Establishment, growth and yield of canola (*Brassica napus* L.) as affected by seed-drill opener, soil quality and crop residue in the Swartland

by

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Abstract

Canola (double low varieties of *Brassica napus*) is an important crop for farmers implementing conservation agriculture (CA). Famers implementing CA seek to minimise soil disturbance before, during and after planting. Many farmers in the grain producing regions (Overberg and Swartland) of the Western Cape have widely adopted CA over the past two decades. Although most farmers rely on tine openers to establish canola, disc openers are becoming more popular. Soil quality in these canola production areas are relatively low. The aim of this study was to compare tine and disc openers and the effects of soil quality and crop residue on canola production, by evaluating establishment, biomass production, leaf area index (LAI), yield, thousand seed mass (TSM) and soil disturbance. The first objective was to determine whether soil quality along with residue level should be considered when choosing between a tine or disc seed-drill opener. The second objective was to compare tine and disc openers to produce canola from soil with contrasting qualities and on fields comparable in size to commercial farms. Trials were conducted in 2016 and 2017 at Langgewens Research Farm in the Swartland area. During the first year of the trial the opener had an effect on canola plant population ($p<0.05$), while during the second year no differences between treatments were recorded ($p>0.05$). Tine openers performed better on high quality soil while disc openers performed better on low quality soil. Crop residue can become a problem when establishing canola with both the tine and disc openers, and establishment was the best at low residue levels. The poorer canola establishment with the disc opener during 2016 might be due to fertiliser application as fertiliser was applied with seeding which may have caused chemical injury to the seed. Overall the tine opener resulted in more biomass than the disc opener during the first year of the trial while similar biomass productions were achieved during the second year. The leaf area-index (LAI) was similar except that a higher LAI was recorded with the tine opener on low residue levels on high quality soil at 30 days after emergence during the 2017 season. Treatments had no effect on TSM in 2016 ($p>0.05$), while in 2017 a higher TSM was obtained on low quality soil with high residue levels than on high quality soil with low residue levels. The treatments had no effect on yield in both 2016 and 2017 ($p>0.05$). On field scale, similar results were recorded as on small plots with low residue levels, with regards to plant population, biomass production, LAI, yield and TSM. Contrary to what was expected, no difference in disturbance was recorded between tine and disc openers ($p>0.05$), so if the aim is to minimise soil disturbance, either a tine or disc opener can be used. It is recommended that this study is repeated in the southern Cape as soil and climatic conditions differ substantially from the Swartland. It is also recommended that this study is repeated in different years in the Swartland due to seeding in dry soil in both years of this study due to the drought.

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Uittreksel

Kanola (dubbel-lae variteite van *Brassica napus*) is 'n belangrike gewas vir boere wat bewaringslandbou toepas. Bewaringslandbouboere mik vir minimum grondversteuring voor, gedurende en na plant. Baie boere in die graan produserende areas (Overberg en Swartland) van die Wes-Kaap het bewaringsboerderybeginsels oor die afgelope twee dekades aangeneem. Alhoewel meeste boere op tandoopmakers staatmaak om kanola te vestig, neem gewildheid van skyfoopmakers toe. Grondkwaliteit in hierdie kanolaproduksieareas is redelik laag. Die doel van hierdie studie was om tand- en skyfoopmakers met mekaar te vergelyk en die effek wat grondkwaliteit en oesreste op kanolaproduksie het, deur versteuring, vestiging, biomasssaproduksie, blaaroppervlak-indeks (BOI), duisendkorrelmassa (DKM) en opbrengs, te evalueer. Die eerste doelwit was om te bepaal of grondkwaliteit en oesresvlakke in ag geneem moet word wanneer daar tussen 'n tand- en skyfoopmaker gekies word. Die tweede doelwit was om tand- en skyfoopmakers te vergelyk op grond wat verskil in kwaliteit op groot persele wat vergelyk kan word met 'n kommersiële plaas. Die proewe was in 2016 en 2017 uitgevoer op die Langgewens Navorsingsplaas in die Swartland area. Gedurende die eerste jaar van die proef het die oopmaker 'n effek op plantpopulasie gehad ($p<0.05$), terwyl gedurende die tweede jaar geen verskille tussen behandelings waargeneem is nie ($p>0.05$). Tandoopmakers het beter presteer op hoë kwaliteit grond terwyl skyfoopmakers beter presteer het op lae kwaliteit grond. Oesreste kan 'n probleem word wanneer kanola met beide 'n tand- of skyfoopmaker gevestig word en vestiging was die beste by lae oesrestevlakke. Die swakker kanolavestiging met die skyfoopmaker gedurende 2016 kan wees as gevolg van kunsmistoedienning tydens plant wat chemiese skade aan die sade kon veroorsaak het. Oor die algemeen het die gebruik van die tandoopmaker meer biomassa tot gevolg gehad as die gebruik van die skyfoopmaker gedurende die eerste jaar van die proef terwyl soortgelyke biomassaproduksie gedurende die tweede jaar behaal is. Die BOI was soortgelyk behalwe dat 'n hoër BOI aangeteken is vir die tandoopmaker op lae oesreste op hoë kwaliteit grond teen 30 dae na opkoms gedurende die 2017-seisoen. Behandelings het geen effek op DKM in 2016 gehad nie ($p>0.05$), terwyl 'n hoër BOI in 2017 behaal is op lae grondkwaliteit met hoë oesreste as op hoë grondkwaliteit met lae oesresvlakke. Behandelings het geen effek op opbrengs in beide 2016 en 2017 gehad nie ($p>0.05$). Op plaasvlak is soortgelyke resultate behaal as op klein persele met lae oesvlakke, met betrekking tot plant populasie, biomassa produksie, BOI, opbrengs en DKM. Anders as wat verwag is daar geen verskille in grond versteuring tussen tand- en skyfoopmakers waargeneem nie ($p>0.05$). So as die doel is om grondversteuring te verminder kan beide 'n tand- of skyfoopmaker gebruik word. Dit word voorgestel dat die studie in die Suid-Kaap herhaal word omdat grond- en klimaatstoestande verskil van die Swartland. Dit word ook aanbeveel dat die studie oor verskeie jare in die Swartland herhaal word omdat in beide 2016 en 2017 in droë grond geplant is as gevolg van die laat voorkoms van voldoende herfsreën.

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“Agriculture is the most healthful, most useful and most noble employment of man.”- George Washington

This thesis is dedicated to Johan van Huyssteen, a friend who lost his life tragically in a freak accident a month before we would have started our master's degree together.

16 Augustus 1993 – 4 Januarie 2016

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Abbreviations:

C	Carbon
CA	Conservation Agriculture
Ca	Calcium
CEC	Cation exchange capacity
CO_2	Carbon dioxide
G	Gram
ha^{-1}	Per hectare
K	Potassium
LAI	Leaf area index
m^2	Square meter
m^{-2}	Per Square meter
Mg	Magnesium
N	Nitrogen
Na	Sodium
P	Phosphorus
PMN	Potentially mineralisable Nitrogen
SAR	Sodium adsorption ratio
SMAF	Soil management assessment framework
SQI	Soil quality index
T	Ton
TSM	Thousand seed mass
WUE	Water use efficiency

CHAPTER 1

Introduction

1.1 Background

The Mediterranean-type climate region of South Africa is restricted to the south-western parts of the country. The region along the southern coast is referred to as the southern Cape and roughly stretches from Bot River in the west to Albertinia in the east, receiving an annual rainfall of roughly 400 to 600 mm. In the western parts of this region, approximately 70% of the rainfall is received from May to October. Rainfall distribution is somewhat more evenly distributed in the east with about 55% from May to October (Swanepoel et al. 2016). The region along the west coast from Cape Town northwards is called the Swartland, which roughly stretches from Philadelphia in the south to Eendekuil in the north. Its average rainfall is c. 300 to 500 mm per annum with 80% from May to October (Meadows 2003). The natural vegetation in both these regions is classified as lowland coastal renosterveld. Due to the low grazing capacity of the original vegetation, 93% of this area has been transformed to crop and crop pasture production systems (Kemper et al. 1999). The cropping systems in the southern Cape includes wheat (*Triticum aestivum)*, barley (*Hordeum vulgare*), oats (*Avena sativa*) and canola (double low varieties of *Brassica napus*) (Swanepoel et al. 2016). In the Swartland wheat and canola are cultivated in rotation with annual medics (*Medicago* spp.) and clovers (*Trifolium* spp.). Canola is relatively new to South Africa compared to other crops, but is well adapted to the South African climate and can offer the soil various benefits. Canola belongs to the *Brassica* family and is a type of rapeseed which must contain less than 2% erucic acid (Berglund et al. 1997). The solid component must contain less than 30 micromoles of any mixture of the following, 3-butenyl glucosinolate, 4-pentenyl glucosinolate, 2-hydroxy-3-butenyl glucosinolate, and 2-hydroxy-4-pentenyl glucosinolate per gram air dry, oil free seed (Protein Research Foundation 2013). There are three rapeseed species of which *Brassica napus* L. is the only species cultivated in the Western Cape (Protein Research Foundation 2013).

Establishment of canola is important to ensure high yielding crops (Protein Research Foundation 2013). Canola prefers a level, firm, moist seedbed with enough depth for maximum root development (Protein Research Foundation 2013). For the best results, the seeds should be placed at a uniform depth, evenly spread within rows and across individual rows. After planting, seeds should be covered with soil and compacted (Protein Research Foundation 2013).

1.2 Problem statement

Variation in soil types and the associated soil production potential in the Western Cape is large over short distances. Soil quality also differ, sometimes even within a single camp. Soil quality simply refers to the ability of the soil to function. The function of the soil includes the chemical, physical and biological processes (Karlen et al. 1994). It is well known in the literature that soil quality has a major influence on the ability of the plant to sustain productivity. It could be expected that soil quality will have an influence on efficiency of establishment of canola, as this will affect the quality of the seedbed. The effect of tillage has been assessed on soil quality, but the impact of soil quality on planting method of canola has not yet been evaluated. It is important to differentiate between good soil quality and poor soil quality, and the possible link thereof with seedbed quality. Soil with a low quality is characterised as being *inter alia* compact, having a poor aggregate stability, has either too low or too high nutrient levels and low organic matter and microbial activity (Lal 1993). It is hypothesised that poor quality soil needs to be loosened with a tine to create a proper seedbed for effective establishment of canola. On the contrary high quality soils typically perform better under reduced tillage practices, and it is likely easier to create a favourable seedbed for canola. Soil which has a low penetration resistance, good aggregate stability and high organic matter should lead to easier root penetration for canola, especially at an early stage of establishment. Associated higher infiltration rate and better water holding capacity should also be associated with a beneficial seedbed (Lal 1993). We therefore hypothesise that it will be easier to establish canola in high quality soil than in poor quality soil.

To date, canola producers implementing CA practices rely on tine openers to establish canola. The tine opener creates a furrow as it is pulled through the soil, after which the seed, fertiliser and herbicide is placed in the furrow. The furrow closes upon itself as the tine moves forward and a press wheel following the seed dispenser compacts the soil for good soil-to-seed contact. The major risk a tine opener holds in a CA system is that flat, long, wet, detached crop residue blocks the seeder (Kirkegaard 2016). There is, therefore, an increased demand for the use of disc openers in the Western Cape following success in Australia (Wylie 2008). Disc openers are designed to handle more residue as it cuts through the residue into the soil at an angle. Seed is placed within the opening made by the disc. It was found that sowing techniques that push crop residue away from the seeding row (i.e. residue managers), leaving the space above the seeding row open, may eliminate the negative effects of crop residue on canola production (Bruce et al. 2006). A disc opener may be an alternative for a tine opener as it can cut through residue and decreases soil disturbance. The efficiency of planting canola with tines or discs has not been assessed.

1.3 Aim and objectives

The aim of this study was to compare tine and disc openers and the effects of soil quality and crop residue on canola production, by evaluating establishment, biomass production, leaf area index (LAI), yield, thousand seed mass (TSM) and soil disturbance.

The first objective was to test the above mentioned in small plots, which could be managed with a high level of scientific precision.

The second objective was to compare tine and disc openers to produce canola on farm scale fields with contrasting soil qualities to take the inherent large variation in soil types and the associated soil production potential into account.

1.4 Research questions

Two specific research questions, relevant to both objectives apply.

Research question 1: Will a tine or disc opener create a better seedbed for canola?

Research question 2: Does soil quality along with residue level determine whether a disc or tine opener should be used to ensure optimal production of canola?

1.5 Structure of the thesis

This thesis is presented as a compilation of five Chapters, including this Introduction. Each chapter is introduced separately and is written according to the style of the South African Journal of Plant and Soil. Chapter 2 comprises a literature review which gives insight into current establishment practices of canola worldwide and in South Africa. Current understanding of soil quality and residue management are also discussed.

In Chapter 3 the tine and disc openers are assessed on varying soil quality with low, medium and high residue levels in small plots. Canola produced under dryland conditions during the 2016 and 2017 season was evaluated on the Langgewens Research Farm in the Western Cape. The parameters evaluated included biomass production, leaf area index (LAI), seed yield and thousand seed mass (TSM).

In Chapter 4, the tine and disc openers were assessed on field scale plots with varying soil quality comprising of 1500 m^2. This was done parallel to the trial discussed in Chapter 3. The parameters evaluated included, biomass production, LAI, seed yield, TSM and soil disturbance.

Chapter 5 provides the main conclusion of the study. The limitations of the study are highlighted while recommendations for possible future studies are proposed.

1.5 References

Berglund DR, McKay K, Knodel J. 1997. Canola production. NDSU Extension Service.

Bruce S, Ryan M, Kirkegaard J, Pratley J. 2006. Wheat stubble and canola growth-identifying and overcoming limitations. In: Proceedings of the 12th Australian Research Assembly on Brassicas, 2-5 October 2001, Geelong, Victoria. pp 181-185

Karlen DL, Wollenhaupt NC, Erbach DC, Berry EC, Swan JB, Eash NS, Jordahl JL. 1994. Long-term tillage effects on soil quality. Soil and Tillage Research 32: 313-327.

Kemper J, Cowling RM, Richardson, DM. 1999. Fragmentation of South African renosterveld shrublands: effects on plant community structure and conservation implications. Biol. Conserv. 90: 103-111.

Kirkegaard JA. 2016. High yielding canola: Stubble management, planting and fertiliser. Canola Symposium, 20 July, Kronenburg, Paarl, South Africa.

Lal R. 1993. Tillage effects on soil degradation, soil resilience, soil quality, and sustainability. Soil and Tillage Research 27: 1-8.

Meadows ME. 2003. Soil erosion in the Swartland, Western Cape Province, South Africa: implications of past and present policy and practice. Environmental Science & Policy 6: 17-28.

Protein Research Foundation. 2013. Canola Production Guide. SunMedia, Stellenbosch

Swanepoel PA, Labuschagne J, Hardy M. 2016. Historical development and future perspective of Conservation Agriculture practices in crop-pasture rotation systems in the Mediterranean region of South Africa. In: Ecosystem services and socio-economic benefits of Mediterranean grasslands. Kyriazopoulos A, Lopez-Francos A, Porqueddu C, Sklavou P. (eds.). Zaragoza: CIHEAM: 2016, 454 (+ xii) p. Options Mediterraneennes, Series A, No 114.

Wylie P. 2008. High profit farming in northern Australia. GRDC Canberra.

CHAPTER 2

Literature Review: Effects of openers on production potential of canola

2.1 Plant density, spacing and depth

The Protein Research Foundation (2013) advises that the ideal plant density for canola in the Western Cape is 50-80 plants per m^2. This can be achieved with a seeding rate of 4 to 6 kg ha^{-1}. When using hybrid cultivars the seeding density can be reduced to 3 to 4 kg per hectare. Until recently the aim in Australia was also to establish between 50 and 80 plants m^{-2} (Potter et al. 1999), but now the recommended plant density for hybrid cultivars in low rainfall areas (<300 mm per annum) in Western Australia is 20 to 25 plants m^{-2} and 30 to 40 plants m^{-2} for open pollinated cultivars (French et al. 2016). In high rainfall areas (450 to 550 mm) the rate of plants m^{-2} increases to 30 to 40 plants m^{-2} for hybrids, and 40 to 60 plants m^{-2} for open pollinated cultivars (French et al. 2016). Following these seeding rates, the number of seeds planted m^{-2} is much more than the number of plants that emerged. Harker et al. (2012) reported that only c. 50% of planted canola seeds emerged. In South Australia Potter et al (1999) found that plant densities above 50 plants m^{-2} do not have a substantial influence on yield in high yielding areas. A 12-16% difference in yield was found between 20 plants m^{-2} and maximum yield obtained for the specific trial (Potter et al. 1999). Potter et al (2001) found that in low rainfall areas yield increased up to plant densities of 20-25 plants m^{-2}, densities above this had no effect on yield. Canola, therefore, has the capacity to compensate for yield under conditions where plant establishment is poor (Malhi and Gill 2004). Row spacing is recommended at a width of between 200 and 250 mm for canola production (Protein Research Foundation 2013). The Protein Research Foundation (2013) found that wider row widths will decrease yield. In trials conducted in South Australia where 150 mm and 300 mm row spacing were compared, Potter et al (2001) found that there was no significant difference in yield between the two treatments. In a similar study in Southern Manitoba, Morrison et al. (1990) reported that the 150 mm row spacing had a higher yield, produced more pods and lodged less than the 300 mm row spaced crop. Canola should be seeded at a depth of 10 to 30 mm deep (Karow 2014). Harker et al. (2012) found that seeding canola shallower (10 mm) shortened the time to emergence by two days. Emergence density and ground cover was also improved by planting shallower (10 mm) rather than planting deeper (40 mm). It is therefore recommended to plant canola 20 to 30 mm deep if planting takes place early in the season. When planting takes place later in the season, canola should be planted 10 to 20 mm deep (Harker et al. 2012). Malhi and Gill (2004) found that seeding canola deeper than optimal (15 mm) reduced both emergence and yield. A trial conducted in North Dakota by Bryan et al (2008) found that seeding at a depth of 12 to 25 mm resulted in higher yields compared to deeper seeding.

2.2 Planting methods for canola

Conventional tillage practices do not fit into the conservation agriculture (CA) model (Bahri and Bansal. 1992). Hence only no-till and zero-till seeders can be used to establish crops within a CA system. The tine seeder is defined as a no-till seeder and the disc seeder is defined as a zero-till seeder (Ashworth et al. 2010). It is important to understand that a zero-till seeder causes less disturbance than a no-till seeder (Swanepoel et al. 2017). Each of these openers can be used in combination with different coulters, press wheels, single shoots and double shoots. According to Bahri and Bansal (1992) the performance requirements for a no-till seeder are good residue cutting, good seeding depth control and uniform placement of seed. Internationally tine seeders are mostly used for the establishment of canola. For optimal establishment canola seed requires to be placed at a uniform depth on a firm, moist seedbed. Seeds need to be evenly spread within each row and also across individual rows. Seed needs to be covered with soil and compacted for good soil-seed contact (Protein Research Foundation 2013).

A tine opener creates a seedbed which is favourable for canola germination. The furrow opened by the tine opener enables the producer to drill the seed in wet soil deeper down. Relative to the soil surface planting depth could be 5cm plus but in base of furrow the seed is only 1-2cm deep. This enables the disc openers to plant under less favorable conditions. Pre-emergent herbicide can be used effectively with planting. Canola is very vulnerable to seed row-placed fertiliser (Malhi and Gill 2004). Fertiliser can be separated effectively from the seed by placing the fertiliser underneath and away from the seed. The roots develop deeper in the soil and grow more vertically than horizontally; this allows the plant to access deeper soil moisture. The disadvantages of tine openers include higher superficial soil disturbance than disc openers (Tessier et al. 1991). It has a limit regarding the amount of residue it can handle, as too much residue blocks the seeder (Kirkegaard 2016). A disc opener holds several advantages. Tessier et al. (1991) found that a disc opener causes less superficial soil disturbance than a tine opener, and because of this it may improve soil structure and biological activity. Row spacing can be narrower than with tined seed-drills. Seedbed utilisation can be increased with narrower row spacing which decreases the in-row concentration of fertiliser (Ashworth et al. 2010). However, there are disadvantages associated with narrower row spacing, such as higher seeder cost per meter width, lower weight share per seeder unit which may result in poorer root penetration, higher implement draft requirements and an inability to use inter-row sowing techniques (Ashworth et al. 2010). There are commercial disc seeding technologies that are able to split-band (separately apply) seeds and fertiliser. Fertiliser toxicity can be effectively reduced or removed with split-banding with single disc or double disc openers or split-banding with separate disc openers (Ashworth et al. 2010). Split-banding with separate discs is much more reliable in its ability to separate fertiliser and seed, while still retaining accurate and uniform seed placement (Ashworth et al.

