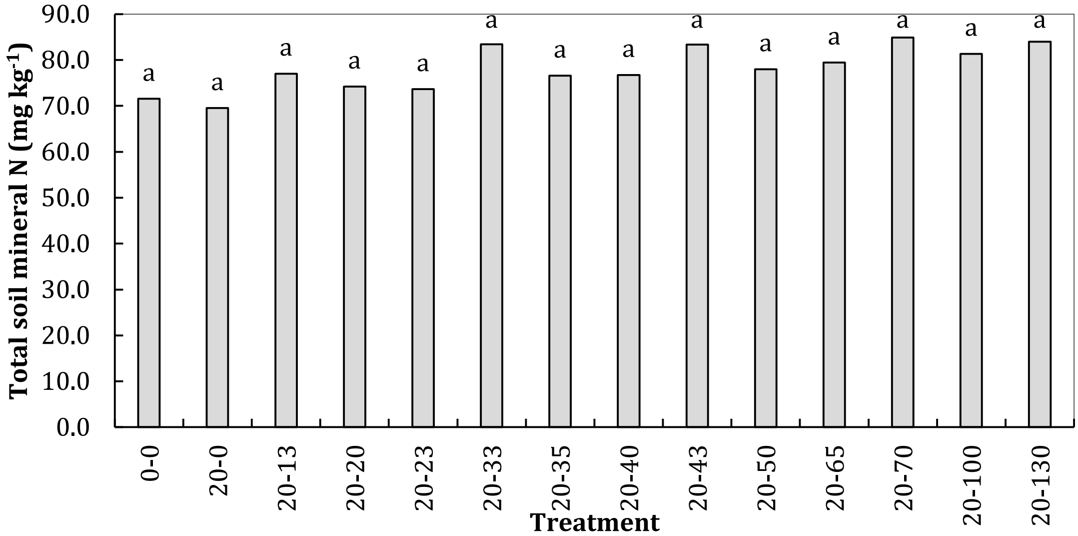

Figure 3.23: Total N content at 60 DAP as affected by rate and time of N application on Roodebloem. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed) and 30 days after planting. P=0.189; Soil Water Content=19.44%±0.65

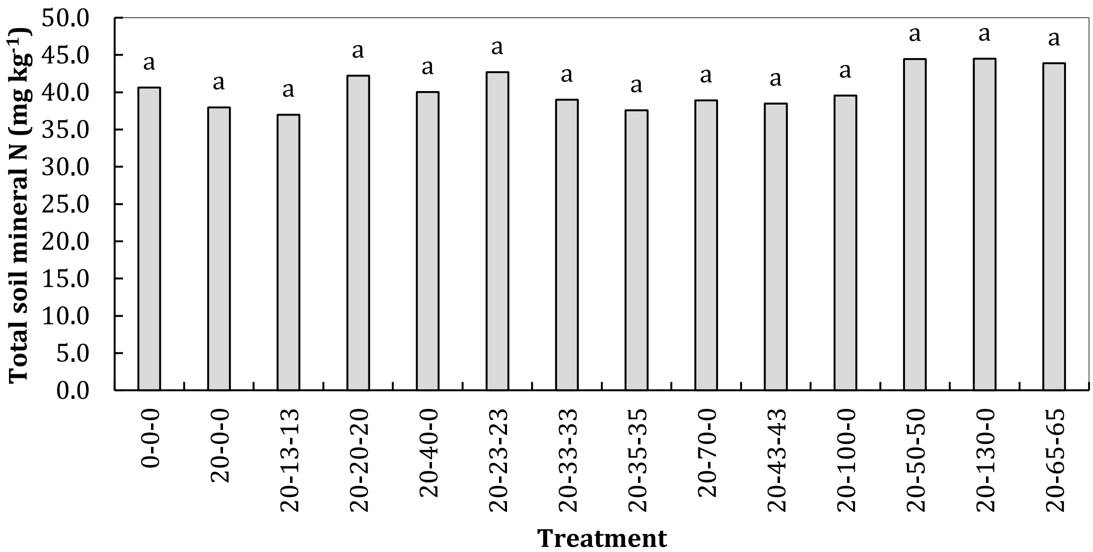

Figure 3.24: Total N content as affected by rate and time of N application on Roodebloem. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser

rate at planting (placed with seed), 30 and 60 days after planting. P=0.688; Soil Water Content=17.37%±0.39.

3.4.3.2. Leaf area index (LAI) and aboveground biomass

LAI did not differ (P>0.05) at 30 DAP. Control treatment one (0-0-0-0) had a LAI of 1.17 m^2m^{-2}, while control treatment two (20-0-0-0) had a LAI of 1.05 m^2 m^{-2} (SD = 0.23). Although the LAI did not differ (P>0.05) between treatments, N fertilisation tended (P<0.1) to increase LAI at 30 DAP (Figure 3.25). Treatment 20-70 had the highest LAI, followed by treatments 20-100 and 20-130. The LAI ranged from 2.77 m^2 m^{-2} for treatment 20-0 to 5.92 m^2 m^{-2} for treatment 20-70 with high variation (SD=1.51) at 60 DAP, but the treatments did not differ (P>0.05) (Figure 3.25). The LAI between treatments did not differ at 90 DAP and showed no trend (P>0.1) related to time and rate of N application (Figure 3.26).

The biomass production did not differ (P>0.05) between treatments at 30 DAP. Control treatment one (0-0-0-0) had a biomass of 15.87 kg ha^{-1} and control treatment two a biomass of 13.57 kg ha^{-1} (SD =3.27). At 60 and 90 DAP, treatments did not affect (P>0.05) biomass production (Figures 3.27 and 3.28, respectively). Although treatments had no effect (P>0.05) on biomass production at 90 DAP, there was a trend (P<0.1) for higher biomass production at higher rates of N. Treatments 20-130 and 20-100 resulted in the highest (P<0.1) biomass production. Both treatments received the bulk of their N at 30 DAP.

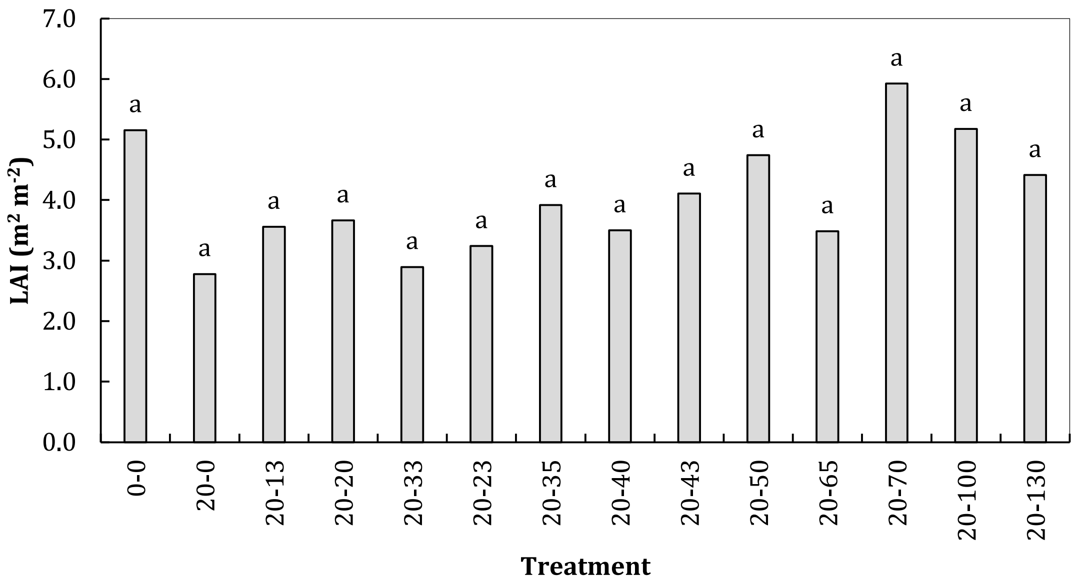

Figure 3.25: LAI as affected by rate and time of N application on Roodebloem at 60 days after planting. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed) and 30 days after planting. P=0.074; Soil Water Content=19.44%±0.65

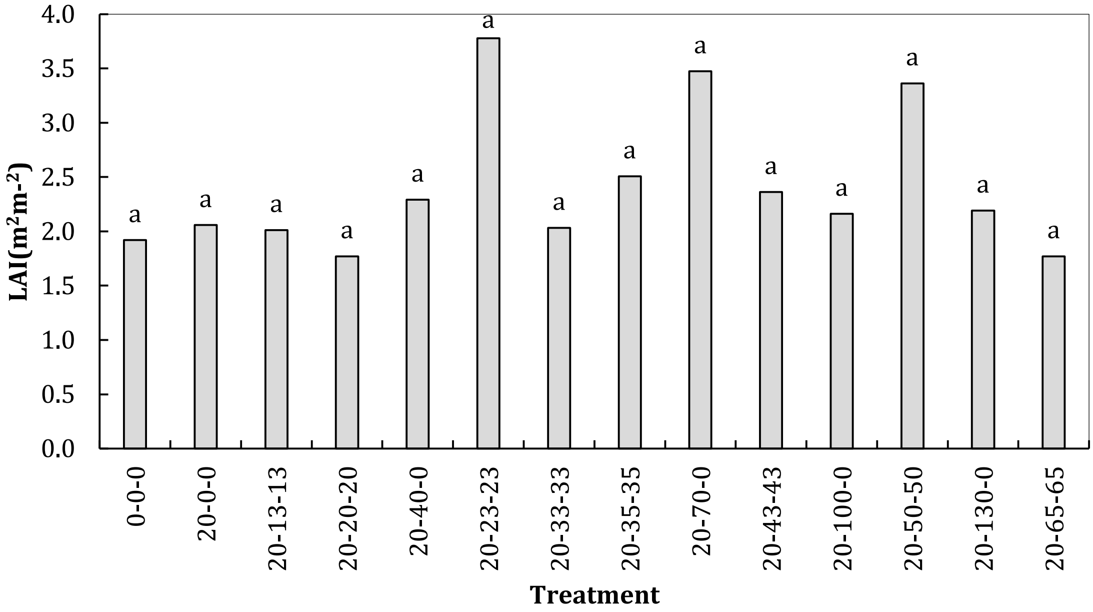

Figure 3.26: LAI as affected by rate and time of N application on Roodebloem at 60 days after planting. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed), 30 and 60 days after planting. p=0.145; Soil Water Content=17.37%±0.39