2010). Root establishment is more horizontal than vertical, this can be viewed as either an advantage or a disadvantage. The plant will be able to more easily access surface water and nutrients, but it can become a problem when it becomes dry. The major risk a disc seed-drill holds is hairpinning and poor soil penetration by the disc opener. Hair-pinning occurs when the disc does not cut through the residue, but rather folds it under the pushing force of the disc blade into the furrow created, this is prone to happen on soft soil (Ashworth et al. 2010). When hair-pinning occurs, the seed is not placed at a uniform depth and proper establishment will be compromised. Decomposition of the stubble surrounding the hair-pinned area that surrounds the seed may also play role in lower germination rate especially when planted under conditions that favors decomposition. Kirkegaard (2016) found that the emergence of disc sown canola seedlings was only 50% that of tine sown canola seedlings. This may be due to the poor seedbed preparation by the disc seeder.

2.3 Optimal soil conditions for canola

Soil temperature should ideally be higher than 10^{o}C for canola to germinate as Nykiforuk and Johnson-Flanangan (1994) reported significant reductions in germination at temperatures below 10^{o}C. Morrison et al (1989) determined that the baseline temperature for canola is 5^{o}C (*c*. Brassica napus L.). Adequate soil moisture levels are necessary for canola seeds to germinate. When the soil moisture and temperature conditions are favourable, a canola seed will burst open and the radicle will appear after only 17 hours. After 7 to 10 days, the seedlings will emerge aboveground as two heart-shaped cotyledons (Protein Research Foundation 2013). In general, ideal soil moisture content would be where 80% of soil pores are filled with water and 20% filled with air, however the clay content of the soil will determine at which percentage soil moisture it is achieved. (Brady and Weil 2002).

2.4 Fertiliser placement

Canola requires higher rates of N, P and S than other crops (Hocking et al. 2003). Due to the size of canola seed the adoption of reduced tillage requires that the application of fertiliser at seeding does not reduce seedling density due to chemical injury (Hocking et al. 2003). Fertiliser placed in close contact with seeds can delay or reduce crop establishment (Ashworth et al. 2010). It is important to consider crop aspects when applying fertiliser with seeding. Small seeds like linseed and canola are more susceptible to fertiliser induced toxicity, while cereals, especially barley, are less susceptible to fertiliser damage (Ashworth et al. 2010). This is mainly attributed to single radicle crops (like canola) not being able to compensate if the centre radicle is affected (Ashworth et al. 2010). Canola and lupins are highly susceptible to N and P toxicity and often suffer a reduced plant emergence response. Hocking et al. (2003) found that establishment of canola (cultivars: Oscar, Hyola 42, Karoo and Charlton) was reduced by 40-65% when fertiliser was placed with the seed, while the different tillage treatments (conventional cultivation, one-pass tillage and no-tillage) did not alter this response. Placing fertiliser with seed also reduced the dry matter production by 40% at flowering, but there was no difference in dry matter production at physiological maturity (Hocking et al. 2003).

Soil moisture level plays an important role in the success of placing fertiliser with seed when planting. When soil moisture levels are high the toxic effects of fertiliser are diluted, but when moisture conditions are low, toxic effects will be greater and seed-placed fertiliser should be reduced by up to 50% (Malhi et al. 2001).

2.5 Crop residue management

Soil cover plays a vital role in a CA system. Covering the soil with crop residue from the previous crop buffers soil temperature, which leads to higher microbial activity (Bruce et al. 2006). An organic soil cover can be achieved in two ways. It can either be achieved by chopping the residue of the previous crop and spreading it out during harvest, or it can be achieved by planting a cover crop. The soil should at least be 30% covered directly after planting to obtain maximum benefit (Friedrich and Kassam 2011). Bruce et al. (2006) found that a paddock that was covered with 6 tons of wheat residue per hectare from the previous year, produced 25% less canola seed than a paddock from which all residues were removed before planting. Residue plays a vital role in soil health and can bring great advantages, but it needs to be managed well. Kirkegaard (2016) found that crop residue covering the rows decrease the growth of canola. This is due to the physical effect of the straw. The wheat residue shades the canola and light quality underneath the straw changes ratio of red to far red light which causes plants to etiolate. The plants grow long and spindly to get through the residue. When the plant opens its cotyledons above the residue the cotyledons are much smaller than what it should be because the plant used most of its energy to grow the spindly hypocotyl. Soil cover does not have the same effect on canola as on wheat, because the growth point of canola at this early stage is already above ground where the temperature is lower than beneath the straw (Kirkegaard 2016).

The orientation of the crop residue is important for the disc opener's operation and seed establishment. In tine-based systems residue is cut short to maximise flow within the tine layout, but this is not optimal for disc-based systems (Ashworth et al. 2010). Optimal residue handling is achieved when the disc interacts least with the residue. To achieve this, the crop needs to be cut high and the chaff spread evenly over the full width of the harvester front. Tall, upright stubble will alter the microclimate near the soil surface when the seedlings are still small by reducing wind speed and solar radiation which maintains higher air humidity above the seed row and reduces soil temperature and evaporation (Cutforth et al. 1997). The reduced water evaporation can reduce water stress on the crop during later growth stages (Ashworth et al. 2010). There are, however, certain challenges associated with increased residue height. Photosynthetically active solar radiation, which is essential for plant growth, could be reduced when seedlings are sown into taller stubble (Ashworth et al. 2010). Residue that is present over a canola seeded row will alter the spectral quality of the light and reduce the intensity of the light reaching the canola seedlings before they could emerge through a residue layer (Ashworth et al. 2010). These authors conducted a study in Western Australia which showed that crop establishment decreased with increasing residue height, but final grain yield was not affected when the plant population density was sufficient. There is a trend for higher grain yield with taller stubble and it is mainly attributed to improved water use efficiency (Ashworth et al. 2010). The effect of stubble height on three crops is listed in Table 2.1.

Table 2.1: Effect of stubble height on overall water use efficiency (WUE) and grain yield (Adapted from Cutforth and McConkey 2003)

Stubble height	WUE[#] (kg ha $^{-1}$ mm)	Chickpea yield (kg ha $^{-1}$)	Wheat yield (kg ha $^{-1}$)	Canola yield (kg ha $^{-1}$)
Incorporated	7.1	1403	1907	872
Short (150mm)	7.5	1309	1925	1006
Tall (300mm)	8.0	1339	2030	1119
Extra tall (450mm)	8.5	1209	2070	1164

[#] (three year average and average of three crops)

There are three main residue management options listed in Table 2.2 along with their benefits and potential limitation. When including rolled cover crops into the CA system, it is important that seeding takes place in the same direction as in which the cover crops were rolled to reduce the risk of hairpinning (Ashworth et al. 2010).

The type of residue definitely had an effect on the cutting ability of the disc seeder as well as the amount of cover it provides. There is, however, no literature confirming this and it is therefore recommended that a study should be done to confirm these differences.

Table 2.2: Benefit analysis of residue related management options (Adapted from Ashworth et al. 2010)

Option	Related benefits	Potential limitations
Retain all crop residue with low harvest height (opposed to removal or burning)	• Reduced soil erosion • Increased water infiltration • Organic matter increases and potential carbon sequestration • Improved soil biology • Reduced soil moisture evaporation and improved crop water use efficiency • Heat insulation • Weeds smothering mulch effect • Dynamic nutrient release to crop	• Increased handling problems at seeding (e.g. hairpinning, poor clearance under narrow row spacing) • May worsen crop sensitivity to IBS herbicides under hairpinning conditions • Increased pest and disease risks depending upon crop rotation
Maximising stubble cutting height and even spread of chaff	• Reduced severity of hairpinning • Positive trellising effects improving growth and harvestability of crop such as lupins, lentils and field peas • Increased moisture capture in furrow and reduced moisture evaporation to wind • More even soil moisture conditions and less crop establishment variability • More efficient harvest (fuel use ha^{-1}, work rate) • Seedling protection in early growth stages • Better IBS herbicide potential in stubble • Further improved water use efficiency	• High residue can have a negative effect on early cereal and canola growth • Reduced surface residue ground cover increasing inter-row evaporation and runoff especially under wider row spacing and down slopes • Not livestock compatible, otherwise full benefits may be achieved
Inter-row sowing	• Minimise disc opener and residue interaction • Access to a potential package of practical, economic and agronomic benefits	• Investment in Real Time Kinematic (RTK) precision guidance • Implement tracking stability required • Unsuitable for narrow row spacing

2.6 Soil erosion associated with different openers

Soil erosion is regarded as one of South Africa's most significant environmental problems. A case study which was done in the Swartland led to the implementation of measures to conserve the soil for future generations. Farmers started to include nitrogen fixing crops like lupins in their rotation to build up the soil nitrogen. Livestock was reintroduced to farms which had become monoculture wheat farms by the 1940's. Contouring was constructed by government to minimise water run-off (Meadows 2003). There are several factors that play a role in soil erosion. These include: soil type, climate, fallow management and crop sequence (Littleboy et al. 1992). It is estimated that 60% of soil erosion is due to human activity (Yang et al. 2003). Implementing CA can reduce soil erosion regardless of whether a tine or disc opener is used. It is a system based approach where soil cover and crop rotation play a much more important role than the choice of opener.

2.7 Soil quality

Soil quality refers to the ability of the soil to function. It includes soil physical, chemical and biological spheres. A few of the particularly important soil quality parameters for canola production will be discussed.

Conservation agriculture has as major impact on soil quality. Zero tillage with residue retention will improve aggregate size distribution when compared to conventional tillage (Govaerts et al. 2009). Soil under CA becomes more stable and less vulnerable to structural deterioration. Aggregate formation is interrupted each time the soil gets tilled. During tillage a redistribution of organic matter takes place and even the smallest changes in soil organic carbon can influence the stability of macro-aggregates (Lal and Stewart 2010). Soil organic matter can increase soil resilience and resistance to deformation and macro porosity. Soil resilience is the soil's ability to return to its initial state after it has been stressed. Recovery can only take place if the soil has not degraded beyond a critical level (Lal 1993). In the topsoil high soil organic matter reduces disintegration of aggregates when they are wetted (Lal and Stewart 2010). Conventional tillage practices reduce macrofauna populations in comparison to CA systems, decreasing the potential positive effect it may have on soil aggregation. Jantalia et al. (2007) found that the type of tillage practice can also influence the distribution of soil organic carbon (SOC) in the soil profile. Higher SOC content was found in the surface layers of the zero tillage plots compared to the conventional tillage plots, but a higher content of SOC was found in the deeper layers of tilled plots where residue is incorporated through tillage (Jantalia et al. 2007). Increased organic C in the soil might have a significant impact on the quality of the seedbed (Swanepoel et al. 2015).

Soil strength is the ability or resistance of the soil to compact or loosen under an applied load. The applied load per surface area is also expressed as the amount of stress. The strength of soil is defined as the maximum amount of stress before permanent deformation occurs (Brady and Weil 2002). This physical property affects root and shoot growth (Ashworth et al. 2010). Soil strength has two characteristics, namely internal cohesion and internal friction. Internal cohesion refers to the bonding between particles and aggregates, where internal friction refers to the resistance to displacement in close contact (Ashworth et al. 2010). Farmers would like to maintain low soil strength to be able to provide a proper seedbed with a disc seeder. Optimal soil strength is important for disc penetration and furrow loosening (Ashworth et al. 2010). The tine seeder is less sensitive to soil strength and will reduce soil strength by deep loosening of poor structured and compacted soil, but will also be more prone to moisture loss (Ashworth et al. 2010). Soil with low strength is of higher quality. The workability of the soil is mostly determined by the soil moisture. At the moisture content where a given tillage event maximises the amount of small aggregates, the soil reaches its optimal workability (Mueller et al. 2003).

Soil friability is a soil structural condition with the tendency to disintegrate under applied stress into smaller fragments (Ashworth et al. 2010). Friability is important to achieve an appropriate tilth and proper seedbed with minimum tillage. The higher the friability, the better soil quality. Soil that is not friable would require high energy at tillage which would lead to a poor seedbed (Ashworth et al. 2010). The poor seedbed would be characterised by large clots and soil dust. Soil friability would improve with higher soil organic matter, higher aggregate stability and lower soil density. Literature shows that there is a need for a quick and easy method to determine soil friability while in the field (Ashworth et al. 2010). This will help to determine the suitability of the soil for zero-till crop establishment.

Soil consistency describes the physical state of the soil and is mainly influenced by its moisture content (Ashworth et al. 2010). However, the moisture content is not enough to describe the condition of the soil and can be misleading. The other factors that contribute to the physical state of soil includes its strength, stickiness and mouldability (Ashworth et al. 2010). Fine textured soils like clay-loam and clays show significant changes with changes in the moisture content.

Soil chemistry relevant for this study has already been discussed in the section regarding fertiliser application.

There are different soil-and measurement indices used in practice. These include the Soil Management Assessment Framework (SMAF). This tool comprises three steps, namely indicator selection, indicator indication and integration into a soil quality (SQ) index value (Andrews et al. 2004). The design of this framework allows for researchers to continually update and refine the interpretations for many soils. This tool focuses on the effect that soil management has on soil quality. Whether soil quality is a factor to consider when choosing between tine and disc openers, has not been evaluated. Furthermore, the effects of residue from the previous crop on effectiveness of a tine or disc seed-drill opener should also be determined.

2.8 References

Andrews SS, Karlen DL, Cambardella CA. 2004. The soil management assessment framework. Soil Science Society of America Journal 68 (6): 1945-1962.

Ashworth M, Desbiolles J, Tola E. 2010. Disc Seeding in Zero-Till Farming Systems: A review of technology and paddock issues. West Australian No-Tillage Farmers Association.

Bahri A, Bansal RK. 1992. Evaluation of different combinations of openers and press wheels for no-till seeding. Revue Marocaine des Sciences Agronomiques et Veterinaires.

Brady NC, RR Weil. 2002. The Nature and properties of soils (13th edn.) Chapter 12: Soils organic matter. Prentice Hall

Bruce S, Ryan M, Kirkegaard J, Pratley J. 2006. Wheat stubble and canola growth-identifying and overcoming limitations. In: Proceedings of the 12th Australian Research Assembly on Brassicas, 2-5 October 2001, Geelong, Victoria. pp 181-185.

Cutforth HW, McConkey BG. 1997. Stubble height effects on microclimate, yield and water use efficiency of spring wheat grown in a semiarid climate on the Canadian prairies. Canadian Journal of Plant Science 77: 359-366.

Cutforth HW, McConkey BG 2003. Direct seeding: Water use, yield, residue management'. Preceedings of the 2004 Direct Seeding Conference. Saskatchewan Soil Conservation Association. "The Key to sustainable management." 11-12 February 2004, Regina SK, Canada.

French RJ, Seymour M, Malik RS. 2016. Plant density response and optimum crop densities for canola (*Brassica napus L*.) in Western Australia. Crop and Pasture Science 67: 397-408.

Friedrich T, Kassam A. 2011. January. Mechanization and the global development of conservation agriculture. In 23rd Annual SSCA Conference, 13 January, Saskatoon, Canada. FAO 1-15

Govaerts B, Verhulst N, Castellanos-Navarrete A, Sayre KD, Dixon J, Dendooven L. 2009. Conservation agriculture and soil carbon sequestration: between myth and farmer reality. Critical Reviews in Plant Science 28: 97-122.

Harker KN, O'Donovan JT, Blackshaw RE, Johnson EN, Lafond GP, May WE. 2012. Seeding depth and seeding speed effects on no-till canola emergence, maturity, yield and seed quality. Canadian Journal of Plant Science 92: 795-802.

Hocking PJ, Mead JA, Good AJ, Diffey SM. 2003. The response of canola (*Brassica napus L*.) to tillage and fertiliser placement in contrasting environments in southern NSW. Animal Production Science 43: 1323-1335.

Jantalia CP, Resck DV, Alves BJ, Zotarelli L, Urquiaga S, Boddey RM. 2007. Tillage effect on C stocks of a clayey Oxisol under a soybean-based crop rotation in the Brazilian Cerrado region. Soil and Tillage Research 95: 97-109.

Karow RS. 2014. Canola. Corvallis, Or.: Extension Service, Oregon State University. Available at https://catalog.extension.oregonstate.edu/em8955

Kirkegaard JA. 2016. High yielding canola: Stubble management, planting and fertiliser. Canola Symposium, 20 July, Kronenburg, Paarl, South Africa.

Lal R. 1993. Tillage effects on soil degradation, soil resilience, soil quality, and sustainability. Soil and Tillage Research 27: 1-8.

Lal R, Stewart BA. Eds. 2010. Food security and soil quality. CRC Press

Littleboy M, Silburn DM, Freebairn DM, Woodruff DR, Hammer GL, Leslie JK. 1992. Impact of soil erosion on production in cropping systems. I. Development and validation of a simulation model. Soil Research 30: 757-774.

Malhi SS, Gill KS. 2004. Placement, rate and source of N, seedrow opener and seeding depth effects on canola production. Canadian journal of plant science 84: 719-729.

Malhi SS, Grant CA, Johnston AM, Gill KS. 2001. Nitrogen fertilization management for no-till cereal production in the Canadian Great Plains: a review. Soil and Tillage Research 60: 101-122.

Meadows ME. 2003. Soil erosion in the Swartland, Western Cape Province, South Africa: implications of past and present policy and practice. Environmental Science & Policy 6: 17-28.

Mueller L, Schindler U, Fausey N, Lal R. 2003. Comparison of methods for estimating maximum soil water content for optimum workability. Soil and Tillage research 72: 9-20

Morrison MJ, McVetty PBE, Shaykewich CF. 1989. The determination and verification of a baseline temperature for the growth of Westar summer rape. Canadian Journal of Plant Science 69: 455-464

Morrison MJ, McVetty PBE, Scarth R. 1990. Effect of row spacing and seeding rates on summer rape in southern Manitoba. Canadian Journal of Plant Science 70:127-137.

Nykiforuk CL, Johnson-Flanagan AM. 1994. Germination and early seedling development under low temperature in canola. Crop Science 34: 1047-1054.

Potter TD, Kay JR, Ludwig IR. 1999. Effect of row spacing and sowing rate on canola cultivars with varying early vigour. Seeds 1000: 2.

Potter TD, Kay JR, Ludwig IR, Frischke BM. 2001. Effect of row spacing and sowing rate on canola cultivars in low rainfall areas. Seeds 1000: 2.

Protein Research Foundation. 2013. Canola Production Guide. SunMedia, Stellenbosch

Swanepoel PA, du Preez CC, Botha PR, Snyman HA and Habig J. 2015. Assessment of tillage effects on soil quality of pastures in South Africa with indexing methods. *Soil Research*, *53* (3), pp 274-285.

Swanepoel PA, Agenbag GA, Strauss JA. 2017. Considering soil quality for choosing between disc or tine seed-drill openers to establish wheat. South African Journal of Plant and Soil (In press)

Tessier S, Saxton KE, Papendick RI, Hyde GM. 1991. Zero-tillage furrow opener effects on seed environment and wheat emergence. Soil and Tillage Research 21: 347-360.

Yang D, Kanae S, Oki T, Koike T, Musiake K. 2003. Global potential soil erosion with reference to land use and climate changes. Hydrological processes 17: 2913-2928.

CHAPTER 3

A comparison of tine and disc openers to establish canola through residue and on soils with contrasting qualities.

3.1 Introduction

The conventional cropping system in the Western Cape historically involved the use of mouldboard and/or tine tillage to produce winter cereals such as wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare)* in monoculture. This system used to be the most important production system, but farmers started to experience problems with crop diseases, grass weeds and declining productivity. Most farmers in the Western Cape cropping region started implementing conservation agriculture (CA) practices since the early 2000s, as it is viewed as a more sustainable way of farming (Swanepoel et al. 2016). Conservation agriculture is based on three principles; minimum soil disturbance, soil cover and crop rotation (Derpsch et al. 2010). Currently, farmers are predominately using tine openers to establish crops. From the late 1990s, canola (*Brassica napus* L.*)* became a popular crop to include in the crop rotation systems in the Western Cape.

Temporal separation of crops (i.e. crop sequences) on the same field has numerous advantages. Establishing canola every third or fourth year allows farmers to control grass weeds, as canola is a broad-leaved crop, by using selective herbicides against grasses (Pieterse 2010). Root disease pressures are also lowered on a field where crops are rotated between years as the life cycle of pathogens, which are host-specific, are disrupted (Lamprecht et al. 2011). Currently, canola is produced only in the southern Cape and Swartland production areas in the Western Cape, and not on a significant scale elsewhere in South Africa.

In CA systems where no or very little crop residue is removed from the field, the residue that covers the soil surface increases with time (Kirkegaard 2016). The residue mitigates extreme soil temperature fluctuations and minimising evaporative water loss. Water infiltration rates are also increased and run-off is reduced (Smil 1999). Shelton et al. (1991) found that when soil is only 20% covered by residues, soil erosion is 50% less. Kumar and Goh (2002) found that soil fertility is increased in the long term. Although there are many benefits with covering the soil, it also creates some challenges to farmers. There are technical difficulties for the different seed-drill openers to establish canola efficiently in the residue of the previous crop. Farmers in the Swartland have recently relied mostly on tine openers to establish canola within a minimum-tillage system. The major risk of tine openers in CA systems are that residue obstruct the seed-drill opener (Kirkegaard 2016). The residue is dragged along with the opener and causes uneven seed distribution which leads to poor establishment. The greatest advantage of a tine opener to establish canola is the fine seedbed created and seeds placed at a uniform depth. The V-shaped furrow collects rain water and improves soil water content in the seed row and may help to mix herbicides applied before or at planting into the soil.

Disc openers is a relatively new technology in the Swartland area, but are becoming more popular following success of using disc openers in other countries, such as Australia (Wylie 2008). Disc openers are designed to handle more residue as it cuts through the residue into the soil at an angle. The disc opener may be an alternative for the tine opener as it can cut through the residue and causes less soil disturbance than a tine opener (Tessier et al. 1991). However, the cutting ability of the disc may differ along with the amount of residue and soil quality. Hair-pinning can occur when the disc opener does not cut through the residue, but rather bends the residue into the soil (Ashworth et al. 2010). This may cause uneven seed placement and lead to poor establishment. A comparison between tine and disc openers to establish canola has not been done and such investigation is warranted.

Furthermore, low quality soils are characterised as having poor aggregate stability, being compact, having insufficient nutrient levels with low organic matter content and microbial activity (Swanepoel et al. 2017). High quality soils are characterised as having, *inter alia*, good aggregate stability, sufficient nutrient levels, high organic matter content and microbial activity. It is hypothesised that a soil with poor quality should be loosened with a tine to create a proper seedbed for the effective establishment of canola.

The aim of this study was to compare tine and disc openers and the effects of soil quality and crop residue on canola production, by evaluating establishment, biomass production, leaf area index (LAI), yield and thousand seed mass (TSM).

The following hypotheses were tested:

H_0: Canola will perform better when established with tine openers compared to disc openers on low quality soil with low residue levels. The hypothesis is based on the fact that establishment of canola seed in low quality soil requires some soil disturbance (i.e. tine) to create a fine seedbed.

H_A: Canola will perform better or similar when established with disc openers compared to tine openers on high quality soil with high residue levels. This hypothesis is based on the fact that soil with high quality also has higher resilience against disturbance and therefore a better seedbed is created without disturbance.

3.2 Materials and methods

3.2.1 Experimental site

The trial was conducted during 2016 and 2017 at the Langgewens Research Farm (33º 16'42.33" S; 18º 42'11.62" E; 191 m) of the Western Cape Department of Agriculture in the Swartland region. Soils were variable, but the most common soils were duplex soils. According to the South African classification system, the most common soil forms were Swartland, Klapmuts, Sepane, and Sterkspruit soil forms (Soil Classification Working Group 1991). According to the USDA soil taxonomy and the International Classification Systems (IUSS Working Group WRB 2006; Soil Survey Staff, 2003) these soils would be classified as Alfisols and Luvisols according to the two respective classification systems. The mean rainfall over the past 72 years at Langgewens was 398.3 mm per annum with 80% rainfall distributed from May to September (growing season). The 2015 production year was a dry year as it received only 208.4 mm, which resulted in low levels of residue by the onset of this trial in 2016 (Western Cape Government, 2017). During the 2016 season rainfall on Langgewens was 376 mm (270.8 mm in the growing season), which represents an average year (Figure 3.1). The rainfall during the 2017 season was 214.9 mm (Figure 3.1), excluding December (180.4 mm in the growing season). The long-term mean daily minimum and maximum temperatures during the growing season were 9.7 °C and 20.7 °C, respectively. During the summer months, the long-term minimum and maximum means were 15.7 °C and 29.5 °C, respectively. The maximum temperature in 2016 was higher than the long-term mean in May and August, but apart from that, the temperature was similar to the long-term mean. During 2017 the maximum temperature was higher than the long-term means in April and May, while it was lower in August (Figure 3.1). The minimum temperatures were similar to the long-term mean.

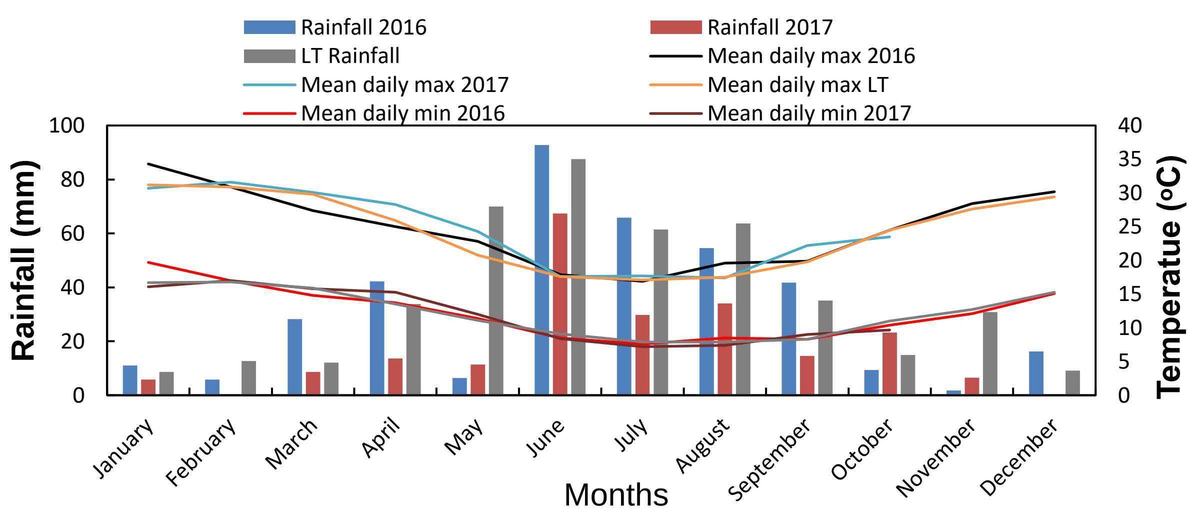

Figure 3.1: Long-term mean monthly rainfall and monthly rainfall for 2016 and 2017, as well as the long-term minimum and maximum temperatures

3.2.2 Experimental design and treatments

This study was laid out as a split-plot design with three factors i.e. opener, residue level and soil quality, replicated in 4 randomised blocks. The whole plot factor was soil quality (high or low quality). The sub-plot factor was the opener (tine or disc). Within each sub-plot three residue plots (high, medium or low) were randomly nestled. Each sub-plot comprised 55 m^2 in 2016 and 25 m^2 in 2017. The three different residue levels were manipulated as follows: wheat residue was applied to the high residue plots until no bare soil were visible (5.1 t ha^{-1} in 2016 and 6.4 t ha^{-1} in 2017). Visually estimated half of the amount of residue placed on the high residue plots were placed on the medium residue plots (4.3 t ha^{-1} in 2016 and 6.3 t ha^{-1} in 2017). Residue was removed from the low residue plots as much as possible, without disturbing the soil (1.5 t ha^{-1} in 2016 and 1.9 t ha^{-1} in 2017). Triasine tolerant canola cultivar Hyola 559TT (germination 80 to 89%) was only established on 25 May 2016, which is slightly later than normal practice, since rainfall in May 2016 was lower (6.4 mm) than the long-term mean for May (70.0 mm). During the 2017 season the triasine tolerant cultivar, Atomic, (germination 80-89%) was established on the 3rd of May. Cultivar choice was based upon cultivar evaluation results on Langgewens Research Farm and was in line with best practice for canola production in the Swartland. For both production seasons, canola was planted in dry soil. The gravimetric soil water content was between 3.7 and 5.7% at time of planting. The rain season only started after establishment, allowing germination by the beginning of June for both years. For both years, canola was established at a seeding rate of 3.5 kg ha^{-1} and a depth of approximately 10 mm using an Equalizer no-till seed-drill with exchangeable tine and disc openers. As the tine and disc openers are exchangeable, bias caused by weight and seed delivery efficiency were eliminated. The rows were spaced 300 mm apart.

3.2.3 Crop management

Prior to planting, representative soil cores (ø 45 mm) were taken at three depths, namely 0 to 150 mm, 150 to 300 mm and 300 to 450 mm to assess the soil nutrient status. Accordingly, fertiliser application with planting comprised 2.5 kg N ha^{-1}, 10 kg P ha^{-1}, 5 kg K ha^{-1} and 4 kg S ha^{-1}. In 2016 the fertiliser was placed with the seed for both the disc and tine openers. In 2017 the fertiliser was broadcast prior to planting with the disc opener, while fertiliser was still placed with the seed with the tine opener. The reason for this is that canola seedlings are sensitive to N and K placed in close vicinity to the seed. The disc opener places the fertiliser in close vicinity of the seed where the tine opener places the fertiliser away from the seed with soil between the seed and the fertiliser. This is one of the limitations of disc openers, and may have influenced establishment in 2016. Twenty-one days after the canola emerged in 2017, 50 kg N ha^{-1}, 6.2 P ha^{-1} and 7.8 kg S ha^{-1} was applied as a first top dressing. With the onset of stem elongation, a second top dressing of 40 kg N ha^{-1} and 8 kg S ha^{-1} was applied, only in 2016. Boron was applied as a foliar spray prior to flowering in both years. Weed and pest control were managed according to recommended best practice for the Swartland.

3.2.4 Data collection

3.2.4.1 Soil sampling

Soil samples taken prior to planting were used to determine nutrient deficiencies in order to correct through fertilisation or soil amelioration. Soil chemical analyses included pH (water and KCl), extractable P, exchangeable Ca, Mg, Na and K and electrical conductivity with standard methods prescribed by the Non-affiliated Soil Analysis Work Committee (1990). The formula used to determine Sodium adsorption ratio (SAR) are as follows: (Swanepoel and Tshuma 2017)

$$SAR = \frac{Na}{\sqrt{0.5 \times (Ca^{2+} + Mg^{2+})}}.$$

Biological analyses included organic C, which was determined with the Walkley-Black procedure (Nelson and Sommers 1982), β-glucosidase activity (Dick et al. 1996) and potentially mineralisable N through aerobic incubation for seven days (Cataldo et al. 1975; Keeney and Nelson 1982). For physical analysis, three additional soil samples were taken per plot to a depth of 150 mm one day prior to planting to determine the aggregate stability (Kemper and Rosenau 1986) and bulk density with the core method (Blake 1965). Clay content was determined with the hydrometer method (Day 1965).

The soil physical, chemical and biological indicator results are listed in Table 1. The Solvita Soil Health test, a commercial service available to farmers, was performed (Table 3.1). A soil microbial rating of ideal is awarded to a soil which achieves between 106 and 140 ppm C when a CO_2-C 24 h burst test is performed. In 2017 both the high and low quality soils were regarded as having ideal microbial rating while both high and low quality soils in 2016 were said to have a low and medium microbial rating, respectively. Due to changes in the services to farmers, a Solvita Soil Health Index was only available in 2016.

The soil management assessment framework (SMAF) was used to classify soils according to high or low soil quality (Andrews et al. 2004). For soil physical quality the aggregate stability, clay content and bulk density were assessed. Soil chemical measures included pH, extractable P, SAR, electrical conductivity and exchangeable K. Soil biological quality was determined using organic C and β-glucosidase activity. The aforementioned list of soil quality indicators was transformed into scores using the algorithms set out by Andrews et al. (2004). The final SMAF score constitutes a combination of these scores, and reflects the overall performance of the soil provided by the physical, chemical and biological processes. The effective soil depth was approximately 450 mm.

Table 3.1: Mean values of indicators for soil quality, and soil quality indices (SQI) of soils classified as having high or low quality for canola production in 2016 and 2017. CEC = Cation exchange capacity, SAR = Sodium adsorption ratio

	Soil quality plots 2016		Soil quality plots 2017	
	Low	High	Low	High
pH (water)	7.2	6.8	6.7	6.8
Exchangeable Ca (mg kg^{-1})	2384	1078	876	1254
Exchangeable Mg (mg kg^{-1})	152.8	98.8	120.8	203.7
Exchangeable Na (mg kg^{-1})	47.3	27.8	26.0	145.3
Exchangeable K (mg kg^{-1})	121.5	152.5	153.5	175.5
CEC (cmol kg^{-1})	13.7	6.9	6.0	9.2
Extractable P (mg kg^{-1})	76.8	83.8	71.3	82.0
Clay (%)	12	9	9	12
Organic C (%)	1.22	1.58	1.06	1.26
Aggregate stability (%)	37.2	47.2	38.8	41.9
Bulk density (g cm^{-3})	1.85	1.75	1.50	1.32
Electrical conductivity (dS^{-1})	0.00	0.00	0.03	0.05
Sodium adsorption ratio	0.07	0.07	0.07	0.29
β-glucosidase activity (μg^{-1} h^{-1})	830	745	1598	1311
PMN (mg kg^{-1})	10.55	11.80	25.39	25.91
CO_2-C burst test (mg kg^{-1})	70.60	65.18	125.50	113.63
Physical SQI (%)	53.84	65.28	74.94	91.70
Chemical SQI (%)	50.24	50.14	100.00	100.00
Biological SQI (%)	59.19	65.54	61.19	85.09
SMAF overall SQI (%)	58	63	77	90
Solvita Soil Health Index	10.74	9.76	-	-

3.2.4.2 Plant parameters

Plant population was determined 30 days after emergence by counting the number of seedlings in four 0.25 m^2 quadrants per plot. Ten plants per plot were sampled at 30, 60 and 90 days after emergence by cutting at ground level. The leaves were separated from the stems and leaf area was measured with a LI-Cor area meter at 30, 60 and 90 days. The LAI was subsequently calculated using the plant population. The same plants were also dried at 60°C for 72 hours and weighed to determine aboveground biomass production at 30, 60 and 90 days after emergence as well as at physiological maturity.

The crop was harvested on 20 November 2016 and 1 November 2017 with a HEGE 140 plot combine. The seed from each plot was cleaned through winnowing with a fan and bagged. Subsequently, yield was determined by weighing the seed of each plot. Thousand seed mass was determined by counting and weighing 1000 seeds.

3.2.5 Statistical analyses

Statistical analyses were performed by using STATISTICA version 13 (Dell Inc. 2016). The Restricted Maximum Likelihood (REML) procedure was used to analyse according to the split-plot design. The three factors (soil quality, opener and residue level), as well as the cross between the three at every level, were regarded as fixed terms. Blocks and the cross between blocks and soil quality/opener, with residue levels nestled within whole blocks, were regarded as random terms. Fisher's least significant differences (LSD) test was conducted at a 5% significance level to determine whether interactions among the three factors of interest were significant. If interactions were not significant, LSD tests were done on the main effects, i.e. soil quality, opener or residue. Residuals were normally distributed and had homogeneous variances. With a split-plot design, it is not possible to test for differences through time using repeated measure analysis and therefore the parameter that were measured repeatedly through time and analysed per time interval (30, 60 and 90 days after emergence and at physiological maturity) will not be compared over time.

3.3 Results

Due to the aim of the study, data presented and discussion will focus on the interactions between the opener, soil quality and/or residue level and little attention will be given to main effects.

3.3.1 Plant population

In the 2016 season, interaction between soil quality and opener was significant ($P<0.05$). The only main factor which had an influence on plant population in 2017 was the residue level (Table 3.2). In 2016 the plant population achieved with the tine opener was higher ($p<0.05$) than with the disc opener when planted on low quality soils, but no difference was recorded on high quality soils regardless of the residue level (Figure 3.2). Plant population of the canola planted with tine and disc openers on high quality soil were 43 and 22 plants m^{-2}, respectively while on low quality soil it was 43 and 29 m^{-2}, respectively. In the 2017 season no difference between plant populations were measured between the tine and disc openers on either low and high quality soils (Figure 3.3). However, on low quality soil the disc opener did establish more plants on low residue level plots than on high residue level plots ($P>0.05$).

Table 3.2: Main effects and interactions between opener, soil quality and residue level for canola plant population in the 2016 and 2017 season at 30 days after emergence.

	Effect	F	P-value
2016	Soil Quality	0.01	0.92
	Opener	20.15	0.00
	Residue levels	0.58	0.58
	Soil Quality x Opener	5.81	0.04
	Soil Quality x Residue levels	0.22	0.81
	Opener x Residue levels	0.76	0.50
	Soil Quality x Opener x Residue levels	0.33	0.73
2017	Soil Quality	1.97	0.19
	Opener	0.57	0.47
	Residue levels	5.57	0.03
	Soil Quality x Opener	1.03	0.34
	Soil Quality x Residue levels	0.93	0.43
	Opener x Residue levels	0.50	0.62
	Soil Quality x Opener x Residue levels	0.74	0.50

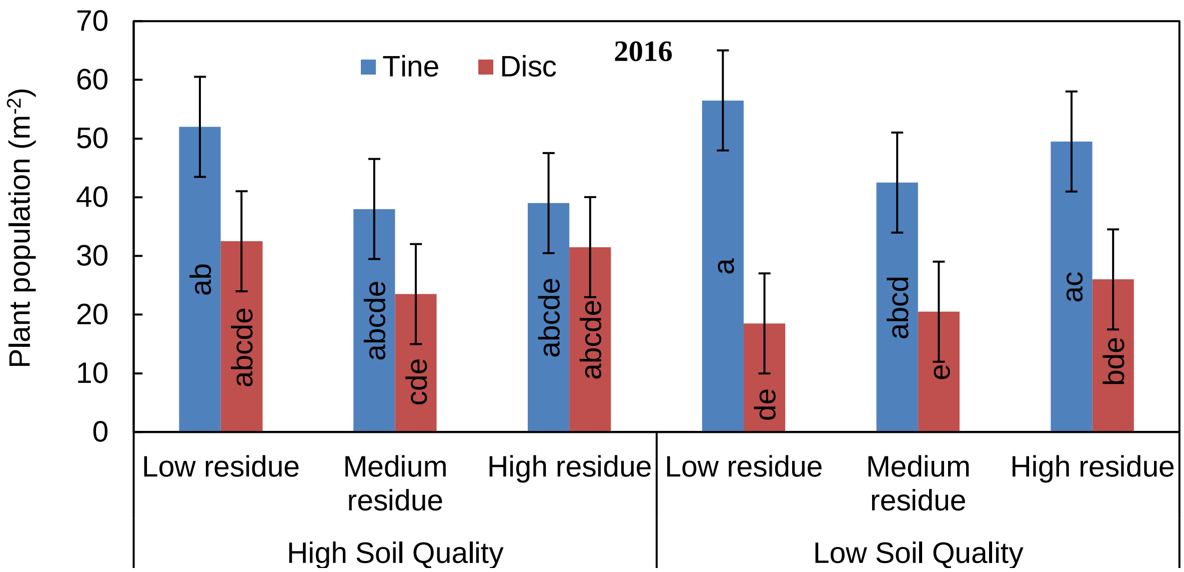

Figure 3.2: Canola plant population (m^{-2}) on high and low quality soil following establishment with a disc or tine seed-drill opener with varying residue levels for the 2016 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

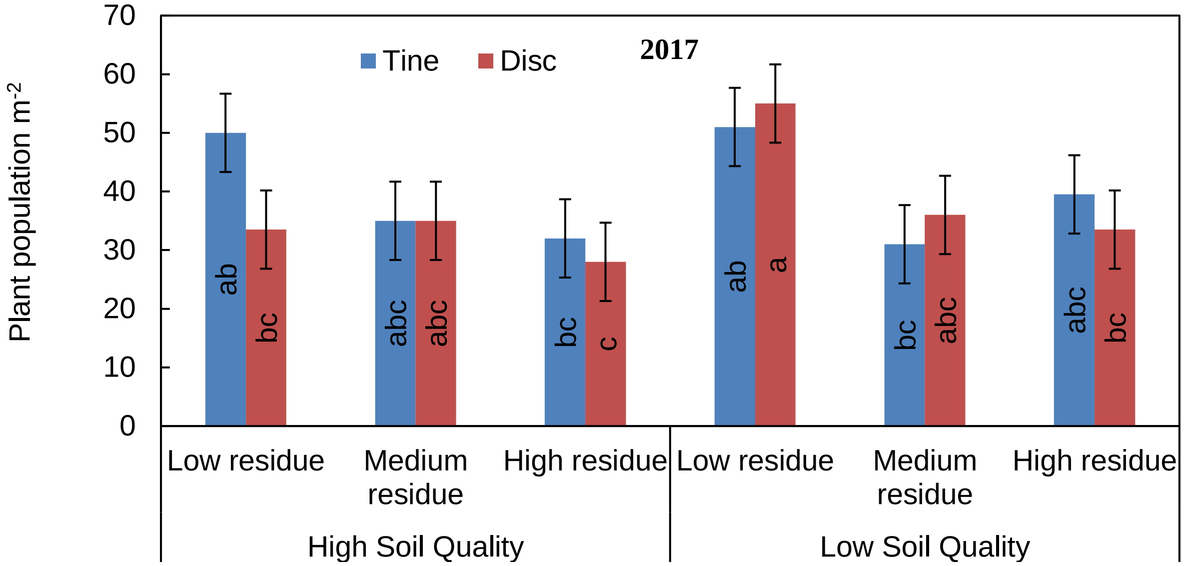

Figure 3.3: Canola plant population (m^{-2}) on high and low quality soil following establishment with a disc or tine seed-drill opener with varying residue levels for the 2017 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

3.3.2 Biomass production

During the 2016 season, at 30 days after emergence no difference in biomass production had beed recorded for high and low quality soil and residue level (Table 3.3 and Figure 3.4). The only significant effect was that of the tine opener which resulted in higher than that of the disc openers on low quality soil with a low residue level ($p<0.05$) (Figure 3.4). In the 2017 season, significant differences due to soil quality, residue level and opener were recorded, although there was no significant interaction (Table 3.3). The tine opener plots produced more biomass on high quality soil with low residue than the disc opener plots ($p<0.05$) (Figure 3.5). Biomass production for different openers on high quality soil with medium and high residue levels was similar, but on low quality soil the tine opener produced more biomass on the low residue level than on medium or high residue levels, while no differences with the disc opener were recorded (Figure 3.5).