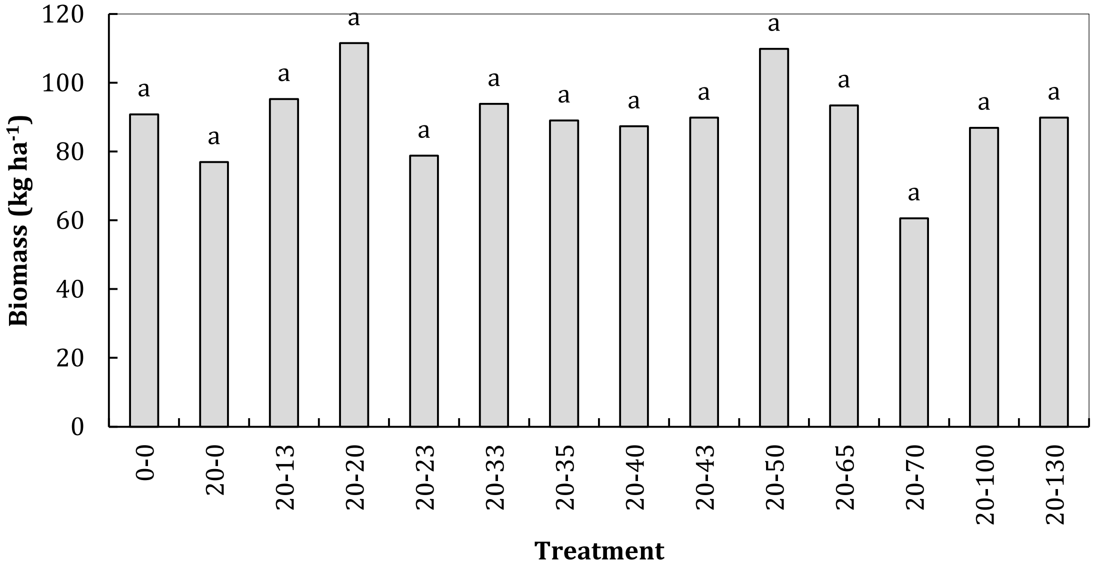

Figure 3.27: Biomass production as affected by rate and time of N application on Roodebloem at 60 days after planting. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed) and 30 days after planting. P=0.898; Soil Water Content =19.44%±0.65

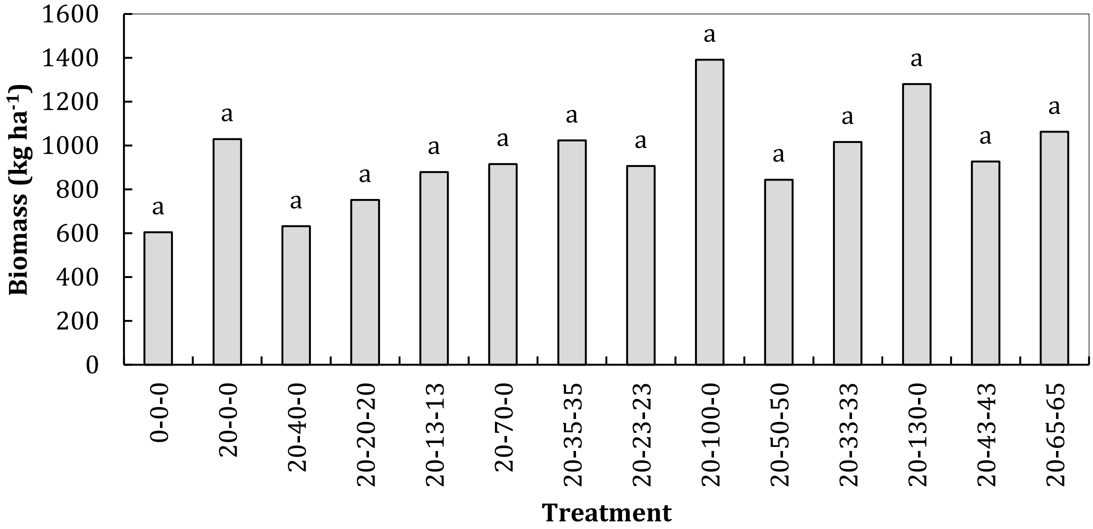

Figure 3.28: Aboveground biomass production as affected by rate and time of N application on Roodebloem at 90 days after planting. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz, in order from bottom to top, fertiliser rate at planting (placed with seed) 30 and days after planting. P=0.066; Soil Water Content=17.37%±0.39

3.4.3.3. Yield and TKM

In 2015, treatment 20-100-0-0 had the highest ($P<0.05$) yield, but did not differ ($P>0.05$) from treatments 20-70-0-0, 20-23-23-23, 20-50-50-0, 20-130-0-0 and 20-65-65-0 (Figure 3.29). Treatment 20-70-0-0 and 20-100-0-0 had a similar application strategy, and yields between these two treatments did not differ ($P>0.05$). Both treatments received 20 kg ha^{-1} of N during planting, with the remainder of the rate applied as a topdressing at 30 DAP.

Thousand kernel mass was not affected ($P>0.05$) by N fertilisation at Roodebloem in 2015 (Figure 3.30).

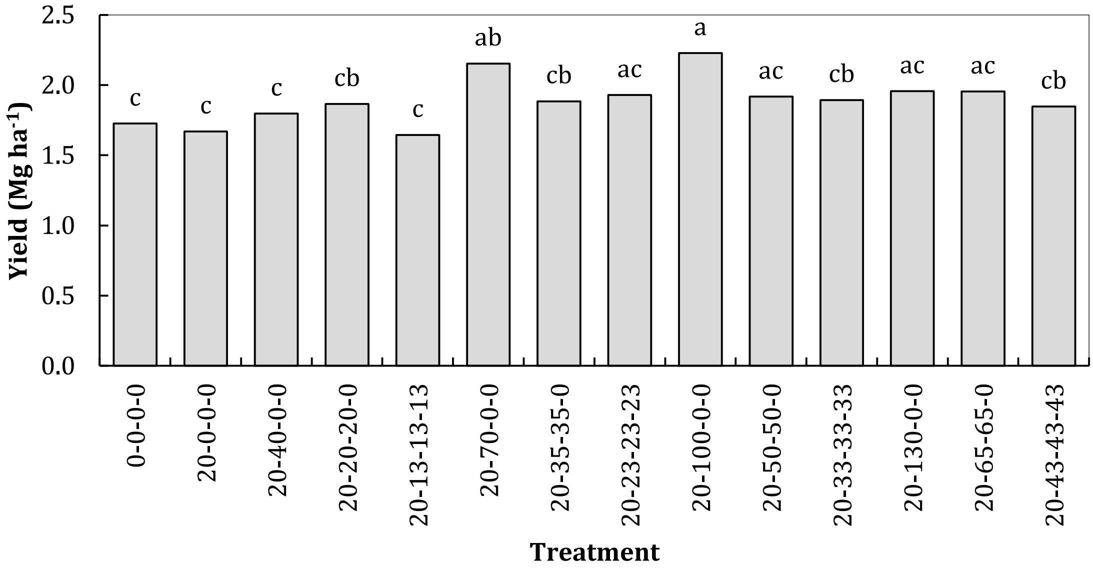

Figure 3.29: Canola yield (Mg ha^{-1}) as affected by rate and time of N application on Roodebloem. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting. P=0.040

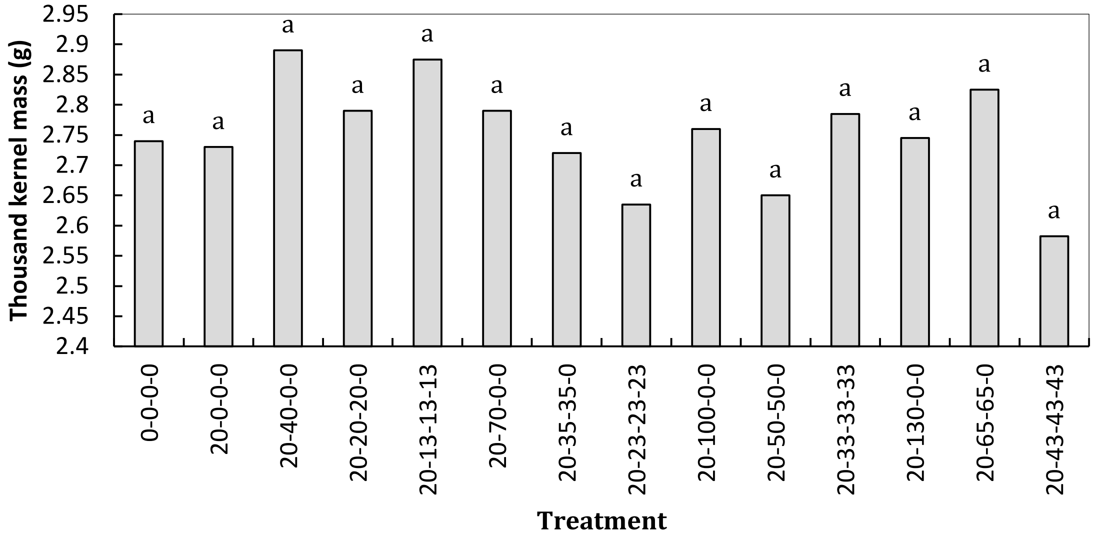

Figure 3.30: Thousand kernel mass as affected by rate and time of N fertilizer application on Roodebloem. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting. P=0.240

3.5. Discussion

3.5.1. Total soil mineral N

Nitrogen in soils are found inorganic and organic forms. For plant production, the most important inorganic forms are nitrate and ammonium. In this study, the sum of nitrate and ammonium are discussed as total mineral N. Organic N is fixed in humic and nonhumic substances in soils. It is largely the nonhumic soil organic matter that can be mineralised to release inorganic N. Subsequently, N in soil that is available to plants is a function of both applied inorganic N (as fertiliser or through symbiotic N fixation) and N released through mineralisation from organic matter (Barker and Bryson 2007). The proportion of N released through mineralisation can be substantial in the Western Cape, and should be taken into account when N guidelines are developed (Maali and Agenbag 2003). The N mineralisation potential of soil from at Altona, Langgewens and Roodebloem was determined at 75% of field water capacity (FWC) and 20°C. It is expected that the N mineralised under field conditions will be lower than the N mineralised under the controlled conditions of the incubation test, because of low rainfall. The soil water content was lower than 75% of FWC for the majority of the season.

At Langgewens, there was a negative N release rate at 14 days after the incubation started, after which the N released increased towards 28 days after the incubation started. The release of N through mineralisation at Altona declined from 7-14 days after the incubation started, after which it increased towards 28 days. It was then followed by a decline as much of the N was already released at 28 days after incubation started. The preceding crop and soil type was similar at both localities in the Swartland, with rainfall distribution and temperature differing. Annual medics, which has the ability to fix atmospheric N symbiotically with *Rhizobium*, was planted at both Langgewens and Altona in the previous growing season, while wheat was planted at Roodebloem. Langgewens had less N released than Altona. At Roodebloem the negative mineralisation rate initially might be due to soil microbes feeding of available N in the soil to decompose the wheat residue with a high C:N ratio from the previous season, which may lead to immobilisation of N. Also, the mineralisation potential is partly determined by the soil type while the soil type also determines in part the ability of the soil to store soil moisture. Soils of all three sites were shallow (250 – 300 mm) sandy loams with a high gravel content (>40%).

The soil water content (SWC) for the duration of the growing season was below 20% of FWC at Langgewens and Altona. The distribution and rate of rainfall at Roodebloem was close to the long-term average rainfall for that area, and was only lower than long-term average at around 90 DAP. Temperatures were also lower than long-term averages. A study by Li et al. (2014) on the interactive effects of soil temperature and SWC found that net mineralisation was low at a SWC of 20% of FWC, because of cellular desiccation of soil microbes. Langgewens may have had a low soil microbial activity which may have resulted in low total soil mineral N content which could be ascribed to lower than long-term average rainfall, and subsequently low SWC. The N mineralisation rate tends to increase with increasing temperatures if the SWC is sufficient (Li et al. 2014), and the optimal temperature for soil microbial activity is in the proximity of 25 to 35°C. Higher temperatures may also lead to higher rates of mineralisation, but only if the SWC is sufficient.

In addition to the reduction in mineralisation rate due to low rainfall conditions (low SWC), N-transport to the roots is also impaired by these low rainfall conditions (Jensen et al. 1997). This means that uptake of N by canola roots was likely limited by the dry conditions, especially after 90 DAP. We therefore do not expect differences between treatments after 90 DAP as it would have been equally low.

In Germany, soil samples are taken in spring to determine soil mineral N content to comply with legislation which limits excessive N fertilisation, and avoid environmental pollution. Henke et al. (2009) found that soil mineral N content analysed in spring for oilseed rape (*B. napus*) fields, did not correlate with the optimum rate of N fertilisation. They recommended to rather take soil mineral N samples in autumn, at the beginning of the growing season. A fertiliser programme for N (rate and timing) could then be determined accordingly. However, for the current study, no differences in total soil mineral N was observed between treatments at 30 or 60 DAP at any locality, as well as 90 DAP for Altona and Roodebloem. If fertilisation do not make a difference to soil mineral N content, it is questioned whether accurate recommendations would be possible from taking soil N content into account. More research is recommended. However, differences between treatments in total soil mineral N was detected at Langgewens 90 DAP. The highest total soil mineral N was found at treatments 20-20-20 and 20-43-43, but it only differed from treatments 0-0-0, 20-0-0 and 20-40-0. This gives an indication that higher rates of N leads to higher values of total soil mineral N at this locality. Higher values of total soil mineral N is also found either at treatments where high amounts of the total N rate were applied soon after planting, or where lower levels of N was applied over the duration of the growing season. This might be an indication that the rate of nitrogen that was released through mineralisation was slow, but sufficient for growth in the dry conditions of the season, and that the application of additional N seemingly had little effect on the total soil mineral N content.

Maali and Agenbag (2003) concluded that response to different N-rates with regards to total soil mineral N varied between seasons, due to total rainfall and distribution of rainfall. Their results varied over a period of four years, with differences in rainfall evident. During the year which received the lowest rainfall, the mineral N content varied between different N rates as is expected, and the total soil mineral N content was in line with the values found in the present study at Langgewens at 90 DAP. Differences in results between Maali and Agenbag (2003) and the current results of this study may therefore be due to poor rainfall distribution.

3.5.2. LAI and aboveground biomass

No differences ($P>0.05$) in either LAI or biomass was observed at Altona and Langgewens. The LAI and biomass also did not differ at Roodebloem ($P>0.05$), but certain trends ($P<0.1$) were found. Treatments 20-130 and 20-100 produced relatively higher ($P<0.1$) biomass. Both treatments received the bulk of their N at 30 DAP. Therefore, there was a trend ($P<0.1$) for treatments that received ≥100 kg N ha^{-1} at 30 DAP to have a higher LAI and biomass. Similar results have been reported by Cheema et al (2010), who found that sufficient N during rapid leaf growth enhances LAI and enables the plant to intercept more solar radiation for biomass production. Canola is known to remobilise accumulated N from the leaves to the pods and seeds. Rathke et al. (2006) found that N allows for a delay in leaf senescence. In the current trial, it is therefore expected that the LAI should differ between treatments that received N in three increments versus the treatments that received N in either one or two increments, but these differences did not occur ($P>0.05$). Several factors may have influenced these results, such as planting date,temperatures and soil moistures. These factors will be discussed below.

Roodebloem was planted in the first week of April, the earliest of the three sites, followed by Altona and Langgewens, respectively. Planting occurred later than planned due to low rainfall conditions. Due to the fact that the first rain only came by the end of May, the growing season was short. The early part of the growing season at Langgewens and Altona also experienced slightly higher temperatures than the long-term average, which may have shortened the duration of the vegetative growth stage. Roodebloem experienced sufficient rainfall during the months of June, July and September, with daily maximum temperatures lower or equal to the long-term average during the months of June to September. Hocking and Stapper (2001) emphasised timely sowing to maximise yield potential. Timely sowing allows for a longer photoperiod, which in turn affects the duration of the phenophase of rapeseed (Hartel 2012). The delay in planting dates at Altona and Langgewens therefore shortened the duration of the photoperiod, which in turn affected LAI and biomass production negatively.

The higher than average mean temperatures at Altona and Langgewens may have influenced the duration of the developmental phases of the canola crops. A higher than average mean temperature and a shorter photoperiod leads to a shortening in the developmental phases

(Chmeilewski et al. 2004). This will consequently also lead to a lower LAI and biomass production than what is expected under optimal photoperiod duration. Similar results were found by Faraji (2009), who found that lower temperatures during vegetative growth allows for better biomass and LAI production. This may be an indication as to why Roodebloem had a tendency ($P<0.1$) to produce more biomass at higher rates of N (Figure 3.28).

Results by Tesfamariam et al. (2010) found that water stress during the vegetative period and flowering stage significantly reduced the LAI. They found that sufficient plant available soil water for the duration of the season have led to a higher LAI and that the leaf canopy remained functional for a longer period. The water stressed treatments had a lower leaf area duration and was therefore less capable to accumulate a high biomass. This is also in agreement with results from Ehlers (1996), who reported that sustained drought conditions over the growing season also accelerates leaf senescence which in turn may have caused lower biomass production.

Jensen et al. (1997) stated that drought conditions also leads to impaired N-transport to the roots. Plants absorb water from the soil through the root and transport it to the stem, leaves and flowers. The root hairs are in close contact with the thin film of water surrounding the soil particles. This corresponds with the results in the current study, and indicates that the drought conditions therefore may have caused applied N to not be taken up by the plants at Altona and Langgewens. This is in contrast with Roodebloem, where sufficient SWC may have led to sufficient uptake. With the findings of Tesfamariam et al. (2010) as background, these drought conditions may have led to accelerated leaf senescence, which in turn influences biomass production, N remobilisation and ultimately yield adversely.

In a season where water stress led to a delay in the planting date, and higher than long term average temperatures occurred, N fertilisation had no meaningful effect on the production of biomass and LAI in the present study.

3.5.3. Yield

Yield only differed ($P>0.05$) at Roodebloem, in the southern Cape. Treatments 20-70-0-0 and 20-100-0-0 led to the highest yield, but did not differ from various other treatments. Taking these treatments into consideration, it can be derived that treatments that received more than 50 kg N ha^{-1} at 30 DAP resulted in the highest yield at Roodebloem. Yields were generally below 2 Mg ha^{-1}, with only treatments 20-70-0-0 and 20-100-0-0 higher than 2 Mg ha^{-1}.

No differences were found between treatments at Altona and Langgewens. Current recommended guidelines for canola production in the Swartland dictates that N should be split into three increments: at establishment, 30 to 40 days after establishment and again at 60 to 70 days after establishment (Protein Research Foundation, 2015). However, during years with adverse climate, particularly rainfall, the last top-dressing could be decreased or omitted. When these guidelines are then followed, no topdressing would be advised for 2015, as it was a year with lower rainfall than average (Figure 3.1), and with a poor distribution during the growth season. The results in Figure 3.1 support this guideline, but one can further suggest that no N fertiliser is required at 30 days after planting in very dry years. One should, however, also consider this when the soil's potential to release N is in the ranges that was found in this situation (Figure 3.4).

The yield results at Altona and Langgewens are in contrast with results by Cheema et al. (2010) and Hocking et al. (1997), but the results at Roodebloem corresponds with their findings. They found increasing yields with increasing rates of N, but also found a decrease in yield at the higher rates of N applied. However, Cheema et al. (2010) applied three irrigations, at branching, flowering and pod formation, which in effect ensured sufficient moisture during the growth period of the crop. This would therefore not be directly comparable to the dryland conditions of this trial. Hocking et al. (1997) reported above average rainfall conditions. Sieling and Christen (1997) also found higher yields at higher rates of N. Sieling and Christensen (1997) found an increase in yield from 3.21 Mg ha^{-1} to 3.84 Mg ha^{-1} where the N rate was increased from 80 kg N ha^{-1} to 200 kg N ha^{-1}.

The distribution of N that led to the highest yield at Roodebloem was for treatments 20-70-0-0 and 20-100-0-0. This indicates that a second and third topdressing seemingly had little or no effect on yield. These results at Roodebloem is in correspondence with Barlog and Grzebisz (2004), who found the highest yield where N was applied as 80 kg N ha^{-1} at the start of vegetation and 80 kg N ha^{-1} three weeks later. This allowed for rapid development at the beginning of growth and fast growth at flowering. Contrastingly, Rathke et al. (2006), found a strong relationship between N-uptake during reproductive growth and yield. We would expect treatments that received N at 90 DAP to therefore differ in yield in comparison with treatments that did not receive N at 90 DAP, which was not the case. This may be due to a finding by Rathke et al. (2006), who found little difference in yield at high rates of N, between split application and no split application. Barlog and Grzebisz (2004), who tested only one high rate of N (160 kg N ha^{-1}), found little difference in yield between two or three split applications.