Table 3.3: Main effects and interactions between opener, soil quality and residue level for biomass production at 30 days after emergence.

	Effect	F	P-value
2016	Soil Quality	2.78	0.13
	Opener	4.80	0.06
	Residue levels	0.34	0.72
	Soil Quality x Opener	0.37	0.56
	Soil Quality x Residue levels	0.28	0.76
	Opener x Residue levels	1.06	0.38
	Soil Quality x Opener x Residue levels	0.40	0.68
2017	Soil Quality	6.67	0.03
	Opener	7.66	0.02
	Residue levels	18.04	0.00
	Soil Quality x Opener	0.03	0.87
	Soil Quality x Residue levels	0.70	0.52
	Opener x Residue levels	2.94	0.10
	Soil Quality x Opener x Residue levels	2.13	0.18

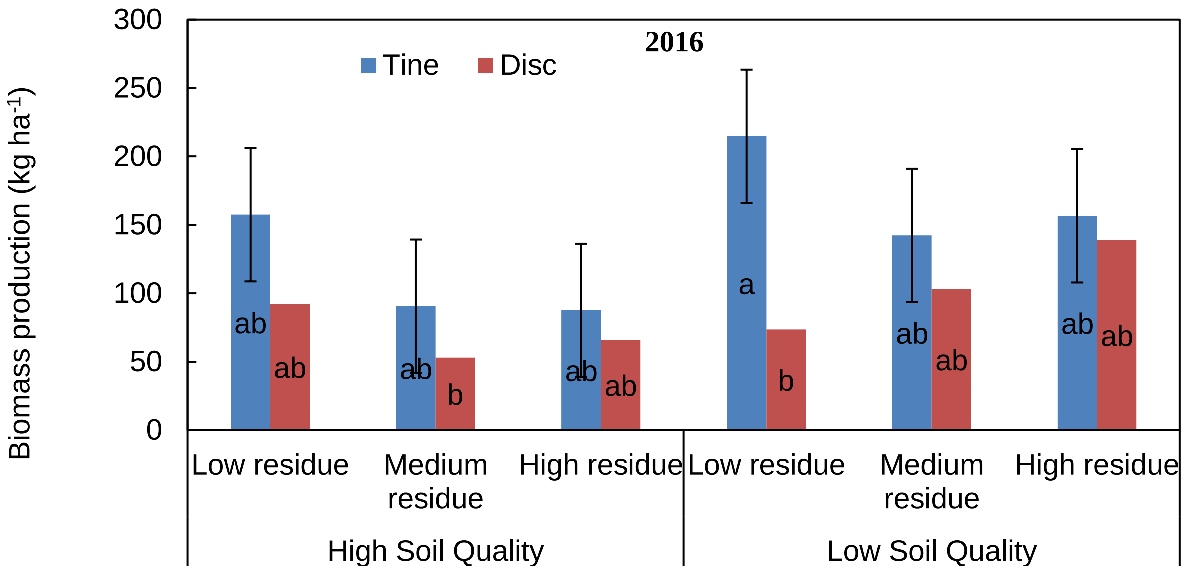

Figure 3.4: Biomass production 30 days after emergence with tine and disc openers, on high and low quality soil with low, medium and high residue levels for the 2016 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

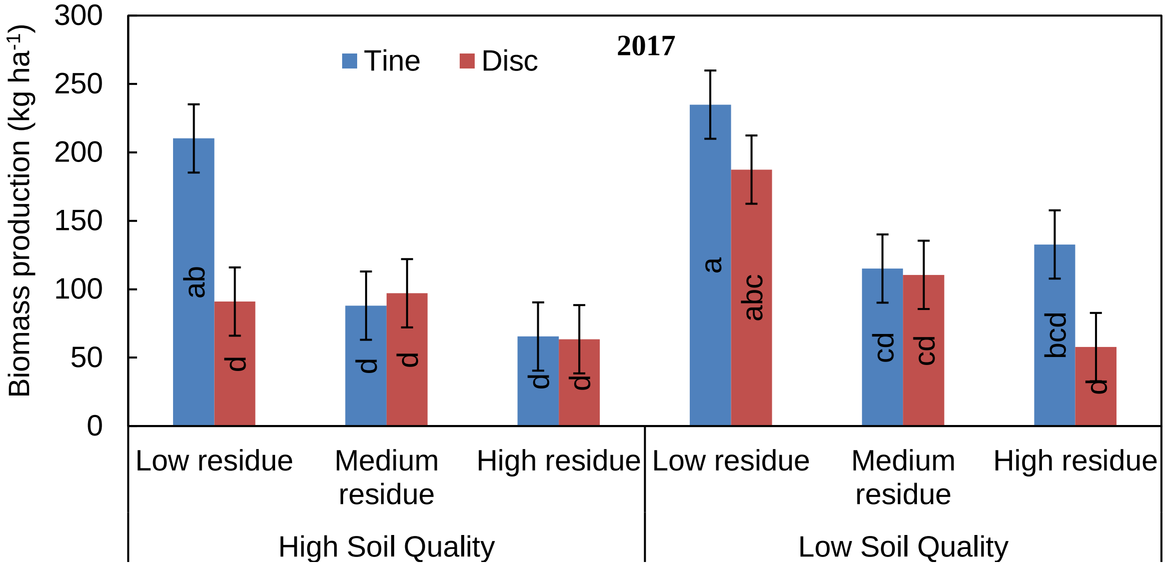

Figure 3.5: Biomass production 30 days after emergence with tine and disc openers, on high and low quality soil with low, medium and high residue levels for the 2017 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

At 60 days after emergence in the 2016 season there was a significant interaction between soil quality and opener for biomass production (Table 3.4). An overall higher biomass production was achieved on low quality soil compared to high quality soil (Figure 3.6). There were no differences between openers (tine or disc) or between residue levels at high soil quality. At low soil quality residue also had no influence and tine openers produced more biomass than disc openers ($p<0.05$) at low and high residue levels. At 60 days after emergence in the 2017 season residue level had a significant effect on biomass production and although no significant interaction was recorded (Table 3.4), the disc opener performed better on low quality soil with low residue level than with high residue level ($p<0.05$). Biomass produced on the medium residue level did not differ from the low or high residue levels (Figure 3.7). On high quality soil no differences were recorded between openers or residue levels ($P>0.05$) in terms of biomass.

Table 3.4: Main effects and interactions between opener, soil quality and residue level for biomass production at 60 days after emergence.

	Effect	F	P-value
2016	Soil Quality	8.80	0.02
	Opener	7.10	0.03
	Residue levels	0.08	0.93
	Soil Quality x Opener	6.06	0.04
	Soil Quality x Residue levels	0.23	0.80
	Opener x Residue levels	0.20	0.82
	Soil Quality x Opener x Residue levels	0.69	0.53
2017	Soil Quality	0.68	0.43
	Opener	0.04	0.84
	Residue levels	3.51	0.07
	Soil Quality x Opener	2.83	0.13
	Soil Quality x Residue levels	1.42	0.29
	Opener x Residue levels	0.33	0.72
	Soil Quality x Opener x Residue levels	0.52	0.61

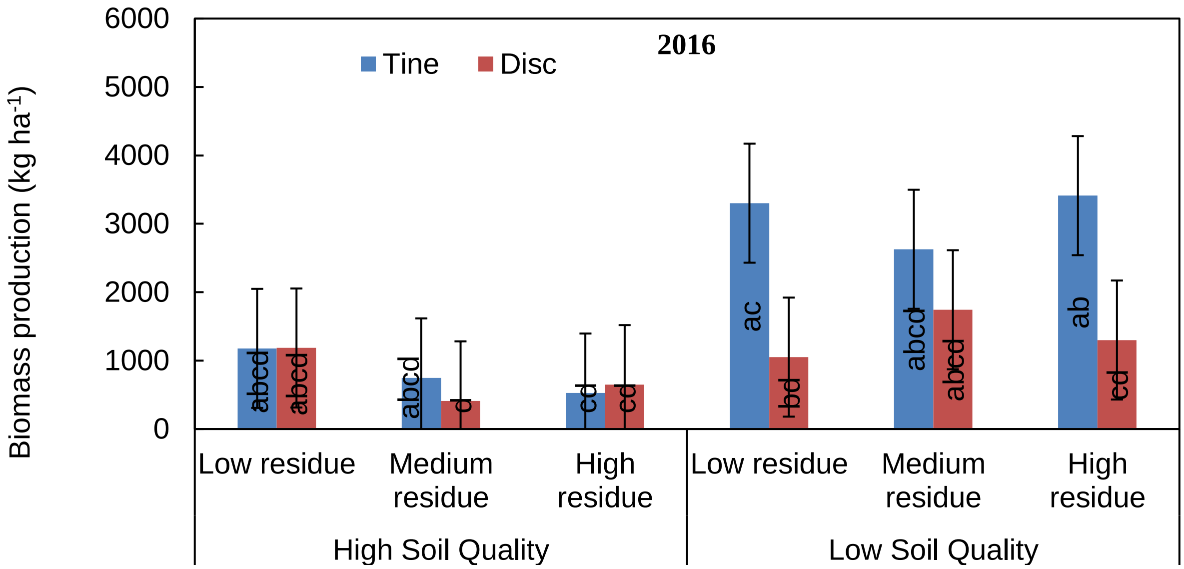

Figure 3.6: Biomass production 60 days after emergence in the 2016 season with a tine and disc opener on high and low quality soils with low, medium and high residue levels. An Interaction occurred between opener and soil quality. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

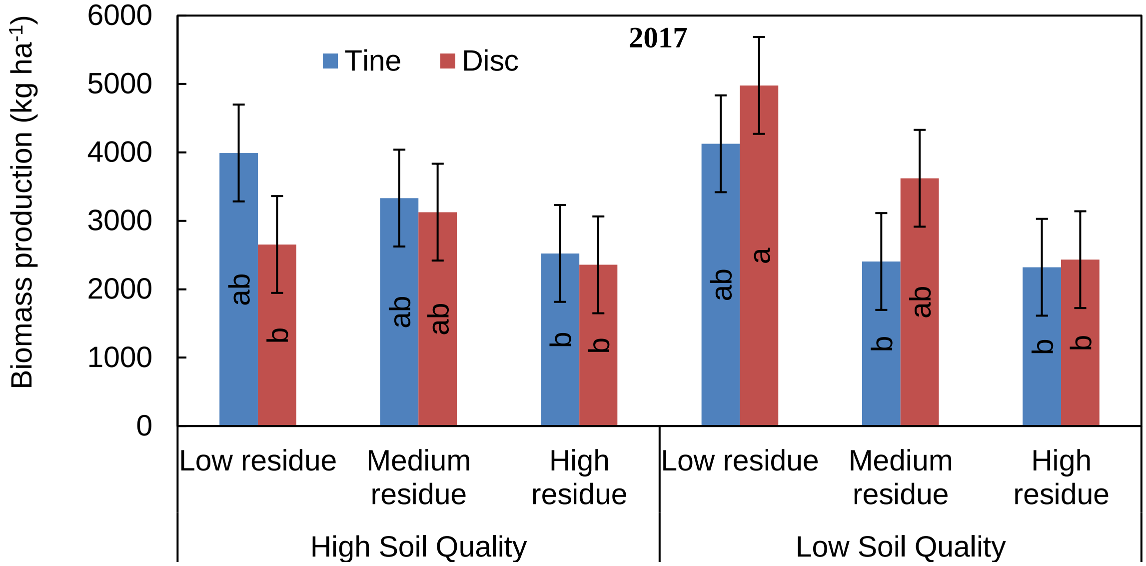

Figure 3.7: Biomass production 60 days after emergence in the 2017 season. Only residue had an influence on the amount of biomass produced on high quality soil. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

There was no significant interaction between soil quality, residue level and opener with regard to biomass production at 90 days after emergence in the 2016 season, but opener had a significant effect (Table 3.5), with the tine opener producing more biomass than the disc opener (Figure 3.8). During the 2017 season, treatments did not have any significant effect on biomass production at 90 days after emergence, (Table 3.5, Figure 3.9) with the exception of higher biomass produced by the disc opener on low quality soil with low residue level than the biomass produced by the disc opener on high quality soil with low residue level.

Table 3.5: Main effects and interactions between opener, soil quality and residue level for biomass production at 90 days after emergence.

	Effect	F	P-value
2016	Soil Quality	0.25	0.63
	Opener	5.42	0.04
	Residue levels	0.80	0.48
	Soil Quality x Opener	0.11	0.75
	Soil Quality x Residue levels	0.13	0.88
	Opener x Residue levels	0.57	0.58
	Soil Quality x Opener x Residue levels	1.76	0.23
2017	Soil Quality	0.03	0.87
	Opener	0.42	0.53
	Residue levels	1.02	0.40
	Soil Quality x Opener	1.39	0.27
	Soil Quality x Residue levels	3.19	0.09
	Opener x Residue levels	0.62	0.56
	Soil Quality x Opener x Residue levels	0.42	0.67

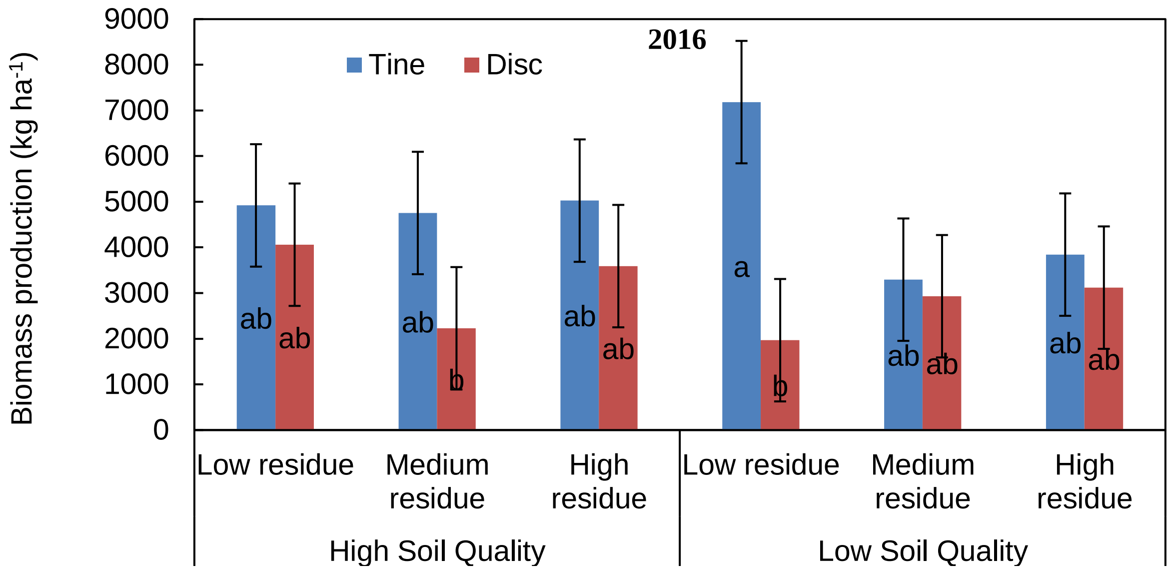

Figure 3.8: Biomass production 90 days after emergence with tine and disc openers for the 2016 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

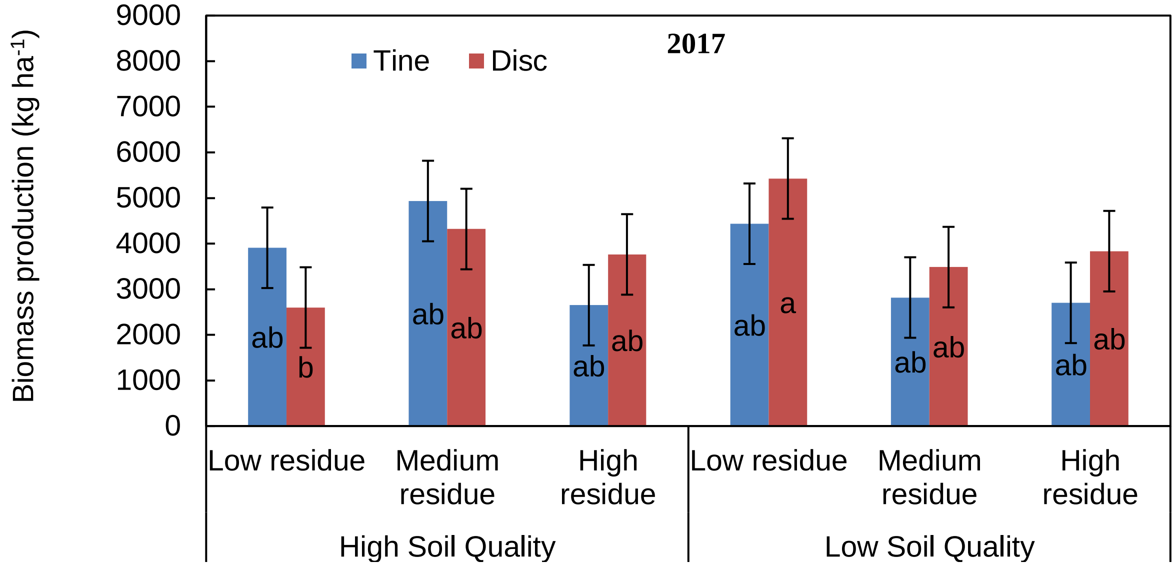

Figure 3.9: Biomass production 90 days after emergence with tine and disc opener for the 2017 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

At physiological maturity in the 2016 season, opener had a significant effect on biomass production but no interaction was recorded between opener, soil quality or residue level (Table 3.6). However, on low quality soil the tine opener produced more biomass on low residue than the disc opener ($p<0.05$) (Figure 3.10). In the 2017 season there was no main treatment effect or interactions on biomass production at physiological maturity (Table 3.6, Figure 3.11).

Table 3.6: Main effects and interactions between opener, soil quality and residue level for biomass production at physiological maturity.

	Effect	F	P-value
2016	Soil Quality	0.01	0.91
	Opener	7.54	0.02
	Residue levels	0.39	0.69
	Soil Quality x Opener	1.89	0.20
	Soil Quality x Residue levels	0.38	0.70
	Opener x Residue levels	1.80	0.22
	Soil Quality x Opener x Residue levels	1.09	0.38
2017	Soil Quality	0.23	0.64
	Opener	0.67	0.43
	Residue levels	0.58	0.58
	Soil Quality x Opener	2.77	0.13
	Soil Quality x Residue levels	0.10	0.90
	Opener x Residue levels	0.74	0.50
	Soil Quality x Opener x Residue levels	0.37	0.70

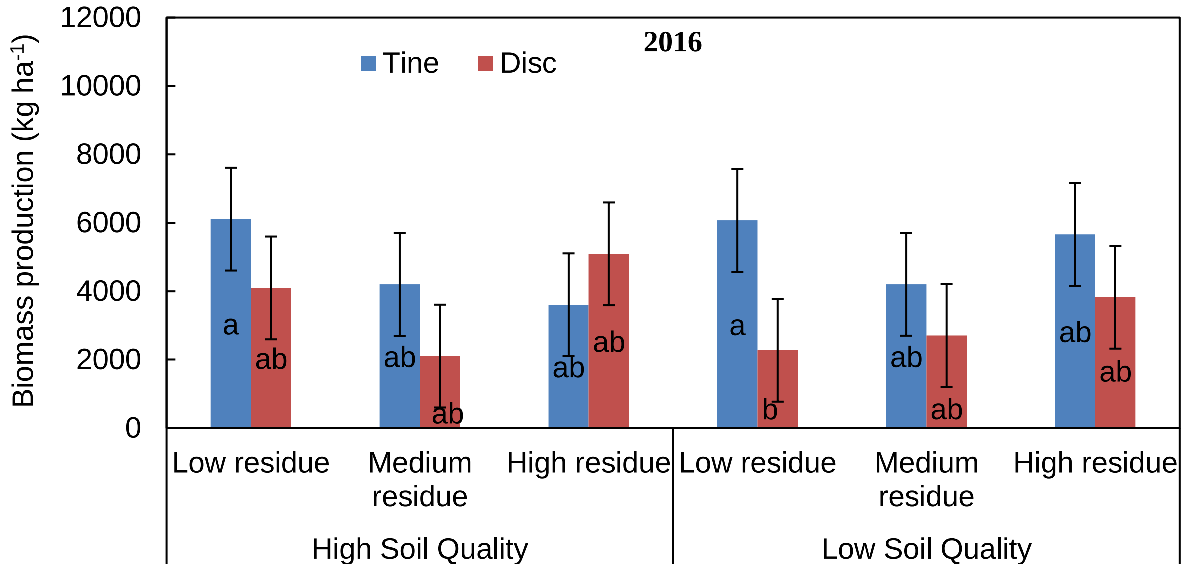

Figure 3.10: Biomass production at physiological maturity with tine and disc openers for the 2016 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

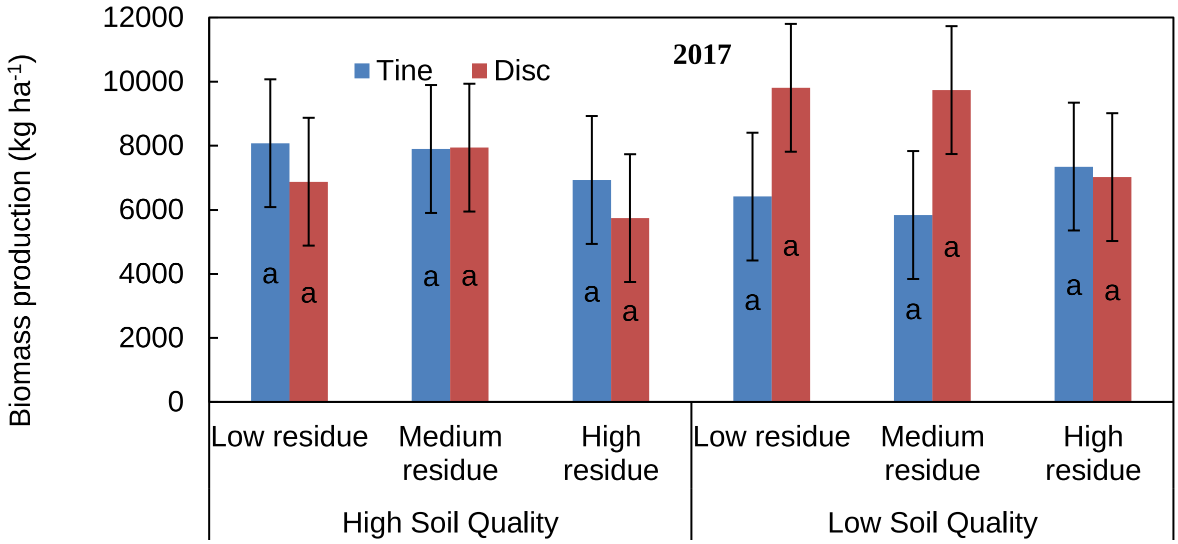

Figure 3.11: Biomass production at physiological maturity with tine and disc openers for the 2017 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

3.3.3 Leaf area index (LAI)

LAI was not determined at 30 days after emergence in the 2016 season, however it has been determined for the 2017 season. There was no significant interaction between soil quality, residue level and opener after emergence in the 2017 season, but soil quality had a significant effect (Table 3.7). The disc opener produced a higher LAI on low quality soil with low residue level than the tine opener on high quality soil with low residue level (Figure 3.12). On high quality soil 30 days after emergence the LAI on the plots where the tine opener was used on low residue levels were higher than for the disc opener (Figure 3.12). None of the other treatments on high soil quality were different from each other. On low soil quality both openers produced a higher LAI on low residue levels than on high residue levels ($p<0.05$).

Table 3.7: Main effects and interactions between opener, soil quality and residue level for LAI at 30 days after emergence.

	Effect	F	P-value
2017	Soil Quality	7.35	0.02
	Opener	0.19	0.68
	Residue levels	0.20	0.82
	Soil Quality x Opener	1.70	0.23
	Soil Quality x Residue levels	0.71	0.52
	Opener x Residue levels	1.09	0.38
	Soil Quality x Opener x Residue levels	2.91	0.11

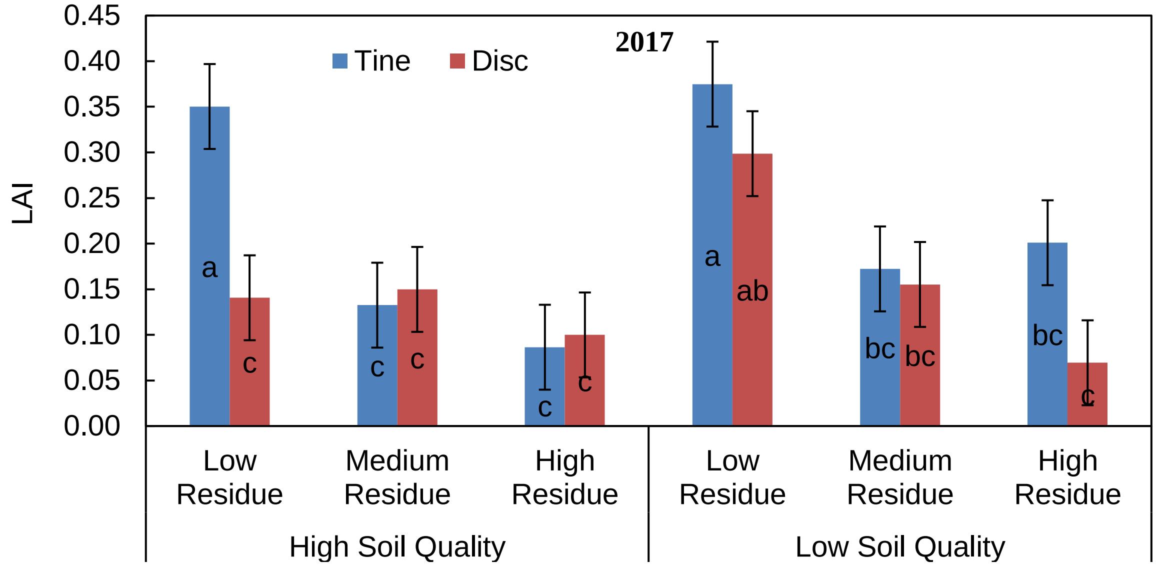

Figure 3.12: Leaf area index (LAI) 30 days after emergence in 2017. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

There was no significant interaction between soil quality, residue level and opener with regard to LAI at 60 days after emergence in the 2016 season, but soil quality had a significant effect (Table 3.8). A higher LAI was recorded where the tine opener was used on low soil quality with low residue levels than on high soil quality with low residue levels (Figure 3.13). There were no other differences recorded between any of the treatments. In the 2017 season, there were no interactions between soil quality, opener and residue level (Table 3.8). However, a higher LAI was recorded for the disc opener on low quality soil with a low residue level compared to the tine opener on low quality soil with a medium residue level (Figure 3.14).

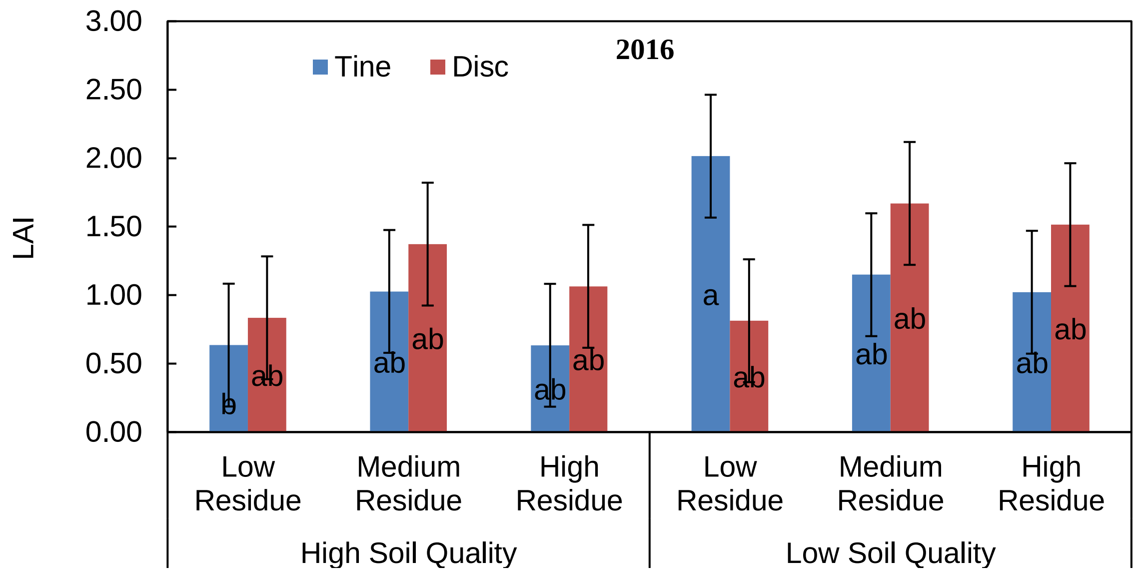

Figure 3.13: LAI at 60 days after emergence in the 2016 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

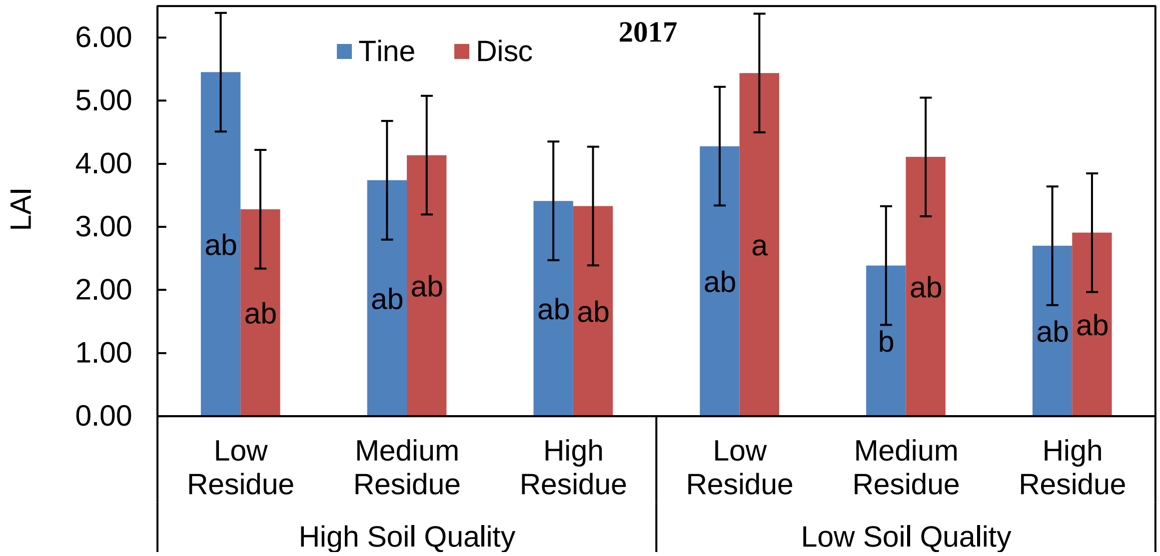

Figure 3.14: LAI 60 days after emergence in 2017 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

No significant interaction between soil quality, residue level and opener with regards to LAI at 90 days after emergence in the 2016 season has been recorded (Table 3.9). Similar LAIs was recorded for all treatments (Figure 3.15). During the 2017 season no interaction between soil quality, opener and residue has been recorded (Table 3.9). LAI was similar between treatments, except that the disc opener achieved a higher LAI on low quality soil with high residue than on high soil quality with low residue as well as a higher value than the tine opener on low quality soil with a medium residue level (Figure 3.16).

Table 3.8: Main effects and interactions between opener, soil quality and residue level for LAI at 90 days after emergence.

	Effect	F	P-value
2016	Soil Quality	0.45	0.52
	Opener	0.49	0.50
	Residue levels	0.43	0.66
	Soil Quality x Opener	0.14	0.72
	Soil Quality x Residue levels	2.11	0.18
	Opener x Residue levels	0.22	0.81
	Soil Quality x Opener x Residue levels	0.65	0.54
2017	Soil Quality	0.15	0.71
	Opener	1.22	0.30
	Residue levels	0.86	0.46
	Soil Quality x Opener	5.33	0.05
	Soil Quality x Residue levels	2.14	0.17
	Opener x Residue levels	0.65	0.55
	Soil Quality x Opener x Residue levels	0.14	0.87

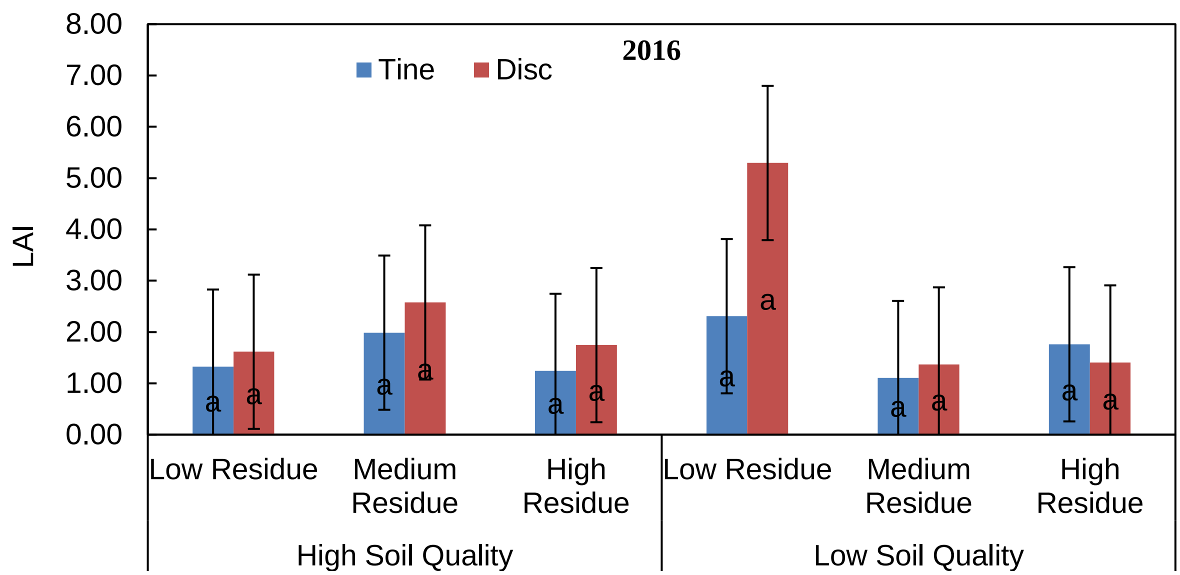

Figure 3.15: LAI 90 days after emergence in the 2016 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

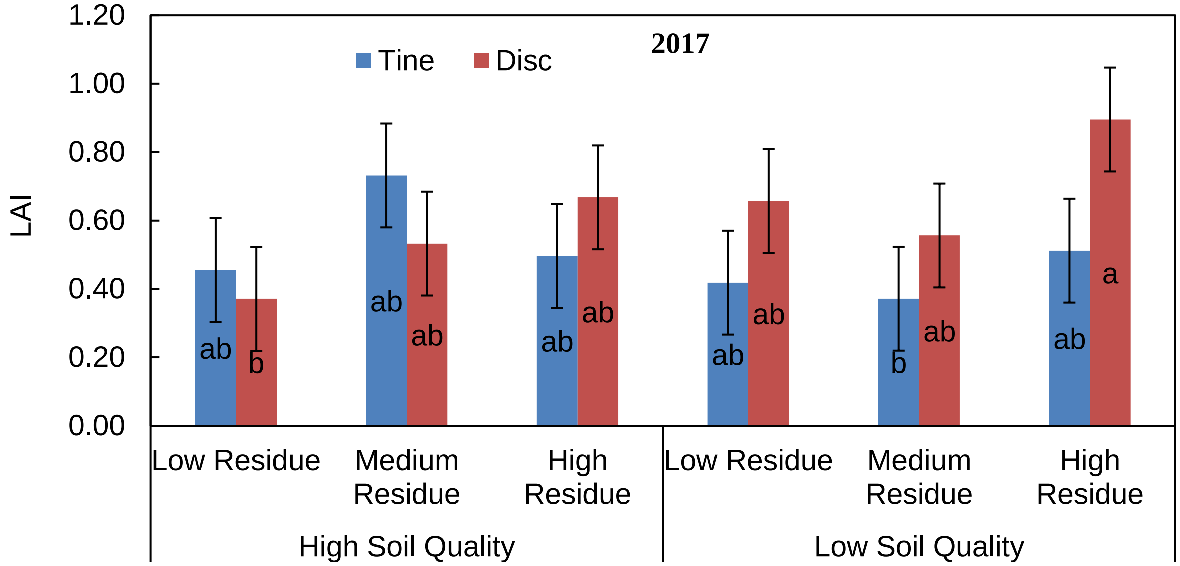

Figure 3.16: LAI 90 days after emergence in the 2017 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

3.3.4 Yield

During 2016, no significant differences in yield due to the soil quality, residue level or opener or interaction between these main factors were recorded (Table 3.10), but the tine opener tended to result in higher yields than the disc opener in the 2016 season regardless of soil quality or residue level (Figure 3.17). During the 2017 season no significant effects due to main factors or interaction were recorded (Table 3.18), but on low quality soil a higher yield was achieved where the tine opener was used on medium residue levels ($p<0.05$) compared to the disc opener. (Figure 3.20).

Table 3.9: Main effects and interactions between opener, soil quality and residue level for canola plant population for the 2016 and 2017 season.