Yield is determined by the number of pods, seeds per pod and weight per seeds. Robertson et al. (2016) emphasised the importance of timely sowing in determining final yield to make most of rainfall received during the growing season. Timely planting allows plants a more extend period for vegetative growth, leading to a deeper root system to access more soil moisture. This is particularly important in regions with Mediterranean-type climate, where the rainfall is restricted to the cooler months. Hocking et al. (1997) found that 14% of total dry matter accumulated after flowering, largely due to the mobilisation of accumulated N from leaves and branches, which is in accordance with Robertson et al. (2014) who found that yield was positively correlated with biomass production where water and temperature stress was absent. This might explain why results of Cheema (2010) and Hocking et al. (1997) were contradictory to the results at Altona and Langgewens, but in agreement with the results found at Roodebloem.

Gan et al. (2014) and Masaud (2007) found a reduction in yield components when water stress occurred during flowering. By planting at the correct time, grain-filling can occur after very cold winters, but before high summer temperatures and water shortages towards the end of the growing season can limit yield. Roodt et al. (1984) and Olson (1960) also concluded that a decrease in available water towards the end of the growing season had a significant impact on the dry weights of pods. It may therefore be possible that the delayed planting date due to a lack of sufficient soil moisture may have impacted yield adversely at both Langgewens and Altona, but not at Roodebloem where soil moisture was sufficient. Currently it is advised that a topdressing is only effective if more than 110mm of rainfall was received before application (Turner 2014). Roodebloem received above average rainfall during June, just after application. SWC was not measured at 30 DAP due to technical difficulties, but it is expected that SWC was sufficient.

Thurling (1978), found that high temperature stress during first anthesis may reduce yield, while pod abortion increased when anthesis occurred during the warmer part of the growing season (McGregor 1981). These findings are also confirmed by Morrison (2002), who found that temperatures higher than 29.5 °C during the period of bolting to the end of flowering reduced seed weight per pod and therefore yield. The differences in temperatures between the Swartland areas (Altona and Langgewens), and Roodebloem may be therefore be an indication as to why differences in treatments was significant at Roodebloem. Due to lower temperatures during flowering at Roodebloem, pod development was not negatively affected, whereas the higher temperatures in the Swartland may have impacted pod development adversely.

3.6. Conclusion

The highest yield at Roodebloem was realised at N-levels of 90-120 kg N ha^{-1}, applied as 20 kg N ha^{-1} at planting and the remainder at 30 DAP. No significant response to N applications was recorded in the Swartland. These preliminary results indicate that in a low rainfall year, the application of additional N as a topdressing, made no significant difference in yield in the

Swartland. Due to lower N mineralisation potential of Swartland soils, higher optimum levels are expected in normal and high rainfall years, than in the southern Cape. Taking the abovementioned findings into consideration, the effect of treatments might have been significant due to combination of lower temperatures, sufficient soil moisture and high levels of N available during vegetative growth. It is recommended that this study should be repeated in other years, before accurate general guidelines for N fertilisation of canola could be constructed.It is further recommended that model simulations be run, where various scenarios based on the long-term weather data of the canola growing areas be incorporated.

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Chapter 4

The effect of time and rate of nitrogen application on agronomic parameters

4.1. Abstract

Canola is increasing in popularity as a dryland crop in the southern Cape and Swartland grain production areas of South Africa. Canola has a high requirement for nitrogen (N), and response of canola to N fertiliser application is common. Nitrogen fertilisation is generally the highest input cost in canola production. Refined N fertilisation management strategies are necessary to enhance profitability of canola production. Field experiments were conducted in 2015 at Langgewens and Altona (moderate and high production potential zones in the Swartland) and Roodebloem (southern Cape). The trial was laid out as a factorial arranged in a randomised block design, with six N rates (0, 20, 60, 90, 120 and 150 kg N ha^{-1}), which was applied in one, two or three increments after planting, replicated in four blocks. Twenty kg N ha^{-1} was applied at planting. The rest was divided in equal increments either 30 days after planting (DAP), 30 and 60 DAP or 30, 60 and 90 DAP. No differences (P>0.05) were observed in agronomic N use efficiency (ANUE) at Altona and Langgewens, while treatments had a significant effect on ANUE at Roodebloem. The treatment that received 20 kg N ha^{-1} at planting and 100 kg N ha^{-1} at 30 days after planting and no N later, had the highest water use efficiency (WUE), but did not differ (P>0.05) from a number of treatments that received more than 90 kg N ha^{-1} at various time intervals. Water use efficiency at Altona and Langgewens was not affected by treatments (P>0.05). Preliminary results indicate that an N fertilisation strategy of applying 20 kg N ha^{-1} at planting and >50 kg N ha^{-1} 30 DAP, leads to the highest ANUE and WUE. At both Altona and Langgewens the highest gross income was obtained by treatment that received no N at all, while at Roodebloem the highest gross income was obtained by applying 90 kg N ha^{-1} for the entire duration of the growing season.

4.2. Introduction

Nitrogen (N) is generally the most liming nutrient (Grant 1993), and crop responses to N fertilisation is common (Ozer 2003). This is also true for canola, which is, next to wheat and barley the most important field crop in the Western Cape of South Africa. Furthermore, N is one of the most expensive inputs for canola production. Canola has a relatively high requirement for N and, compared to other crops produced in the southern Cape and Swartland, a low N use efficiency (NUE) (Sylvester-Bradley 2009). Canola removes 40 kg ha^{-1} N from soil to produce one ton of grain, in comparison with wheat, which only removes 21 kg ha^{-1} N to produce one ton of grain (Protein Research Foundation 2013). The NUE as defined by Moll et al. (1982) is the amount of grain yielded per available unit of N. This available amount includes both fertiliser applied and residual N in soil. As the determination of the amount of N in the soil, and how much N is taken up by the plant proves to be difficult, the agronomic N use efficiency (ANUE) is a better parameter. The ANUE indicates the difference in yield as a response to the N applied as fertiliser. While the ANUE of canola is mainly determined by cultivar (Svečnjaka and Rengel 2006), it is also influenced by environmental conditions, such as temperature and soil moisture (Rathke et al. 2006). The water use efficiency (WUE) gives an indication of the grain produced for each millimeter of rain received in the growing season. The WUE can be used to determine potential restraints to yield other than a lack of rainfall (Cocks et al. 2001). International research and adapted fertiliser programmes for wheat are currently used as source for fertiliser guidelines for canola production in the Western Cape, but due to climate differences within the canola production area, we expect that the optimal rate of N fertiliser and the distribution thereof will differ from international guidelines. The aim of this study is to determine the optimal N fertiliser rate and the distribution thereof to maximize NUE and WUE for canola. Furthermore, this study will refine N application strategies to maximise the profitability of canola in the Western Cape.

4.3. Materials and Methods

The experimental procedure, treatments, seedbed preparation and trial management, and statistical analyses are discussed comprehensively in Chapter 3. In this chapter procedures for agronomic parameters is discussed. Grain yield (kg ha^{-1}) was determined after the removal of foreign material (chaff). Two agronomic parameters were determined using the following formulae:

4.3.1. Agronomic nitrogen use efficiency (ANUE)

The ANUE was calculated with the following formula according to Wright et al. (1998):

$$ANUE\ (kg\ seed\ kg\ N\ applied^{-1}) = \frac{kg\ grain\ yield\ per\ kg\ N\ applied}{N\ fertiliser\ applied\ (kg\ ha^{-1})} \tag{1}$$

4.3.2. Water use efficiency (WUE)

The WUE was calculated as follows using the formula from Robertson and Kirkegaard (2005):

$$WUE(kg\ grain\ mm^{-1}\ rainfall) = \frac{Yield\ (kg\ grain)}{(Rainfall\ (mm) from\ April\ to\ October) - 120\ mm} \tag{2}$$

4.3.3. Sensitivity analyses

A sensitivity analyses was conducted for each locality to determine the most profitable management strategy based on the yield realised under the climatic conditions experienced. The gross income of each treatment and each N fertiliser rate was determined at each locality, giving an indication of the profitability of each N fertiliser rate, as well as the profitability of dividing these rates in various times of application. Goss income was determined as follows:

$$Gross\ income = (Yield \times Income\ of\ canola\ (R\ ton^{-1})) - Price\ of\ LAN\ (R\ ton^{-1}))$$

(3)

The income (R ton^{-1}) of canola was set at R5343 ton^{-1}, while the cost of limestone ammonia nitrate (LAN) was set at R 5693 ton^{-1}. Since LAN consists of only 28 % N, the price of N was calculated as R20.33 kg^{-1} N. Both these prices were obtained from the grain division at Overberg Agri Cooperation and is relevant for the 2015 production year.

4.4. Results

4.4.1. Agronomic nitrogen use efficiency (ANUE)

The ANUE between treatments at Langgewens and Altona did not differ (P>0.05) between treatments. It ranged from 1.54 to 1.76 kg grain yield kg^{-1} N at Langgewens (Figure 4.1) and between 3.03 and 3.62 kg grain yield kg^{-1} N applied at Altona (Figure 4.2). Differences (P<0.05) between treatments in ANUE was observed at Roodebloem (Figure 4.3). It ranged between 1.58 and 2.21 kg grain kg^{-1} N fertiliser applied. Treatment 20-100-0-0 had the highest ANUE, but did not differ (P>0.05) from treatments 20-50-50-0, 20-23-23-23, 20-65-65-0, 20-130-0-0 and 20-70-0-0.

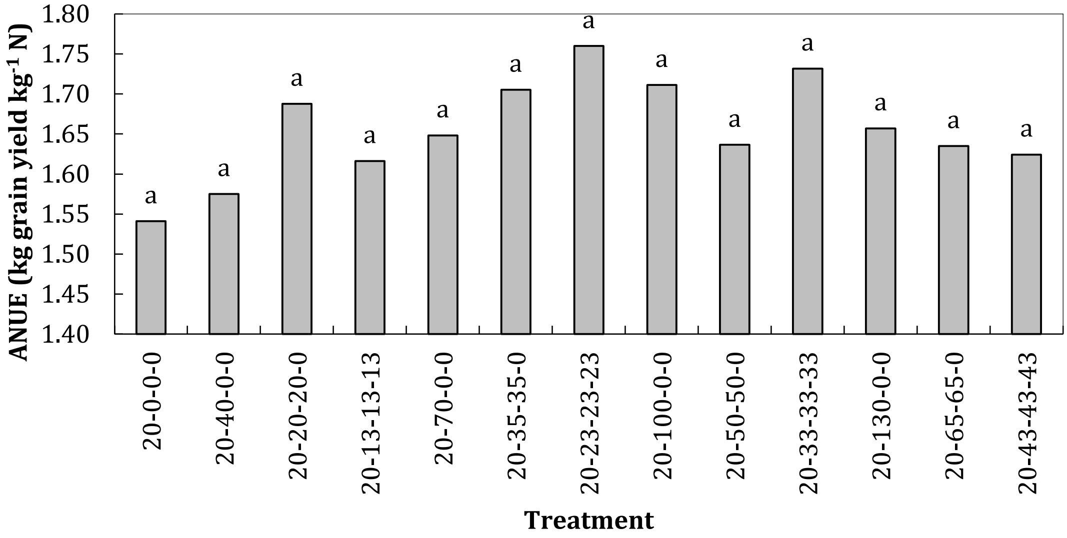

Figure 4.1: Agronomical nitrogen use efficiency (ANUE) as affected by rate and distribution of N application at Langgewens Research Farm. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting.

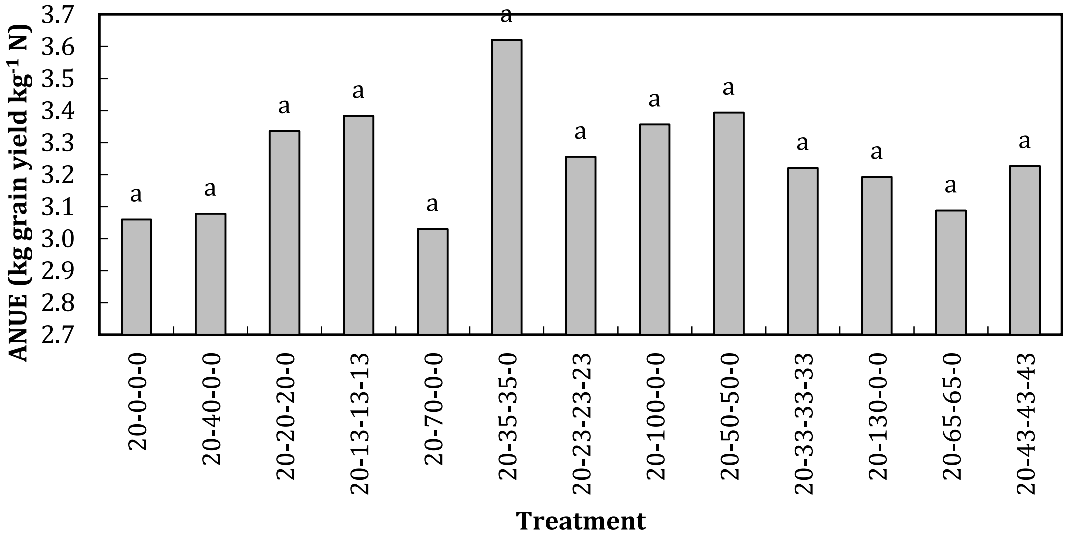

Figure 4.2: Agronomical nitrogen use efficiency (ANUE) as affected by rate and distribution of N application at Altona. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting.

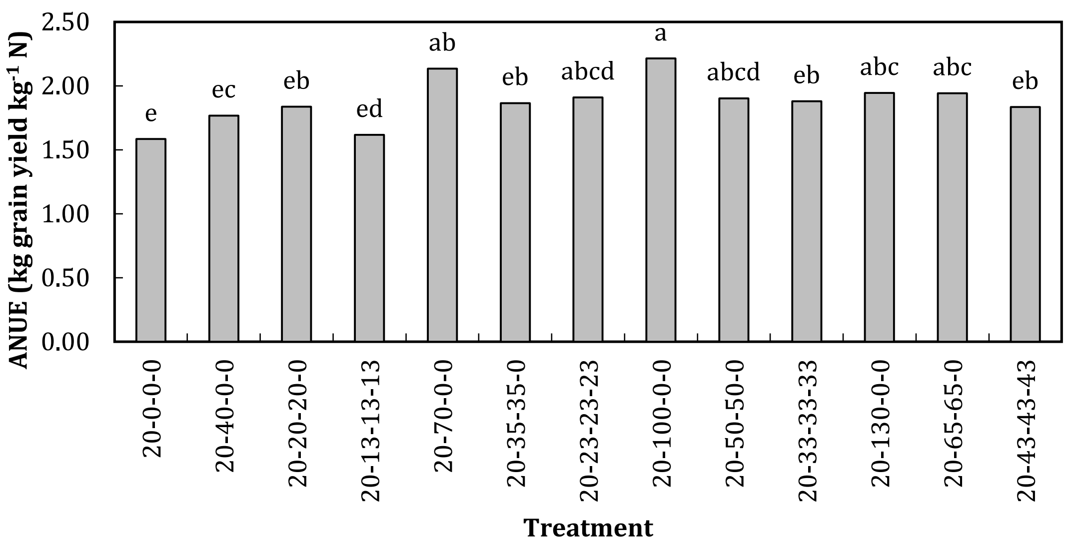

Figure 4.3: Agronomical nitrogen use efficiency (ANUE) as affected by rate and distribution of N application at Roodebloem. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting.

4.4.2. Water use efficiency (WUE)

The WUE varied between 29.15 kg grain mm^{-1} rainfall for treatment 20-40-0-0 to the highest of 32.34 for treatment 20-23-23-23, but treatments did not differ (P>0.05) at Langgewens Research Farm (Figure 4.4).

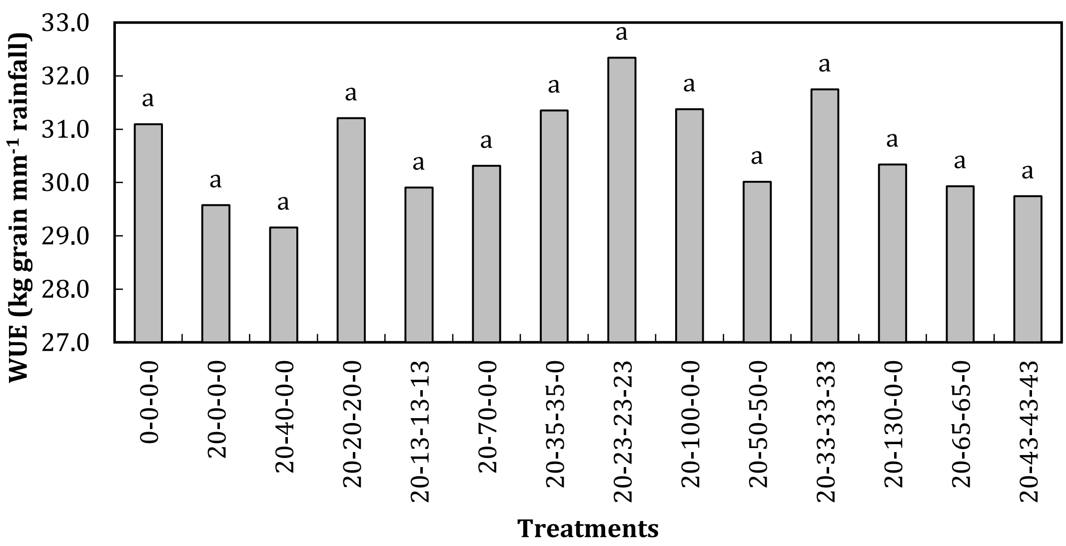

Figure 4.4: Water use efficiency (WUE) as affected by rate and distribution of N application on Langgewens Research Farm. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment,

viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting.

The WUE did not differ (P>0.05) between treatments at Altona (Figure 4.5), with little variation in values.

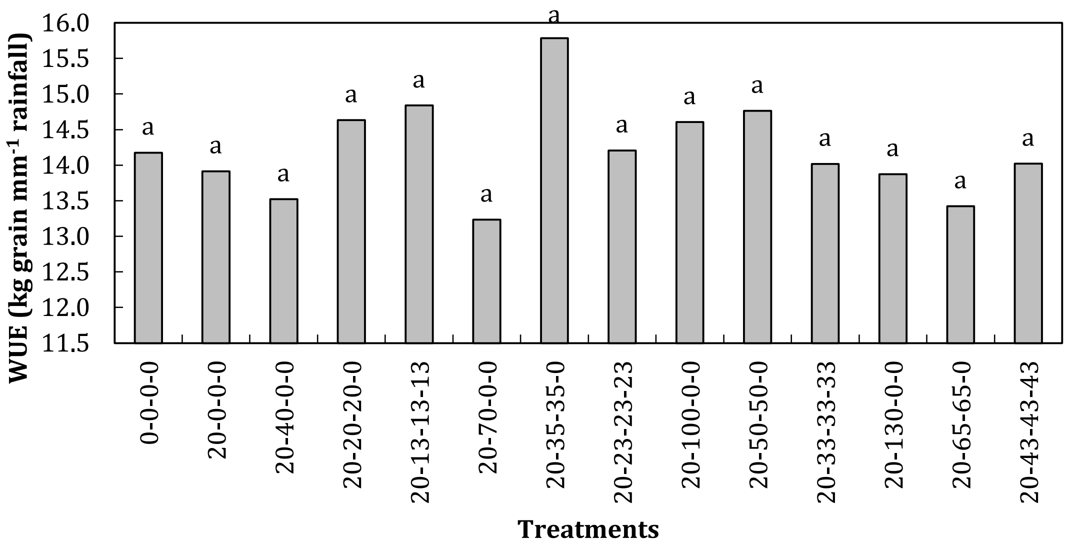

Figure 4.5: Water use efficiency (WUE) as affected by rate and distribution of N application at Altona. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting.

Treatments affected (P<0.05) WUE at Roodebloem. Treatment 20-100-0-0 had the highest WUE, but did not differ (P>0.05) from treatments 20-70-0-0, 20-23-23-23, 20-50-50-0, 20-130-0-0 and20-65-65-0 (Figure 4.6).