2016	Soil Quality	F	P-value
	Opener	0.97	0.35
	Residue levels	1.64	0.23
	Soil Quality x Opener	0.09	0.92
	Soil Quality x Residue levels	0.02	0.90
	Opener x Residue levels	0.00	1.00
	Soil Quality x Opener x Residue levels	0.03	0.97
	Soil Quality	0.06	0.94
2017	Soil Quality	3.68	0.09
	Opener	0.26	0.62
	Residue levels	0.78	0.49
	Soil Quality x Opener	5.23	0.05
	Soil Quality x Residue levels	0.19	0.83
	Opener x Residue levels	0.51	0.62
	Soil Quality x Opener x Residue levels	1.57	0.26

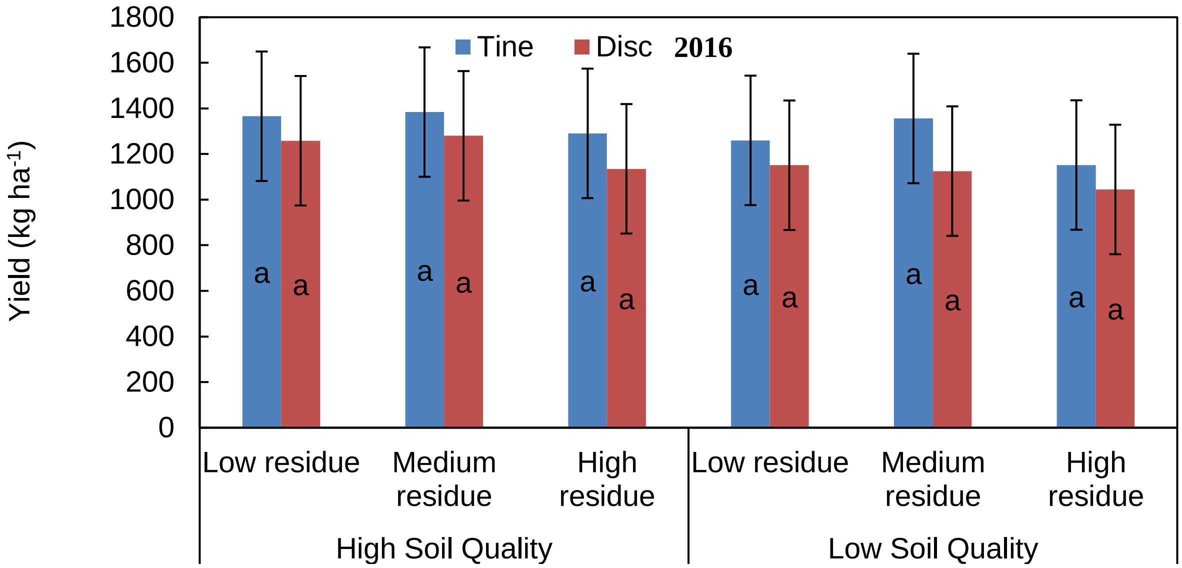

Figure 3.17: Canola seed yield measured in 2016. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

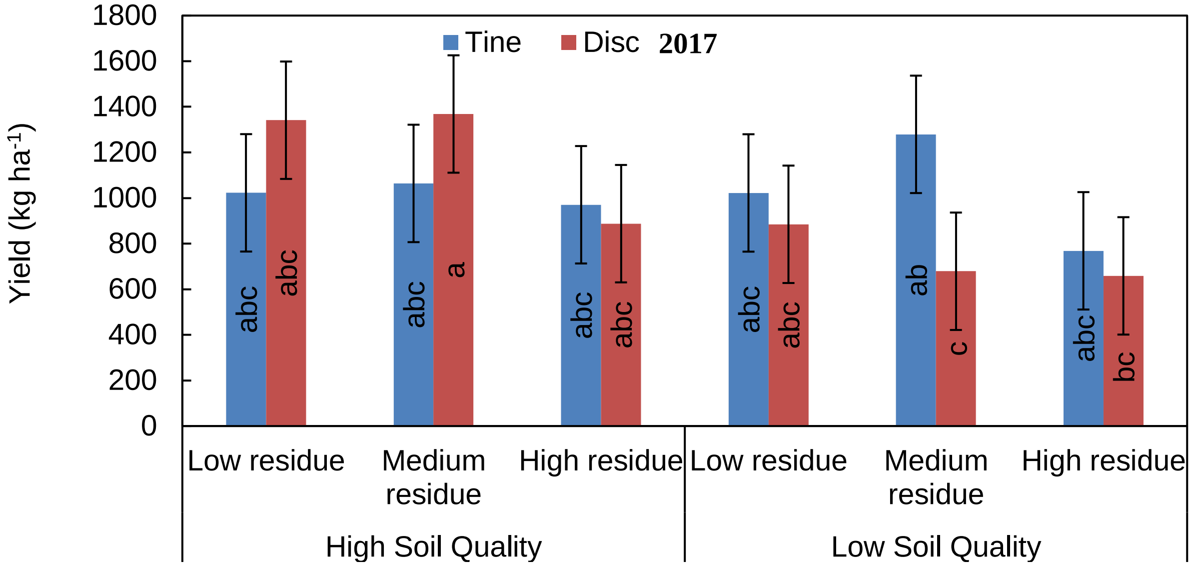

Figure 3.18: Canola seed yield measured in 2017. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

3.3.5 Thousand seed mass (TSM)

No interactions were recorded between soil quality, opener or residue level for TSM during the 2016 season (Table 3.11). Similar TSM was recorded for all treatments (Figure 3.19). During the 2017 season no interactions were recorded between soil quality, opener or residue level for TSM, but soil quality had a significant influence. Similar TSM were recorded between all treatments, except on high quality soil a higher TSM was achieved where the tine openers was used on high residue level plots than on low residue level plots (Figure 3.20)

Table 3.10: Main effects and interactions between opener, soil quality and residue level for TSM at 30 days after emergence.

	Effect	F	P-value
2016	Soil Quality	0.02	0.90
	Opener	0.87	0.38
	Residue levels	0.53	0.61
	Soil Quality x Opener	2.97	0.12
	Soil Quality x Residue levels	0.44	0.66
	Opener x Residue levels	0.47	0.64
	Soil Quality x Opener x Residue levels	0.13	0.88
2016	Soil Quality	3.72	0.09
	Opener	1.45	0.26
	Residue levels	1.26	0.33
	Soil Quality x Opener	0.16	0.70
	Soil Quality x Residue levels	0.60	0.57
	Opener x Residue levels	1.33	0.31
	Soil Quality x Opener x Residue levels	2.02	0.19

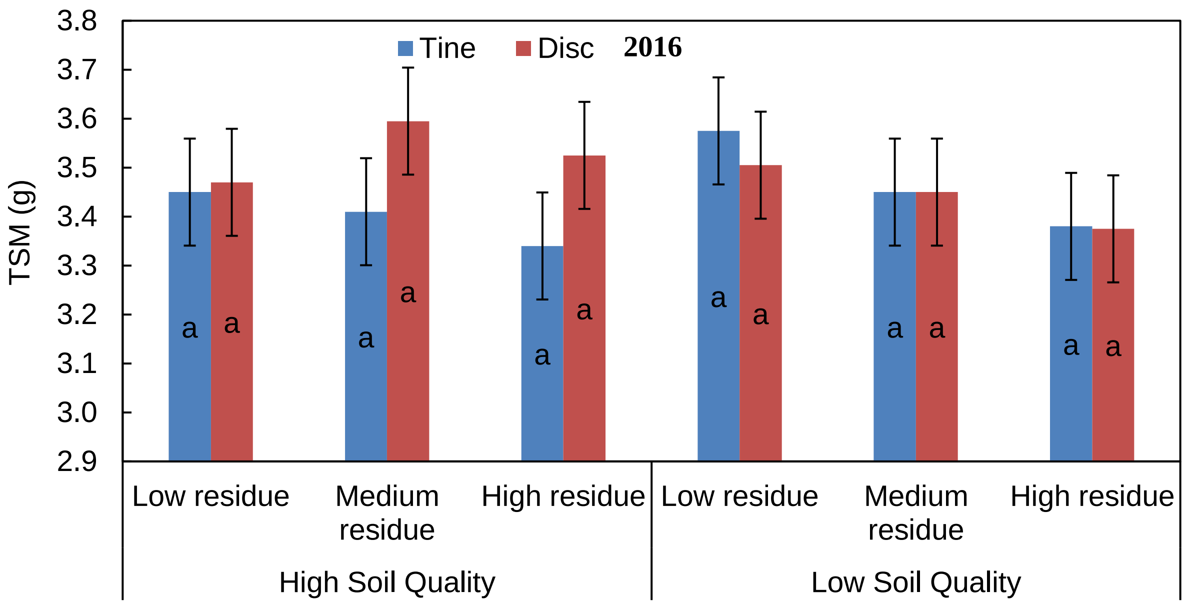

Figure 3.19: TSM measured in 2016 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

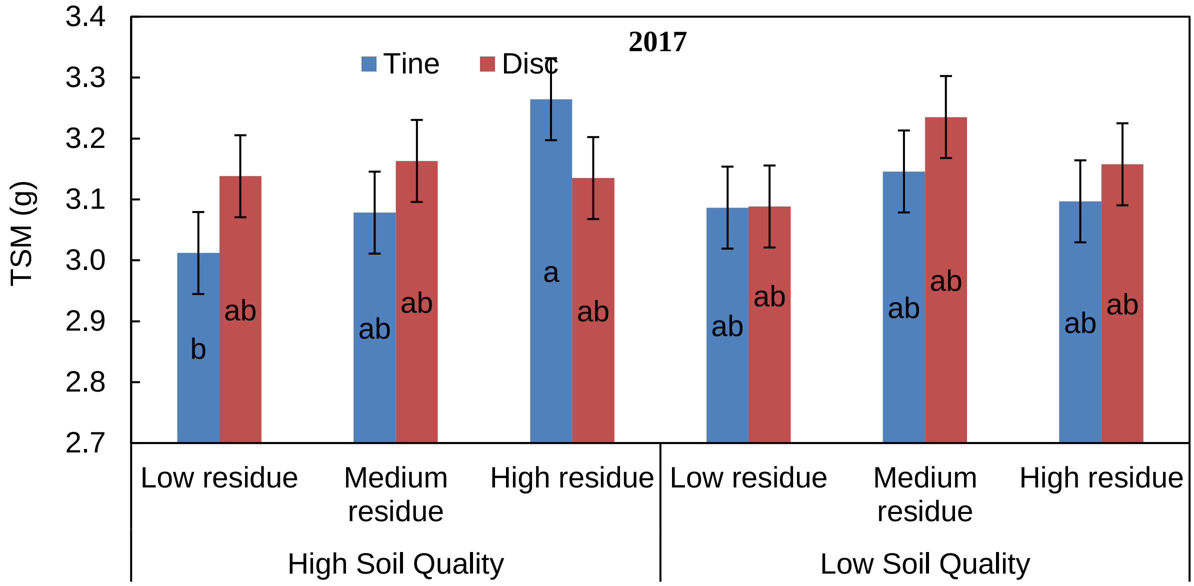

Figure 3.20: TSM measured in 2017 season. The same letter within bars did not differ at p = 0.05. The error-bars display the standard error within each treatment.

3.4 Discussion

3.4.1 Residue manipulation

The residue manipulated prior to planting was done by hand and samples were taken to determine the amount of residue applied. Therefore, the residue applied in 2016 and 2017 were not exactly the same. The residue applied on low and high residue plots were similar, but the residue applied on medium plots differed substantially. In 2016, 4.3 t ha^{-1} was applied on medium residue plots and in 2017 and 6.3 t ha^{-1}, which is the same as the amount of residue applied on high residue plots. Therefore, the results obtained between medium and high residue plots on both high and low quality soil during the 2017 season may be similar.

3.4.2 Plant population

The plant population established by the disc opener was suboptimal in 2016. A plant population for the Swartland of 50 to 80 plants m^{-2} is recommended (Protein Research Foundation 2013) and would probably have an adverse effect on yield. In Western Australia, plant population of more than 50 plants m^{-2} did not have a significant effect on yield (French et al. 2016). Angadi et al. (2003) found that similar yields were obtained in a wide range of plant populations, (20 to 80 plants m^{-2}) when precipitation where higher than normal in the Prairie region of Canada. It was found that seed yield only reduced were plant populations are lower than 40 plants m^{-2} in a dry season. Reducing plant population from 80 plants m^{-2} to 40 plants m^{-2} did not have any effect on seed yield (Angadi et al. 2003). French et al. (2016) found that the overall economic optimum plant density for canola in Western Australia was 30 to 40 plants m^{-2}. In the current study in 2017 the plant population achieved with the disc seeder was much higher than in the 2016 season, this can likely be ascribed to the change in fertiliser application as discussed in crop management section. Applying fertiliser with seeding may have caused chemical injury in 2016 where in 2017 it was avoided by broadcasting the fertiliser prior to planting. In an Australian study where the effect of fertiliser placement was assessed, Hocking et al. (2003) found that plant population was lower for the treatments where fertiliser was placed with the seed compared to where fertiliser was broadcast before seeding. Placing fertilisers away from seed with the disc opener is not possible as seed and fertiliser delivery is combined. Broadcasting fertiliser is the alternative, but is associated with lower fertiliser use efficiencies than band placement. This is one of the limitations of using a disc opener for canola establishment.

In the current study, the tine opener achieved an adequate plant population according to the recommendations on the low residue plots during the 2016 season, but the plant population when planted through medium and high residue levels were below optimal. During the 2017 season both the tine and disc openers achieved optimal plant populations (>50 plants m^{-2}) on the low residue level on low quality soil, while only the tine was able to achieve optimal plant population on high soil quality where the residue level was low.

3.4.3 Biomass production

Within the first 30 days, biomass production is relatively slow as the plants and their leaves are still small which means their photosynthetic capacities are limited (Walton et al. 1999). When canopy closure is reached a rapid increase in growth occurs till it reaches a maximum after which it starts to decline when pod fill sets in. With pod filling large amounts of nutrients in leaves and stems may be mobilised from the leaves and stems to help fill the pods (Walton et al. 1999). When the plants reach physiological maturity, biomass decreases rapidly as the plants shed their leaves. When the plants reached physiological maturity in the 2017 season the biomass production was similar between all treatments. Hocking et al. (2003) found that placing fertiliser with the seed reduces biomass production at all growth stages up until physiological maturity where no differences in biomass production were found. Canola plants therefore have the capacity to compensate for sub-optimal establishment by producing big plants with a dense canopy.

On low quality soil where the tine opener was used more biomass was produced than the disc opener on low residue in the 2016 season ($p<0.05$). This difference was recorded through the production cycle from 30 days after emergence to physiological maturity. Soil quality seems to have caused the poorer establishment, which led to lower biomass production. This might be due to soil physical quality (Table 3.1) and in particular a higher stone fraction causing the seed-drill to seed at uneven depths and some of the seed deposited on top of the soil. Although biological quality also differed between the high and low soil quality plots (Table 3.1), it is not expected to have played a significant role in explaining differences between biomass productions.

3.4.4 Leaf area index (LAI)

Towards spring, the LAI increases rapidly as temperatures increases. It reaches a maximum just after the plants start to flower. For canola to be able to intercept approximately 90% of the incoming solar radiation, a LAI of 4 is required (Walton et al. 1999). The LAI decreases rapidly from late flowering to physiological maturity as the plants shed their leaves. The LAI at 30 days was higher on low residue plots. This can be attributed to the fact that the canola seedlings were able to grow through the low residue faster than on medium and high residue plots. Towards 60 days after emergence in the 2017 season, the plants grew rapidly and the differences seen at 30 days after emergence were eliminated. During the 2017 season at 90 days after emergence the overall LAI decreased a lot from 60 days after emergence as a result of moisture stress which certainly had a negative effect on pod filling and grain yield. There was no difference observed between openers. The LAI on low quality soil with high residue level was higher than the LAI on high quality soil with low residue level. This was the complete opposite than what was recorded at 30 days after emergence. The LAI increased slowly after the canola was planted in May.

3.4.5 Yield

In 2016 no differences in yield were observed between treatments. However, there was a tendency that were the tine opener was used a higher yield was achieved than were the disc opener was used regardless of the soil quality or residue level. The lower yield of the disc opener can be attributed to fertiliser placement with the seed when planting with the disc opener. Although placing fertiliser with the seed can cause 40 to 65% lower emergence, it does not necessarily cause a lower yield as plots with fewer plants compensate by producing more seed per plant or bigger plants (Hocking et al. 2003). However, this compensation is limited as the yields were only comparable at one of the two locations where Hocking et al. (2003) conducted their trials. The potential yield is determined by the number of pods per plant, seeds per pod and mass per seed. It is important to sow canola early to give the plants the opportunity to make use of all the rainfall received during the growing season as this will have an effect on final yield. Robertson et al. (2014) found that wheat yield was positively correlated with biomass production if temperature and water stress are absent. The dry May (only 6.3 mm rainfall) experienced in the Swartland in 2016 resulted in a later seeding (25 May) due to the lack of sufficient soil moisture. This might have had a negative impact on yield as Olsson (1960) found that the decrease in available water towards the end of the season had a large effect on the dry weight of pods. In the 2017 season seeding took place on 5 May already, which were best practice in the Swartland area. However, this had little effect as it only rained 10.5 mm at the end of May in comparison to the long-term mean of about 70 mm. Canola yields of about 1.8 t ha^{-1} are regarded as good yields for the Swartland region. In this trial yields of only 1.0 – 1.4 t ha^{-1} were achieved, which were acceptable for this particular year with adverse climate conditions.

3.4.6 Thousand seed mass (TSM)

There were no differences in TSM between any of the treatments in 2016. There was a tendency that a higher TSM was achieved on plots with medium and high residue levels. This can be attributed to more moisture being available for the plants towards the end of the season compared to low residue plots. The TSM measured in this trial can be regarded as normal as Angadi et al. (2003) found similar results for TSM varying between 2.7 g and 3.6 g in a trial conducted in the Prairie region of Canada.

3.4.7 General discussion

The H_0 hypothesis could be accepted only for the 2016 season with regards to biomass production were the tine opener produced more biomass on low quality soil with low residue levels than the disc opener. In 2017 similar amounts of biomass has been produced with both the disc and tine openers. Similar yields were achieved in both years. The H_A hypothesis is accepted for 2017. There was a tendency that the disc opener resulted in higher yields on high soil quality with low and medium residue levels in 2017, while a similar yield was recorded on high residue levels. Similar yields were recorded when both openers were used on high quality soil in the 2016 season. This indicates that one can expect significant variation in results between years, and that the season dictates production potential of canola.

As high soil quality, at least for 2017, was associated with a higher yield, the SMAF used for the assessment, can be regarded as a reliable indication of soil quality (Swanepoel et al. 2015). However, the Solvita Soil Health Test indicated the inverse of the SMAF, i.e. the high quality plots according to SMAF, had a lower soil health score than the SMAF low quality plots. Although the Solvita Soil Health test can give farmers an indication of soil health, the accuracy and reliability of the test is questionable. The limitation lies within the fact that it gives estimated PMN and calculated microbial biomass, which are not exact.

3.5 Conclusion

The two seasons' weather conditions in which could have caused the trial was conducted differed substantially, although for both years the canola was planted in dry soil. The mean annual rainfall for the 2016 season was in line with the long-term rainfall mean at 376 mm for the year, whilst in 2017 only 214.9 mm was recorded. The tine opener established canola better than the disc opener in the 2016 season regardless of residue level or soil quality. The fact that the disc opener performed worse than the tine opener can be attributed to fact that fertiliser was placed with the seed which caused chemical damage to the seed. This was changed in the 2017 season and fertiliser was broadcast before planting with the disc opener which led to the tine and disc opener performing similarly. Residue remained a problem and establishment with both the tine and disc openers, were the best at low residue levels. Residue management starts when the crop is harvested. More attention should therefore be given to improve choppers and spreaders on combine harvesters as it is important to chop residue short enough and spread it evenly for seed-drills to be able to plant through the residue the following year. Combine manufactures has been improving the choppers and spreaders on the new combine models. It is, however, important for farmers to strive towards implementing the new technology as it will improve their CA systems. Application of chemicals that break down the residue quicker can also be considered, while partial burning of residue can also be implemented although it is not ideal. The yields achieved for the canola planted with the two different openers were similar over all three levels of residue, on both high and low quality soil. Canola is not produced in isolation, but rather as part of a crop rotation system. Therefore, it is important to take the parallel wheat trial into consideration when evaluating results of this study (Swanepoel et al. 2017).

3.6 References

Ashworth M, Desbiolles J, Tola E. 2010. Disc Seeding in Zero-Till Farming Systems: A review of technology and paddock issues. West Australian No-Tillage Farmers Association.

Andrews, SS, Karlen DL, Cambardella CA. 2004. The soil management assessment framework. Soil Science Society of America Journal 68: 1945-1962

Angadi SV, Cutforth, HW, McConkey BG, Gan Y. 2003. Yield adjustment by canola grown at different plant populations under semiarid conditions. Crop Science 43: 1358-1366.

Blake GR. 1965. Bulk density. In: Black CA, Evans DD, Ensminger LE, White JL, Clark FE (Eds.), Methods of Soil Analysis. Part 1. Physical and Mineralogical Properties. American Society of Agronomy, Madison, WI, USA. pp. 374e390.

Cataldo DA, llaroon lll, Schrader LE, Youngs VL. 1975. Rapid colormetric determination of nitrate in plant tissue by nitration of salicylic acid. Communications in Soil Science and Plant Analysis 6:71-80.

Day PR. 1965. Particle fractionation and particle-size analysis. In: Black CA (Ed.), Methods of Soil Analysis: Part I, Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling. Agronomy Society of America, Madison, Wisconsin. pp 545–567.

Dell Inc. 2016. Dell Statistica (data analysis software system), version 13. Software.dell.com

Derpsch R, Friedrich T, Kassam A, Li H. 2010. Current status of adoption of no-till farming in the world and some of its main benefits. International Journal of Agricultural and Biological Engineering 3: 1-25.

Dick RP, Breakwell DP, Turco RF. 1996. Soil enzyme activities and biodiversity measurements as integrative microbiological indicators. In: Doran JW, Jones AJ. (Eds.) Methods for assessing soil quality. SSSA Special Publication No. 49. Soil Science Society of America, Madison, WI. 247-271.

French RJ, Seymour M, Malik RS. 2016. Plant density response and optimum crop densities for canola (Brassica napus L.) in Western Australia. Crop & Pasture Science 67: 397-408.