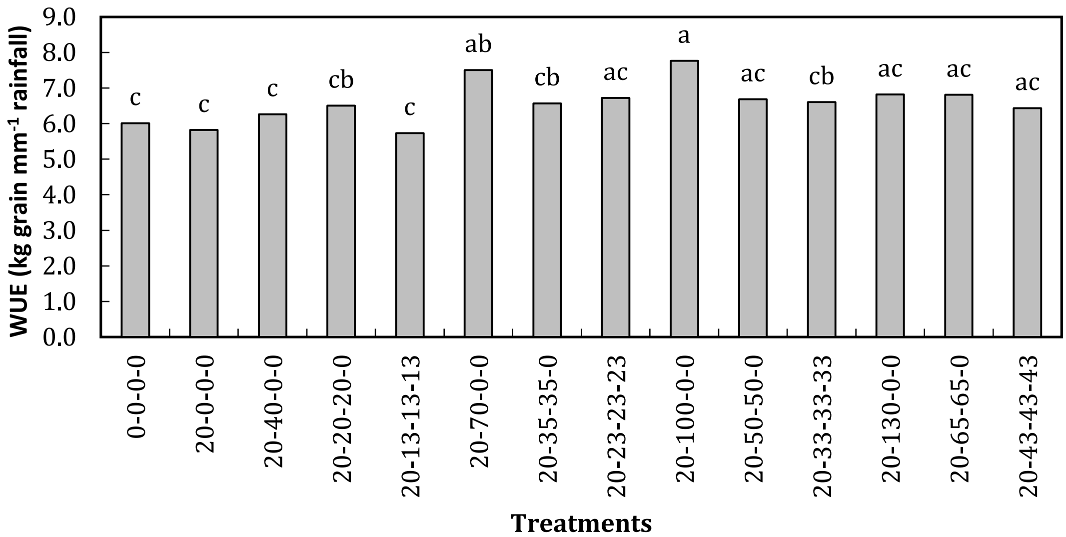

Figure 4.6: Water use efficiency (WUE) as affected by rate and distribution of N application at Roodebloem. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting.

4.4.3. Sensitivity analyses

The sensitivity analyses at Langgewens indicate that the highest economic return was found by applying 0 kg N ha^{-1} (Figure 4.7) during the very low rainfall year where canola was grown after a medic pasture. Applying 20 kg ha^{-1} generated the second highest gross profit, while applying 150 kg ha^{-1} generated the least gross income.

Figure 4.8 indicates the gross income realised by each treatment for Langgwens Research Farm. With the exception of treatment 0-0-0-0, treatments 20-0-0 and 20-20-20-0 and realised the highest gross income, with treatment 20-43-43-43 returning the lowest gross income.

Applying 0 kg N ha^{-1} realised the highest gross income at Altona during the 2015 growing season where canola was grown also after a medic pasture. The rate of 20 kg N ha^{-1} realised the second highest gross income, and declining gross income was observed at 60, 90, 120 and 150 kg N ha^{-1} (Figure 4.9). Treatment 20-35-35-0 realised the highest gross income (Figure 4.10), with a decline in gross income (R ha^{-1}) for treatments that received higher amounts of N, regardless of the time of N application.

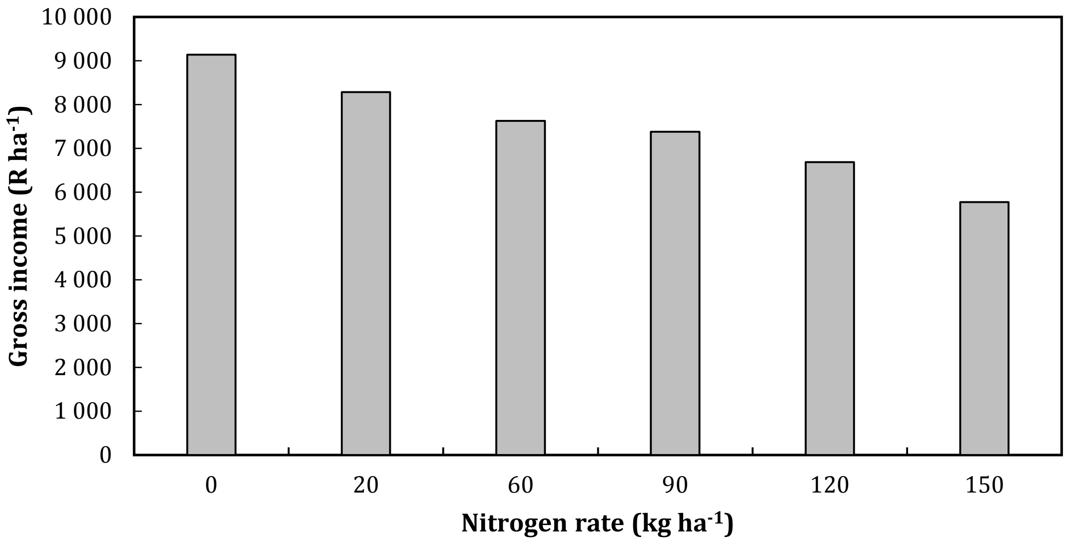

Figure 4.7: Gross income realised by different nitrogen application rates at Langgewens Research farm. Figures on y-axis indicate the gross income [yield (ton ha^{-1}) × income (R ton^{-1}]). Figures on x-axis indicate the rate of nitrogen (kg ha^{-1}) applied.

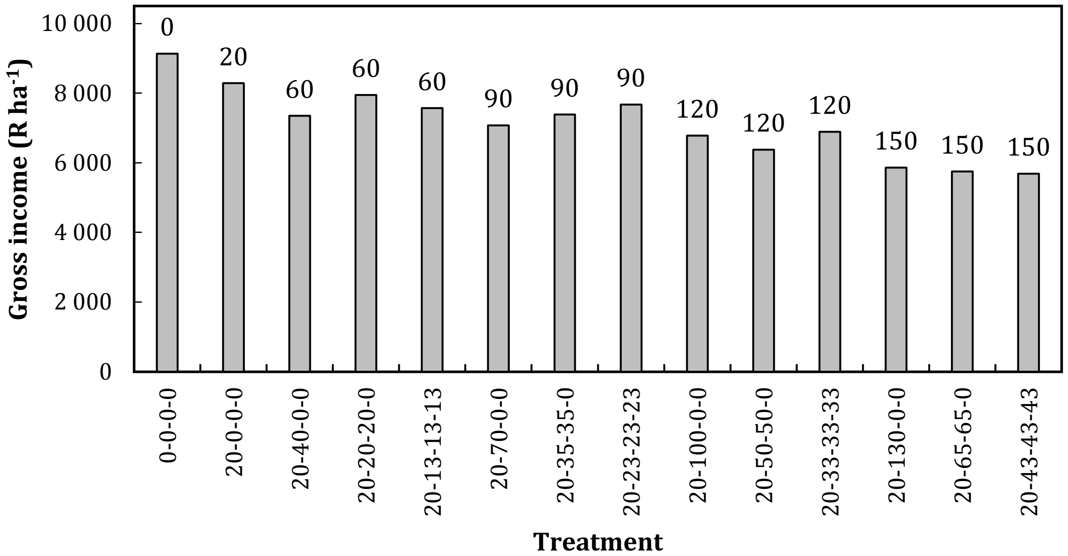

Figure 4.8: Gross income realised by each treatment at Langgewens Research farm. Figures on y-axis indicate the gross income [yield (ton ha^{-1}) × income (R ton^{-1})]. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting. Data labels the total rate of nitrogen (kg ha^{-1}) received.

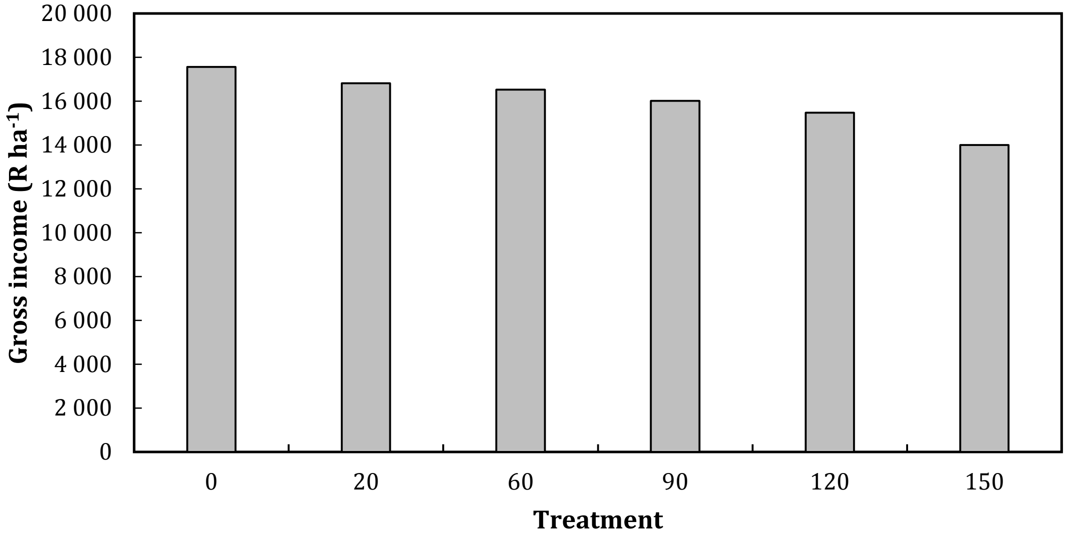

Figure 4.9: Gross income realised by different nitrogen application rates at Altona. Figures on y-axis indicate the gross income [yield (ton ha^{-1}) × income (R ton^{-1})]. Figures on x-axis indicate the rate of nitrogen (kg ha^{-1}) applied.

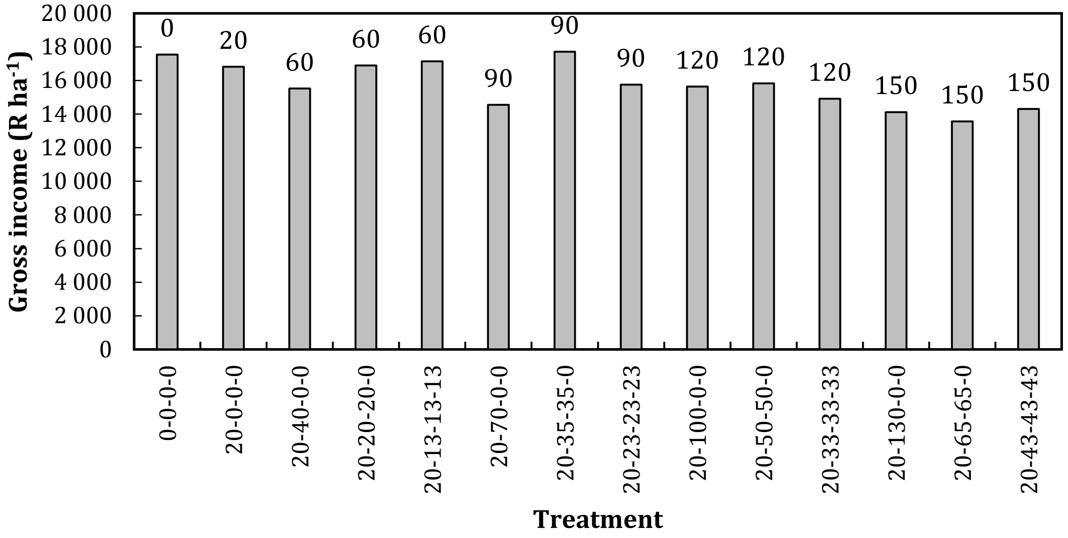

Figure 4.10: Gross income realised by each treatment at Altona. Figures on y-axis indicate the gross income [yield (ton ha^{-1}) × income (R ton^{-1})]. Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting. Data labels the total rate of nitrogen received.