Hocking PJ, Mead JA, Good AJ, Diffey SM. 2003. The response of canola (Brassica napus L.) to tillage and fertiliser placement in contrasting environments in southern NSW. Animal Production Science 43: 1323-1335.

IUSS Working Group WRB. 2006. World reference base for soil resources, 2nd edition. World Soil Resources Report 103, Rome: FAO.

Keeney D R, Nelson DW. 1982. Nitrogen-inorganic forms. In: Page AL, Miller RH, Keeney DR (eds), Methods of Soil Analysis. Part 2. American Society of Agronomy, Madison, WI. 643–698.

Kemper WD, Rosenau RC. 1986. Aggregate stability and size distribution. In: Methods of Soil Analysis, Part 1. Physical and Mineralogical Methods. Agronomy Monograph no. 9. Society of Agronomy/Soil Science Society of America. 425– 442.

Kirkegaard JA. 2016. High yielding canola: Stubble management, planting and fertiliser. Canola Symposium, 20 July, Kronenburg, Paarl, South Africa. (Not published)

Kumar K and Goh KM. 2002. Management practices of antecedent leguminous and non-leguminous crop residues in relation to winter wheat yields, nitrogen uptake, soil nitrogen mineralization and simple nitrogen balance. European Journal of Agronomy 16: 295-308

Lamprecht SC, Tewoldemedhin YT, Calitz FJ, Mazzola M 2011. Evaluation of strategies for the control of canola and lupin seedling diseases caused by Rhizoctonia anastomosis groups. European Journal of Plant Pathology 130(3): 427-439.

Nelson DW, Sommers LE. 1982. Total carbon, organic carbon, and organic matter. In: Page, A.L. (Ed.), Methods of Soil Analysis: Part 2, Chemical and Microbiological Properties. American Society of Agronomy, Madison, Wisconsin. 539–579.

Olsson G. 1960. Some relations between number of seeds per pod, seed size and oil content and the effects of selection for these characters in Brassica and Sinapsis. Hereditas 46: 29–70.

Pieterse, P.J., 2010. Herbicide resistance in weeds–a threat to effective chemical weed control in South Africa. South African Journal of Plant and Soil, 27(1), pp.66-73.

Protein Research Foundation. 2013. Canola Production Guide. SunMedia, Stellenbosch.

Robertson M, Kirkegaard J, Rebetzke G, Llewellyn R, Wark T. Prospects for yield improvement in Australian wheat industry: a perspective

Shelton DP, Dickey EC, Jasa PJ, Vrana VK. 1991. Crop residue management in the western Corn Belt. Crop Residue Management for Conservation. Ankeny (IA): Soil and Water Conservation Society. pp 16-17.

Smil, V. 1999. Crop Residues: Agriculture's Largest Harvest: Crop residues incorporate more than half of the world's agricultural phytomass. Bioscience. 49(4) pp 299-308.

Non-Affiliated Soil Analysis Work Committee, 1990. Handbook of Standard Soil Testing Methods for Advisory Purposes. Soil Science Society of South Africa, Pretoria, South Africa.

Swanepoel, PA and Tshuma, F, 2017. Soil quality effects on regeneration of annual Medicago pastures in the Swartland of South Africa. African Journal of Range & Forage Science. 1-8.

Swanepoel PA, du Preez CC, Botha PR, Snyman HA, Habig J. 2015. Assessment of tillage effects on soil quality of pastures in South Africa with indexing methods. Soil Research 53: 274-285.

Swanepoel PA, Labuschagne J, Hardy M. 2016. Historical development and future perspective of Conservation Agriculture practices in crop-pasture rotation systems in the Mediterranean region of South Africa. In: Ecosystem services and socio-economic benefits of Mediterranean grasslands. Kyriazopoulos, A., Lopez-Francos, A., Porqueddu, C., Sklavou, P. (eds.). Zaragoza: CIHEAM: 2016, 454 (+ xii) p. Options Méditerranéennes, Series A, No 114.

Swanepoel PA, Agenbag GA, Strauss JA. 2017. Considering soil quality for choosing between disc or tine seed-drill openers to establish wheat. South African Journal of Plant and Soil. (In Press)

Soil Classification Working Group. 1991. Soil classification: a taxonomic system for South Africa: memoirs on the agricultural natural resources of South Africa No. 15. Department of Agricultural Development, Pretoria, South Africa.

Soil Survey Staff. 2003. Keys to soil taxonomy. Washington, United States of America: Department of Agriculture.

Tessier S, Saxton KE, Papendick RI, Hyde GM. 1991. Zero-tillage furrow opener effects on seed environment and wheat emergence. Soil and Tillage Research 21: 347-360.

Walton G H, Mendham N, Robertson M, Potter T. 1999. Phenology, physiology and agronomy. Canola in Australia: The first 30 years. Australian Oilseed Federation.

Western Cape Government. 2017. Agri-Outlook: Western Cape weather reports. Henk Cerfonteyn. henkc@elsenburg.com

Wylie P. 2008. High Profit Farming in Northern Australia - A new era in grain farming, Grains Research Development Corporation - Australian Government Canberra.

Chapter 4

Tine or disc seed-drill openers to establish canola in fields of varying soil qualities in the Western Cape

4.1 Introduction

Western Cape soils are characterised by high inherent soil variation, even within a few meters, which results in high variability of productivity within fields (Cooper 2017; Swanepoel et al. 2017). This complicates agronomic management as homogenous soil conditions would facilitate uniformity of the effects of management actions. Information derived from small experimental plots, usually with a high level of uniformity, are often not applicable to entire fields in the Western Cape. It is therefore important to test the applicability of information generated from small plots at field scale. Field scale tests have its limitations, such as the uncertainty of linking a result to a specific factor and can often only be ascribed to multifaceted and complex interaction of many effects. Despite the limitations, field scale trials are more relevant to farmers' situation. Many farmers do not use precision agriculture technology, as equipment is complex and expensive and do one soil test which represents an entire field. A mean soil quality value can therefore be determined per field, which could give farmers an indication of which agronomic practices to follow tailored for high or low soil quality. For instance, Swanepoel et al. (2017) found that soil quality had a significant effect on wheat (*Triticum aestivum* L.) yield and that disc openers are the superior option in poor quality soils. In high quality soils, wheat yield did not differ between disc and tine openers. Agronomic decisions therefore depend on soil quality. It raises the question whether a tine or disc opener can be used to establish canola on soils of low or high quality, or in other words, does soil quality need to be considered when choosing between a tine or disc opener. The aim of this study was to compare tine and disc openers to produce canola from soil with contrasting qualities and on fields comparable in size to commercial farms. This was done by evaluating soil disturbance, biomass production, leaf area index (LAI), seed yield and thousand seed mass (TSM).

4.2 Materials and methods

4.2.1 Experimental site

The trial was conducted during 2016 and 2017 at the Langgewens Research Farm (33° 16'42.33" S; 18° 42'11.62" E; 191m) of the Western Cape Department of Agriculture in the Swartland region. It was conducted in commercial-sized fields with long-term management records. Soils were variable, but the most common soils were duplex soils. According to the South African classification system, the most common soil forms were Swartland, Klapmuts, Sepane, and Sterkspruit soil forms (Soil Classification

Working Group 1991). According to the USDA soil taxonomy and the International Classification Systems (IUSS Working Group WRB 2006; Soil Survey Staff, 2003) these soils would be classified as Alfisols and Luvisols according to the two respective classification systems. Annual rainfall in 2016 was 376 mm with 270.8 mm in the growing season (May to October) and for 2017 only 214.9 mm (January to November) with 180.4 mm in the growing season. Full rainfall distribution alongside monthly temperature extremes for Langgewens can be found in Chapter 3.

4.2.2 Experimental design and treatments

This study was laid out as a split-plot design, with four replicates as blocks. Two factors were evaluated, i.e. soil quality (high or low) and opener (tine or disc). Main plots with high or low soil quality was divided into two equal sub-plots to establish canola using a seed-drill with either tine or disc openers. Therefore, there were 16 experimental units. Whole-plot sizes comprised an area of 3000 m^2.

An Equalizer no-till seed-drill was used for seeding with both openers. The seed-drill had exchangeable tines and discs to avoid potential bias by using different seed-drills that might have a difference in weight and seed delivery system. The preceding crop of two for the four blocks was wheat, while the other two were an annual *Medicago* pasture. The residue level on these camps were less than 450 kg ha^{-1} before seeding for both years, which can be described as low.

4.3 Data collection

4.3.1 Plant parameters

Crop management, the determination of plant population, biomass production and LAI was done in a similar way as described in Chapter 3.

4.3.2 Soil Sampling

Prior to seeding 10 soil samples were taken with a soil core (ø = 45 mm) to a depth of 150 mm. The soil management assessment framework (SMAF) was used to classify the soils (Andrews et al. 2004). The SMAF soil quality index (SQI) for low quality soil for the 2016 and 2017 seasons were 58% and 77%, respectively, while the SQI for high quality soils for the same periods were 63% and 90%, respectively.

4.3.3 Soil roughness

A pin profiler (Figure 4.1) was used to determine and measure the surface roughness and furrow width. This instrument consisted of 42 pins spaced 20 mm apart within a frame where they can slide up and down to conform to surface irregularities (Moreno et al. 2008). The pin profiler was positioned on the plots perpendicular to the direction of seeding directly after seeding. Arithmetical mean surface roughness was calculated as the sum of all height values of the pins, where height was measured from the lowest pin. Mean furrow width was determined as the mean value of the width of the rows, determined by the number of pins which touched disturbed soil on either side of the furrow.

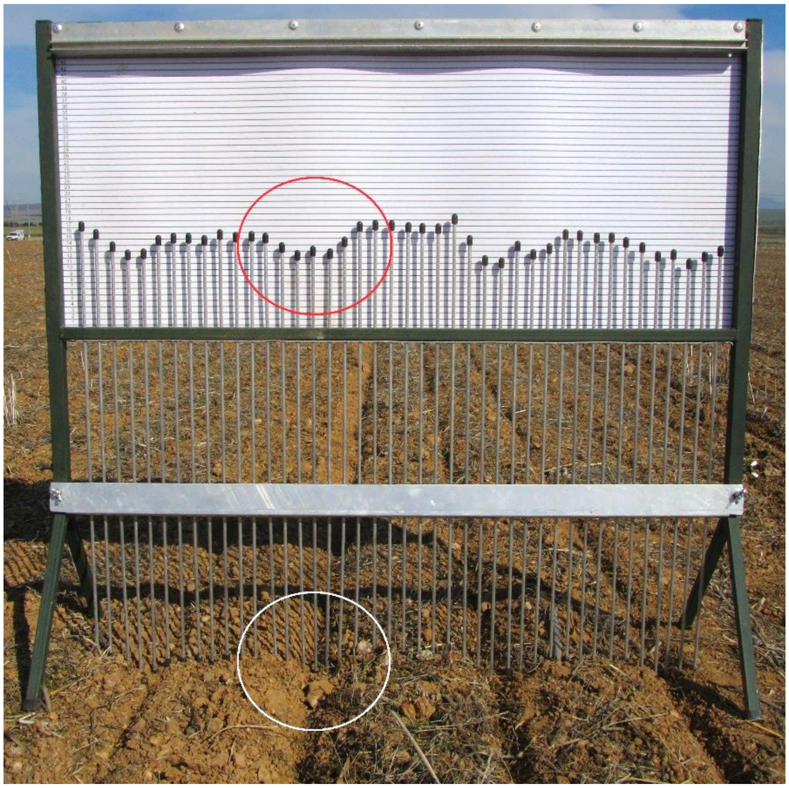

Figure 4.1: Pin profiler used to determine the amount of above ground soil disturbance. The white circle at the bottom indicate the furrow in the soil caused by the opener, while the red circle at the top indicate roughness profile of the furrow.

4.3.3 Statistical analysis

Statistical analyses were done by using STATISTICA version 13 (Dell Inc. 2016). The GLM procedure was used to analyse the split-plot design with factors soil quality (whole plots) and opener (sub-plots). These two factors are regarded as fixed and blocks as random. Fisher's least significant differences (LSD) test was conducted at a 5% significance level to determine whether interactions among soil qualities and seed-drill openers were significant.

4.4 Results and discussion

4.4.1 Soil disturbance

The soil surface roughness and furrow widths were the two measurements taken with the pin profiler to determine soil disturbance. No significant main effects or interaction was recorded for soil surface roughness between any of the treatments for both seasons (Table 4.1; Figure 4.2). Neither were there any significant main effects or interaction between treatments for furrow width (Table 4.2). There was a tendency for the tine opener to result in more surface roughness than the disc opener on low quality soil during the 2016 season, while a similar soil surface roughness has been recorded between openers on low quality soil in 2017 (Figure 4.3). There was a tendency that the tine opener caused a wider furrow width than the disc opener for all treatments during 2016 and 2017, except on high quality soil in 2016.

Table 4.1: Main effects and interactions between opener and soil quality for soil surface roughness for both 2016 and 2017.

2016	Effect	Degrees of freedom	F	P-value
	Soil quality	3	0.68	0.47
	Opener	6	2.68	0.15
	Soil quality x Opener	6	2.88	0.14
2017	Soil quality	3	2.02	0.25
	Opener	6	0.00	0.95
	Soil quality x Opener	6	0.94	0.37

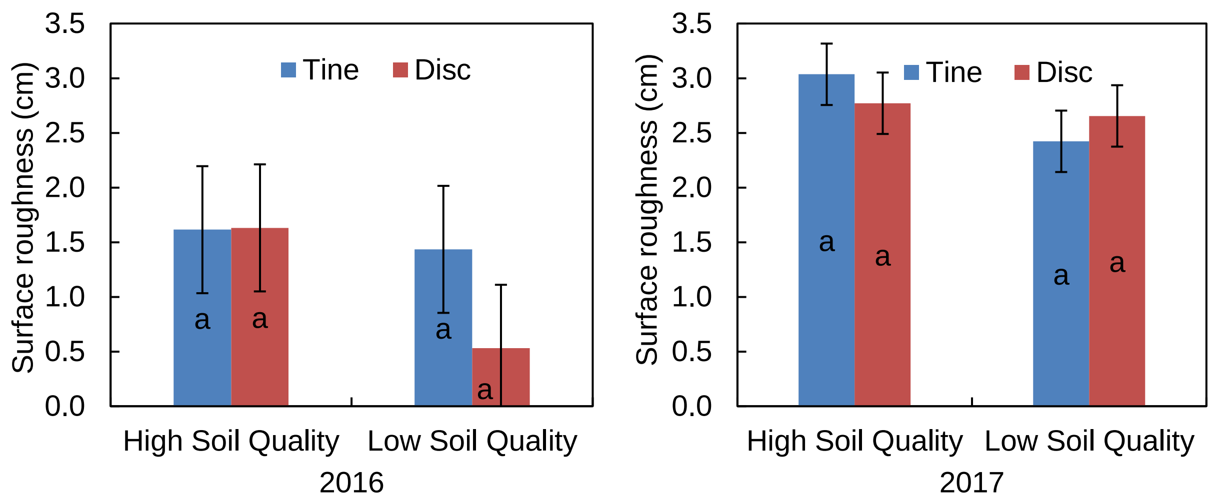

Figure 4.2: Surface roughness caused when seeding with different seed-drill openers. Different letters above the vertical bars indicate the treatments with a significant difference ($P < 0.05$). Error bars indicate the standard error within each treatment.

Table 4.2: Main effects and interactions between opener and soil quality for furrow width for both 2016 and 2017.

2016	Effect	Degrees of freedom	F	P-value
	Soil quality	3	0.68	0.47
	Opener	6	2.68	0.15
	Soil quality x Opener	6	2.88	0.14
2017	Soil quality	3	0.23	0.66
	Opener	6	3.31	0.12
	Soil quality x Opener	6	0.74	0.42

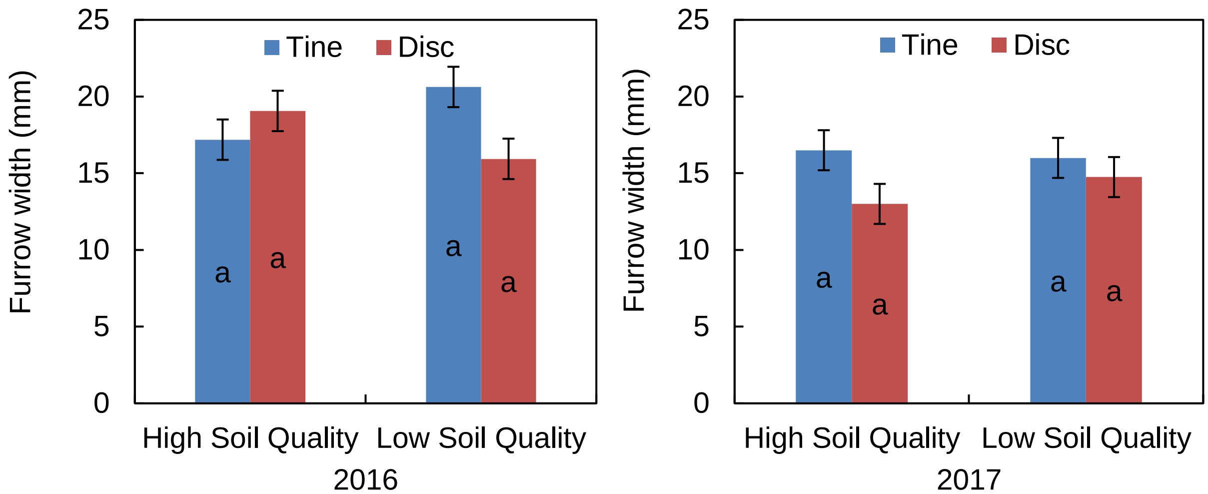

Figure 4.3: Furrow width caused when seeding with different openers (tine or disc). Different letters above the vertical bars indicate the treatments with a significant difference ($P < 0.05$). Error bars indicate the standard error within each treatment.

Reicosky (2015) and Tessier et al. (1991) has found that tine openers disturb soil more than disc openers. However, in this study it was found that both tine and disc openers disturbed soil to a similar extent. A possible reason is the dry soil in which seeding took place for both 2016 and 2017. It is possible that dry soil is more easily disturbed than moist soil. The speed of seeding plays a vital role as slower seeding will disadvantage disc openers as they will lose the ability to cut into the soil (Ashworth et al. 2010). The seeding speed in 2016 was 8 km hour with the disc opener while it was 5 km per hour with the tine opener. In 2017 the seeding speed of the disc opener was increased to 12 km per hour, which is considered best practise, to show that the disc opener disturbs soil less than a tine opener. However, this was not the case as the furrow width was similar and the surface roughness disturbance greater. Another reason for similar soil disturbance profiles between the two openers is the high stone fraction of the soils in the Western Cape (Swanepoel et al. 2016), which may cause the disc opener to seed ineffectively and cause more disturbance as the disc opener displaces stones which are in its path. When seeding takes place in moist soil conditions it is expected that the disc opener disturbs the soil less than the tine opener. The tilt and sweep angle at which the disc cut the soil can also have an influence on the amount of surface roughness and furrow width (Ashworth et al. 2010). It is therefore important that both the tilt and sweep angles of the disc seeder is set correctly as this will influence the establishment of crops. Friedrich and Kassam (2011) found that tine and disc openers disturb soil less than 30% and are both suitable for conservation agriculture systems.

4.4.2 Plant population

No significant interaction was noted between soil quality and opener for both the 2016 and 2017 seasons. In the 2016 season the opener had an effect on the plant population (Table 4.3). The tine opener resulted in a higher ($P<0.05$) plant population than the disc opener on both high and low quality soils (Figure 4.4). In the 2017 season similar plant populations were achieved on both high and low quality soils (Figure 4.4). However, soil quality had an effect on the establishment using a disc opener as a higher ($P<0.05$) plant population was achieved on low quality soil than on high quality soil.

Table 4.3: Main effects and interactions between opener and soil quality for canola plant population for both 2016 and 2017.