The highest gross income at Roodebloem where canola was grown after wheat was obtained by applying 0 kg N ha^{-1}. Realistically it is not feasible to not apply N, and with that in mind the second highest return was obtained by applying 90 kg N ha^{-1}, although very little difference was observed between 90 kg N ha^{-1} and 120 kg N ha^{-1} (Figure 4.11). The treatment that realised the highest gross income (R ha^{-1}) was treatment 20-70-0-0 (Figure 4.12).

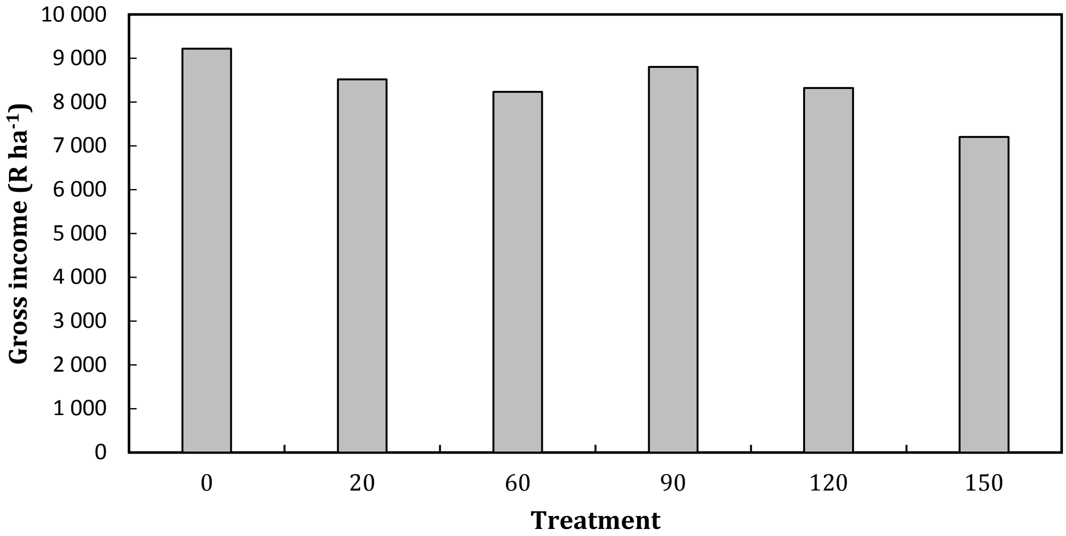

Figure 4.11: Gross income realised by different nitrogen application rates at Roodebloem. Figures on y-axis indicate the gross income [yield (ton ha^{-1}) × income (R ton^{-1})]. Figures on x-axis indicate the rate of nitrogen (kg ha^{-1}) applied.

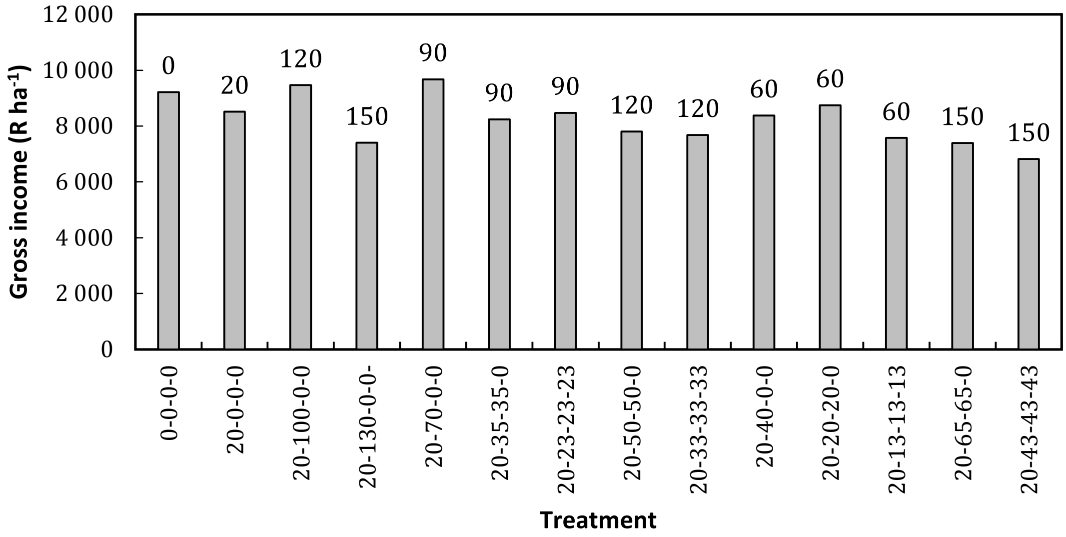

Figure 4.12: Gross income realised by each treatment at Altona. Figures on y-axis indicate the gross income [yield (ton ha^{-1}) × income (R ton^{-1}]). Figures on x-axes indicate the rate of N (kg ha^{-1}) applied at each increment, viz. in order from bottom to top, fertiliser rate at planting (placed with seed), 30, 60 and 90 days after planting. Data labels indicate the total rate of nitrogen received.

4.5. Discussion

Due to the low rainfall climatic conditions of the 2015 growing season, planting occurred later than originally planned at all three localities. The delay in planting dates lead to a growing season that extended the vegetative growing phase into periods of high daily maximum temperatures at Altona and Langgewens. Roodebloem experienced lower than average daily maximum temperatures during June, July and August. A higher than average mean daily temperature leads to a shortening in the developmental phases (Chmeilewski et al. 2004), which ultimately affects, ANUE, WUE and yield adversely.

4.5.1. Agronomic nitrogen use efficiency (ANUE)

The effect of treatments on the ANUE was not significant at Altona and Langgewens, but differences ($P>0.05$) in ANUE and was observed between treatments at Roodebloem.

The ANUE results at Roodebloem indicated that applying a topdressing at 30 DAP of rates >50 kg N ha^{-1} generally led to a higher ANUE. The results further indicated that applying a topdressing at both 60 and 90 DAP have led to a decrease in ANUE, if the amount of N applied at 30 DAP was higher than 50 kg N ha^{-1}. These results are in line with those reported by Ngezimana and Agenbag (2015), who found a decrease in NUE from 30 to 120 kg N ha^{-1} on average in 2009. Gan et al. (2008) and Hamzei (2011) found similar results. These results at Roodebloem might be due to a combination of a large amount of N being available early in the growing season, and the rainfall distribution during the growing season. Treatments at the Swartland localities of Altona and Langgewens may have had no effect on ANUE due to the lower than long-term average rainfall and the poor rainfall distribution that was experienced in the growing season wheat after medics. Hamzei (2011) found a significant interaction between irrigation levels and N fertiliser rate on the ANUE. With decreasing levels of irrigation, yield decreased and ANUE as a result as well. Jensen et al. (1997), stated that drought conditions leads to impaired N-transport to the roots. Plants absorb water from the soil through the root and transport it to the stem, leaves and flowers. The root hairs are in close contact with the thin film of water surrounding the soil particles. The drought conditions therefore may have caused applied N to not be taken up by the plants at Altona and Langgewens, in contrast with Roodebloem.

4.5.2. Water use efficiency (WUE)

The effect of treatments on WUE varied between localities. Treatments had a significant effect on WUE at Roodebloem (Figure 4.6), but not at the Swartland localities of Altona and Langgewens. The highest WUE ± 8 kg grain mm^{-1} grain received) at Roodebloem was generally found at treatments where >50 kg N ha^{-1} was applied 30 DAP. Treatments 20-100-0-0 and 20-

70-0-0 and 20-130-0-0 had the highest WUE (although not different from treatments 20-50-50-0, 20-23-23-23 and 20-65-65-0). The treatments that led to the highest WUE received the bulk of their respective rates at 30 DAP, indicating that sufficient N early in the growing season and favourable growing conditions led to the highest WUE at Roodebloem in the southern Cape.

The WUE according to Robertson and Kirkegaard (2005) for canola ranges between 8-14 kg grain mm^{-1} rainfall, with the average WUE at 11 kg grain mm^{-1} rainfall. The canola at Roodebloem generally had low WUE values, possibly due to *Leptosphaeria maculans* infection. The WUE results at both Swartland localities were higher than the WUE at Roodebloem. Canola at Altona and Langgewens was not affected by *Leptosphaeria maculans,* which may be an indication as to why the WUE values were sufficient.

Biscoe and Gallagher (1977) found that the main factors that delayed leaf formation was water stress and temperature. As soil moisture was sufficient during the early development stage at Roodebloem, and slightly lower than long-term daily maximum temperatures occurred during June, July and August, a stronger leaf canopy might have been established to intercept more solar radiation. Altona also had a LAI above the optimal 3.11 (Cheema et al. 2010). The establishment of a strong leaf canopy will be favoured by the availability of sufficient N to sustain early vegetative growth (Cheema et al. 2010; Mason and Brennan 1998; Rood and Major 1984; Scott et al. 1973). The rapid covering of the soil will lead to a increase in transpiration while reducing the unproductive loss of water through evaporation and therefore increase WUE (Kirkegaard et al. 2016). The results for Roodebloem further indicate that applying a topdressing at both 60 and 90 DAP, led to a lower WUE, if the amount of N applied at 30 DAP was higher than 50 kg N ha^{-1}. The treatments that led to the highest WUE also led to the highest ANUE (Figure 4.3).

These results also in part correspond with those of Hamzei (2011) and Faraji et al. (2009). Hamzei (2011) found that WUE increased with increasing N rates up to 120 kg N ha^{-1}, because of an increase in LAI, while Faraji et al. (2009) found WUE were associated with greater LAI and aboveground dry matter, and lower temperatures during reproductive stages, due to timely sowing.

The delay in planting at all three localities may have had an effect on the leaf canopy establishment. Kirkegaard et al. (2016) and Robertson et al. (2004) emphasised the importance of timely sowing to maximise WUE, through rapid soil coverage, a longer vegetative stage and cooler early growing conditions. The effect of the delay in planting dates might have had less of an influence on Roodebloem than at Altona and Langgewens due to the lower temperatures and better rainfall distribution experienced at Roodebloem.

4.5.3. Sensitivity analyses

Various sources have emphasised N as the largest production input cost for grain production (ARC 2007; Protein Research Foundation 2013; Sands et al. 2011). A sensitivity analyses indicated the gross income, which is a function of yield and cost (partly manageable by the producer), and income (a function of the markets). The sensitivity analyses therefore allowed for an indication of the economic feasibility of each rate of N applied. The analyses at each locality indicated the optimal N-rate on average, regardless of time of N-application, as well as the analyses for every treatment, which takes time of application into account. It is important to take into consideration that applying N in three splits will lead to higher operation costs with regards to fuel, labour etc., which is not taken into account when calculating gross income.

At Langgewens, the highest gross income was observed for N fertiliser rate 0 kg N ha^{-1} (Figure 4.7). This is because no input costs were involved. Although a N fertiliser rate of 0 kg N ha^{-1} generated the highest gross income and N-rate of 20 kg N ha^{-1} the second highest gross income, one can speculate that it is not realistic to not apply N during a season with a rainfall of about long term average and especially if canola is plant after wheat. Various authors have emphasised an increase in yield due to N fertiliser application (Cheema et al. 2010; Grant 1993; Holmes 1980; Rathke et al. 2005; Wright et al. 1998). Taking this into consideration, a N application rate of 60 kg N ha^{-1} realised the highest gross income, with the 90, 120 and 150 kg N ha^{-1} rates showing a decrease in gross income in comparison with the 60 kg N ha^{-1} rate. The decline is due to a relatively constant yield but an increase in N input cost.

The highest gross income (Figure 4.9) at Altona where canola was also grown after medic pasture was also found at N fertiliser rate 0 kg N ha^{-1} as well, with the second highest return at 20 kg N ha^{-1}. As was the case at the other Swartland locality, Langgewens, this is due to no differences ($P>0.05$) in yield between the treatments and no or low fertiliser input cost. The N-rate of 60 kg N ha^{-1} generated in the proximity of R17 500 ha^{-1}, and N fertiliser rates of 90, 120 and 150 kg N ha^{-1} showed a decrease in gross income in comparison with 60 kg N ha^{-1}. Interestingly enough, if the time of N-application is taken into consideration (Figure 4.10), the highest gross income was generated by treatment 20-35-35. This may be an indication that applying 90 kg N ha^{-1} in increments of 20 kg N ha^{-1}, followed by 35 kg N ha^{-1} at 30 DAP and 35 kg N ha^{-1} at 60 DAP will generate the highest gross income.

Treatment 20-35-35-0 (Figures 4.2 and 4.5) had the highest ANUE and WUE at Altona. Although the differences were not significant, it may an indication of the positive effect of a higher ANUE and WUE on the gross income of canola.

At Roodebloem which received a rainfall during 2015 not much less than the long term average and canola was grown after a wheat crop, the N fertiliser rate of 0 kg N ha^{-1} generated the highest gross income, followed by the rates of 20, 90 and 120 kg N ha^{-1} generated the second highest gross income, although very little difference was found between the fertiliser rates (Figure 4.11). The N rates of 60 and 150 kg N ha^{-1} generated less gross income due to a low yield and high input cost respectively. Treatments 20-70-0-0 and 20-100-0-0 generated the highest gross income. This is due to differences (P>0.05) in yield (data not shown).

The abovementioned results indicate that the highest gross income in the Swartland localities was generated were 0 kg N ha^{-1} was applied on canola in a year with poor rainfall distribution, in a crop rotation system where canola was produced after medics. In the southern Cape, applying N in excess of 70 kg N ha^{-1} generated the highest gross income in a relatively normal rainfall distribution if compared to the long-term average of the area.

4.6. Conclusion

The results indicate that N fertilisation rate and timing thereof had no significant effect on the ANUE and WUE at the Swartland localities of Altona and Langgewens, which was characterised by a below average rainfall, and where canola was grown after medics. Preliminary results at Roodebloem indicate that applying 20 kg N ha^{-1} and a topdressing at 30 DAP of rates >50 kg N ha^{-1} generally led to the highest WUE and ANUE. The sensitivity analyses indicated that at all three localities, the highest gross income was generated by applying a N rate of 0 kg N ha^{-1}, which one can speculate is not a realistic management practice in normal rainfall years. Further research is advised in this regard.

4.7. References

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Chapter 5
Conclusion and recommendations

5.1. Conclusion

Canola is increasingly becoming more popular as a crop in the southern Cape and Swartland regions of South Africa due to its health benefits for consumers and various other benefits in crop rotation systems for producers. Canola has a relatively low nitrogen use efficiency (NUE), and due to the rising input production cost of N fertilisation, refined N fertiliser guidelines is needed, not only to enhance the yield of canola to satisfy the rising demand of consumers, but also to maximise profitability for producers. Currently, the appropriateness of N fertiliser guidelines for canola in South Africa is questioned. These guidelines are adopted from international literature or adopted from guidelines for wheat, and should be refined for the local environmental conditions.

The objective of this research project was to determine to optimal rate (kg N ha^{-1}) and time of N application for the Swartland (Altona and Langgewens) and the southern Cape (Roodebloem). The effects from rate and distribution of N fertilisation on total soil mineral N, leaf area index (LAI), biomass production, agronomic nitrogen use efficiency (ANUE), water use efficiency (WUE), thousand kernel mass (TKM), grain yield and profitability was determined.

The 2015 season was characterised by dry conditions in the Swartland, with rainfall lower than the long-term average of most months, while Roodebloem received higher than average rainfall during the leaf formation, stem elongation and flowering phases, while the rainfall during the remainder of the year was below the long-term average. The average maximum daily temperatures in summer were generally similar or slightly lower than the long-term average daily maximum temperatures. The average minimum daily temperature was higher during August and September than the long-term average. Soils of all sites were shallow (250 – 300 mm) sandy loams with a high gravel content (>40%). The two Swartland sites was part of a crop rotation system where medics preceded the canola the previous growing season, while wheat preceded canola at Roodebloem.

Total soil mineral N did not differ between treatments at Altona at 30, 60 or 90 days after planting (DAP), while at Langgewens the only differences in total soil mineral N was observed at 90 DAP. Nitrogen applied at a rate higher than 46 kg N ha^{-1}, and at two intervals (30 and 60 DAP), resulted in a higher ($P<0.05$) total soil mineral N content. No differences ($P>0.05$) in LAI, biomass, ANUE, WUE, TKM or yield were observed between treatments at Altona and Langgewens

At Roodebloem, no differences in total soil mineral N was found between treatments. Although the LAI did not differ ($P>0.05$) between treatments, N fertilisation tended ($P<0.1$) to increase LAI at 30 DAP at Roodebloem. Treatments that received more than 70 kg N ha^{-1} tended to have the highest LAI.There also was a trend ($P<0.1$) for higher biomass production at higher rates of N at 90 DAP at Roodebloem. Treatments that received more than 100 kg N ha^{-1} at 30 DAP tended to have the highest ($P<0.1$) biomass production, with both treatments receiving the bulk of their total N rate at 30 DAP. Treatments that received more than 90 kg N ha^{-1}, with applications of more than 23 kg N ha^{-1} at 30 DAP had the highest ANUE and WUE. At Roodebloem, treatments receiveing 20 kg ha^{-1} of N during planting, And a topdressing of more than 70 kg N ha^{-1} at 30 DAP led to the highest yield.

These preliminary results indicated that in a low rainfall year, the application of additional N as a topdressing, made no significant difference in yield in the Swartland. Due to lower N mineralisation potential of Swartland soils, higher optimum levels of N are expected in normal and high rainfall years, than in the southern Cape. The effect of treatments at Roodebloem might have been significant due to combination of lower temperatures, sufficient soil moisture and high levels of N available during vegetative growth. Nevertheless, these results at Roodebloem indicate that treatments that received 20 kg N ha^{-1} at planting and more than 50 kg N ha^{-1} at 30 DAP led to the highest yield.

It can also be concluded from the results obtained in this study that the highest gross profit was realised by applying 0 kg N ha^{-1} at the Swartland localities of Altona and Langgewens, in a year with poor rainfall distribution in a crop rotation system where canola was produced after medics. In the southern Cape, applying N in excess of 70kg N ha^{-1} generated the highest gross income in a relatively normal rainfall distribution if compared to the long-term average of the area. The hypotheses as stated in chapter 1 was as follows:

H_1H_0: Increasing rates of N application will lead to increased yields to an optimum level.
H_1H_1: Increasing rates of N application will not lead to increased yields.

H_2H_0: Split application of N over more than one time of application will increase yield.
H_2H_1: Split application of N over more than one time of application will not increase yield.

The H_1H_0 hypothesis was rejected at Altona andLanggewens as no differences in yield were found at Altona and Langgewens, while at Roodebloem higher rates only increased yield up until 120 kg N ha^{-1}, and for this site, the H_1H_0 was accepted. Split application of N over more than one time of application realised no difference in yield at Altona and Langgewens, and the H_2H_0 hypothesis was rejected at these localities. At Roodebloem, the H_2H_0 hypothesis is accepted, as the highest yield was obtained at treatments where N was applied at planting and 30 days later.

5.2. Recommendations

With regards to the current study, it is recommended that this study be repeated in other years, before accurate general guidelines for N fertilisation of canola could be constructed. Lower than long-term average rainfall and higher temperatures may have influenced results, which is not typical of most other years. Future studies should also determine the total soil mineral N at harvest, as well as the N content of the plants at harvest.

Canola is a good alternative to replace imported protein used in animal feed. Canola as cash crop in South Africa, and particularly the southern Cape and Swartland regions is a fairly young crop when compared to wheat or barley. Unpredictable establishment success and variable yields currently make farmers skeptical about canola cultivation. Various agronomic factors and management practices that can lead to improved yield should therefore be researched. During the current study only medics and wheat preceded canola. It is therefore advised for further studies that the current trial be repeated with different preceding crops than just wheat and medics. The influence of the preceding crop on the availability of the residual N should then be incorporated in fertiliser guidelines.

Current N fertiliser guidelines were developed in the 1960s. As can be expected, various management practices have since changed, including the adoption of minimum-tillage and other conservation agriculture practices. Minimum-tillage supports organic matter accumulation in the topsoil, which in turn may lead to more plant available N in the topsoil. This implies that different N rates may be needed as additional application, than what is currently prescribed. Regardless of these, guidelines are still based on outdated management strategies.

It is further recommended for crop modeling to be implemented to navigate the way forward and refine the recommendation rates by running the model for various scenarios and climatic conditions, to account for variation in temperatures, rainfall and mineralisation potential of soils.