2016	Effect	Degrees of freedom	F	P-value
	Soil quality	3	0.19	0.69
	Opener	6	27.04	0.00
	Soil quality x Opener	6	2.80	0.15
2017	Soil quality	3	2.69	0.20
	Opener	6	1.22	0.31
	Soil quality x Opener	6	3.28	0.12

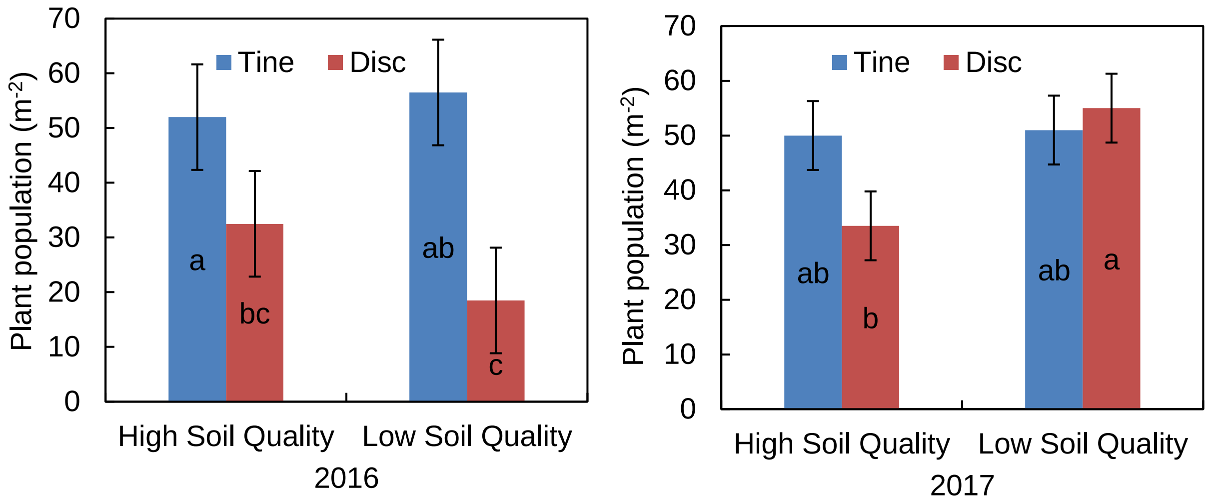

Figure 4.4: Canola plant population (m^{-2}) on high and low quality soil following establishment with a disc or tine seed-drill opener. Values followed by the same letter in each parameter did not differ at p = 0.05 The error-bars display the standard error within each treatment.

In the 2016 season the tine opener resulted in optimal plant population according to the guidelines for the Western Cape (Protein Research Foundation 2013). The disc opener did not perform well and such low plant populations can have a negative effect on yield. Fertiliser application with seeding in the 2016 season most likely caused chemical injury to the seeds as fertiliser was placed in close proximity to the seed (Hocking et al. 2003) as discussed in Chapter 3. The tine and disc openers both resulted in more than 50 plants m^{-2} on low quality soil in the 2017 season, while only the tine opener was able to result in more than 50 plants m^{-2} on high quality soil. French et al. (2016) found that plant populations of more than 50 plants m^{-2} did not have a significant effect on yield in a trial conducted in Western Australia, while Angadi et al. (2003) found that reducing plant populations from 80 to 40 plants m^{-2} did not have any effect on seed yield. Seeding took place under dry soil conditions with low gravimetric soil water content between 3.7 and 5.7% at time of seeding. In the 2016 season seeding took place later than what is considered best practice, which might have han influence on emergence and yield (Protein Research Foundation 2013). In the 2017 season seeding took place in line with best practice (early May), but it only rained for the first time one month after seeding. Although damage to seeds by predators and fungi or bacteria were not expected as the seeds were treated, the seeds might have suffered heat damage due to high soil temperatures. The residue obstructed the tine opener which caused the seed-drill to pull the residue into heaps. This may have caused poorer seed distribution on certain parts as the distribution pipe got blocked. This especially happened on the annual *Medicago* pastures.

4.4.3 Biomass production

No significant interaction was recorded between opener and soil quality in the 2016 season 30 days after emergence (Table 4.4). There were also no differences recorded between main treatments, although the tine opener had the tendency to produce more biomass than the disc opener (Figure 4.5). During the 2017 season the tine opener again resulted in higher biomass compared to the disc opener at 30 days after emergence(Table 4.4), but that was only true for high quality soil. Similar biomass was produced on low quality soil between the disc and tine openers treatments (Figure 4.5)

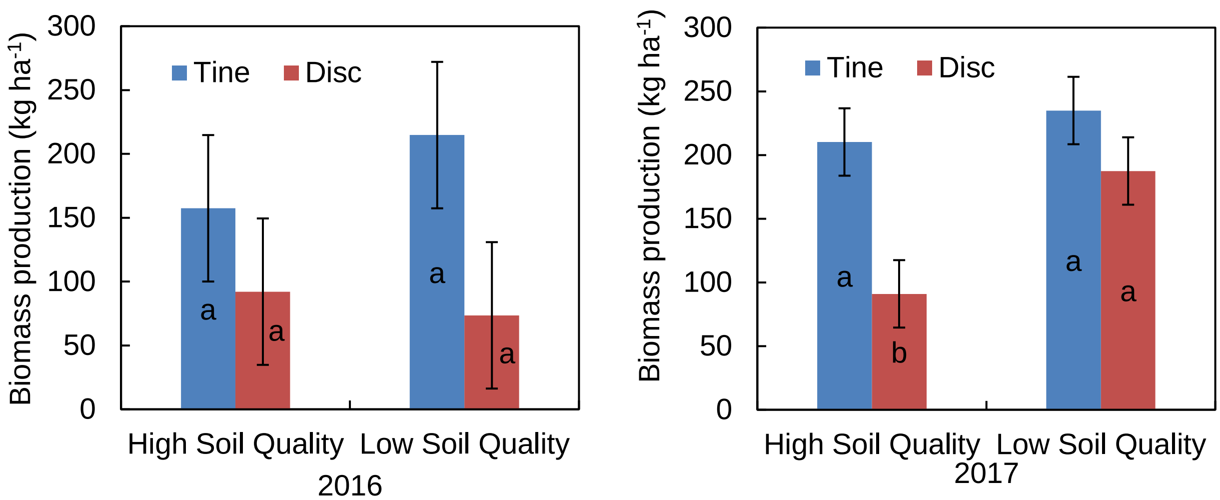

Figure 4.5: Biomass production at 30 days after emergence. Different letters above the vertical bars indicate the treatments with a significant difference (P < 0.05). Error bars indicate the standard error within each treatment.

No significant interaction was recorded at 60 days after emergence in the 2016 season (Table 4.4). Biomass produced by the tine opener treatment on low quality soil was higher than the amount of biomass produced by the other treatments ($p<0.05$). The biomass production on high quality soil was similar between disc and tine openers (Figure 4.6). In 2017 variation was high (Figure 4.6). On the high quality soil, the tine opener produced more biomass than the disc opener ($p<0.05$). The opposite was true for the low quality soil where the disc opener produced more biomass than the tine opener ($p<0.05$).

Table 4.4: Main effects and interactions between opener and soil quality for canola biomass production in the 2016 and 2017 season at 60 days after emergence.

2016	Effect	Degrees of freedom	F	P-value
	Soil quality	3	3.73	0.15
	Opener	6	4.84	0.07
	Soil quality x Opener	6	4.89	0.07
2017	Soil quality	3	4.18	0.13
	Opener	6	2.64	0.16
	Soil quality x Opener	6	53.70	0.00

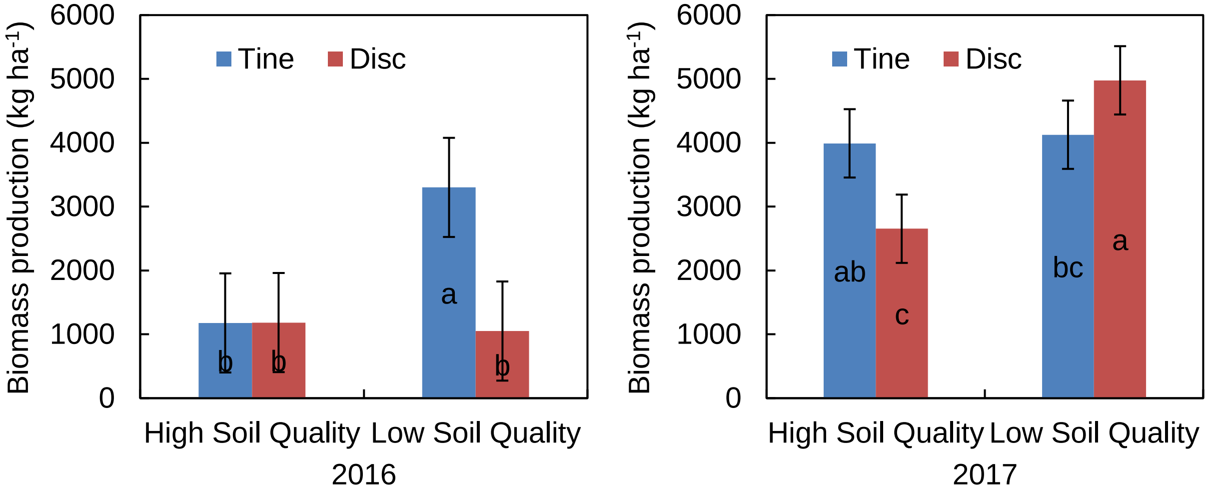

Figure 4.6: Biomass production at 60 days after emergence. Different letters above the vertical bars indicate the treatments with a significant difference (P < 0.05). Error bars indicate the standard error within each treatment.

At 90 days after emergence, no significant interaction was recorded between soil quality and opener for both the 2016 and 2017 season. Similar biomass production was achieved at 90 days after emergence between tine and disc openers on high quality soil during the 2016 season (Figure 4.7). Where the tine opener was used more biomass was produced than where the disc opener was used on low quality soil. No differences between openers has been recorded in the 2017 season. However, the effect of soil quality on biomass production at 90 days after emergence was significant. Treatments with disc openers produced more biomass on low soil quality than on high soil quality (Figure 4.7).

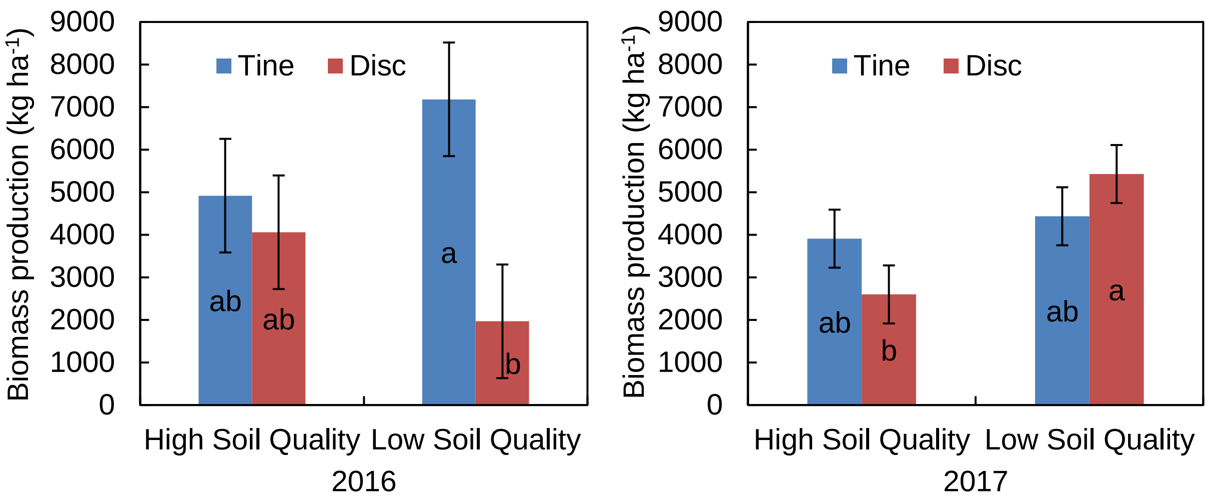

Figure 4.7: Biomass production at 90 days after emergence. Different letters above the vertical bars indicate the treatments with a significant difference ($P < 0.05$). Error bars indicate the standard error within each treatment.

At physiological maturity, no significant interaction was recorded between soil quality and opener for both the 2016 and 2017 season. Where the tine opener was used more biomass was produced on low quality soil than where the disc opener was used at physiological maturity in the 2016 season (Table 3.6; Figure 4.8). The biomass production on high quality soil was similar for disc and tine openers. In the 2017 season no differences were recorded at physiological maturity as all treatments produced similar amounts of biomass (Figure 4.8).

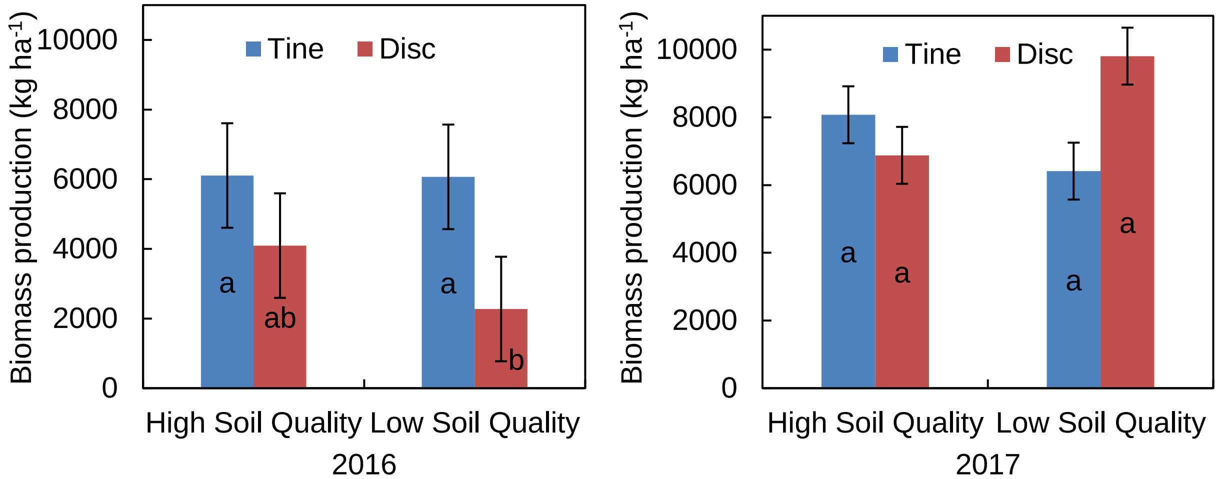

Figure 4.8: Biomass production at physiological maturity. Different letters above the vertical bars indicate the treatments with a significant difference (P < 0.05). Error bars indicate the standard error within each treatment.

Comparable biomass production was achieved at 90 days after emergence between the treatments with tine and disc openers on high quality soil during the 2016 season (Figure 4.7). Where the tine opener was used more biomass was produced than where the disc opener was used on the low quality soil. This was also recorded at 30 days after emergence and therefore it can be attributed to poor establishment as the disc opener on low soil quality was not able to catch up with the rest of the treatments. At physiological maturity in 2016 on low quality soil the disc opener produced less biomass than the tine opener as seen at 30, 60 and 90 days as well ($p<0.05$). This can be attributed to poor establishment caused by uneven placement of the seed. The rock fraction in low quality soil might have been higher and therefore the disc opener might have lifted out of the soil and placed the seeds at uneven depths. In the 2017 season the disc opener compensated well towards the end of the growing season. The overall lower biomass production by the disc opener during the 2016 season can be attributed to fertiliser application with the seed with seeding as Hocking et al. (2003) found that placing fertiliser with the seed reduces biomass production at all growth stages except at physiological maturity.

4.4.4 Leaf area index (LAI)

During the 2016 season LAI was not measured at 30 days after emergence, but in 2017 it was measured. No significant interaction was recorded between treatments (Table 4.5). The high soil quality plots planted with the tine opener had a higher LAI than the disc opener ($p<0.05$). The LAI for tine and disc openers on low quality soil was similar (Figure 4.9).

Table 4.5: Main effects and interactions between opener and soil quality for canola LAI for the 2017 season at 30 days after emergence.

2017	Effect	Degrees of freedom	F	P-value
	Soil quality	3	2.96	0.18
	Opener	6	6.49	0.04
	Soil quality x Opener	6	1.58	0.25

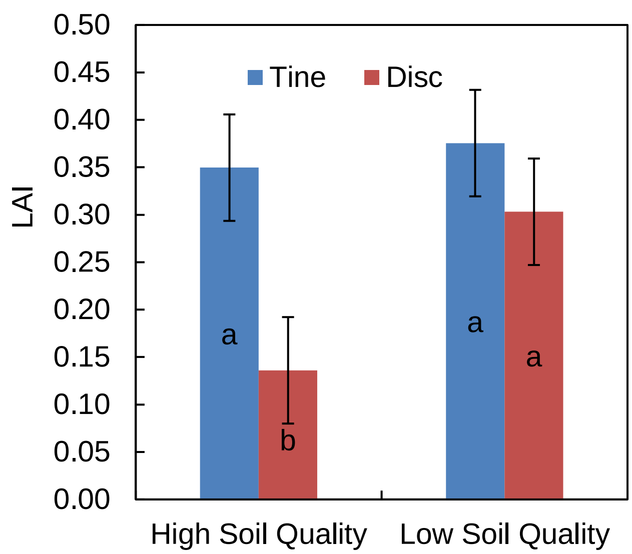

Figure 4.9: Leaf area index 30 days after emergence in 2017. Different letters above the vertical bars indicate the treatments with a significant difference (P < 0.05). Error bars indicate the standard error within each treatment.

No significant interaction was recorded between soil quality and opener at 60 days after emergence in the 2016 season (Table 4.6). There was also no difference between any treatments recorded (Figure 4.10). An interaction between soil quality and opener was recorded during the 2017 season (p<0.05). The LAI was higher in treatments with tine openers than disc opener treatments on high quality soil (p<0.05). The LAI on low quality soil was similar for both disc and tine openers (Figure 4.10).

Table 4.6: Main effects and interactions between opener and soil quality for canola LAI for both 2016 and 2017 at 60 days after emergence.

	Effect	Degrees of freedom	F	P-value
2016	Soil quality	3	2.86	0.19
	Opener	6	1.56	0.26
	Soil quality*Opener	6	3.04	0.13
2017	Soil quality	3	1.16	0.36
	Opener	6	0.95	0.37
	Soil quality*Opener	6	7.84	0.03

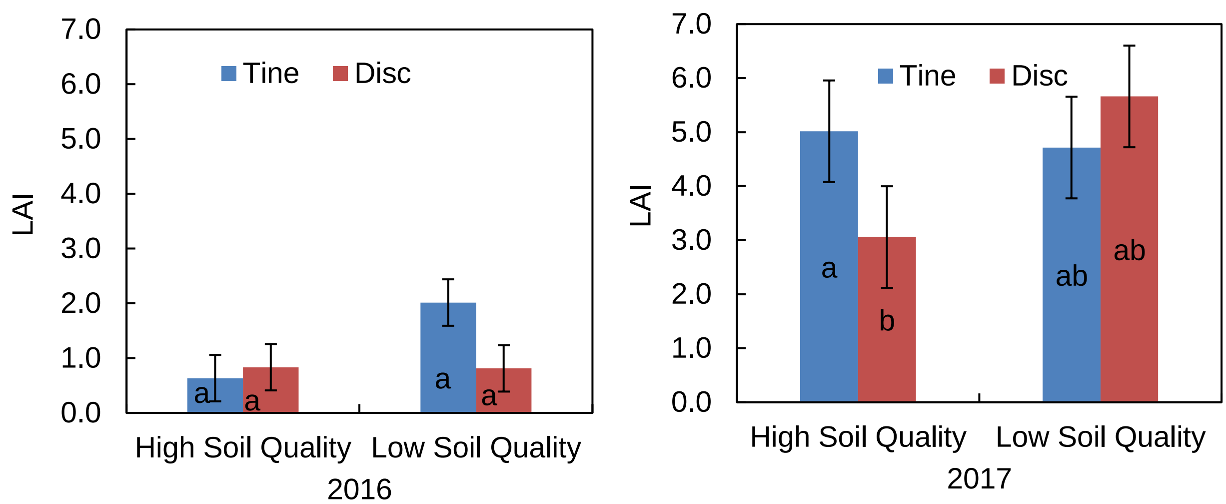

Figure 4.10: Leaf area index 60 days after emergence. Different letters above the vertical bars indicate the treatments with a significant difference (P < 0.05). Error bars indicate the standard error within each treatment.

At 90 days after emergence, no significant interactions were recorded for both 2016 and 2017 (Table 4.7; Figure 4.11). There were also no differences between treatments (Figure 4.11) and LAI in 2017 showed a sharp decline between 60 and 90 days after emergence.

Table 4.7: Main effects and interactions between opener and soil quality for canola LAI for both 2016 and 2017 at 90 days after emergence.

	Effect	Degrees of freedom	F	P-value
2016	Soil quality	3	0.95	0.40
	Opener	6	0.47	0.52
	Soil quality*Opener	6	0.32	0.59
2017	Soil quality	3	0.87	0.42
	Opener	6	0.33	0.59
	Soil quality*Opener	6	1.45	0.27

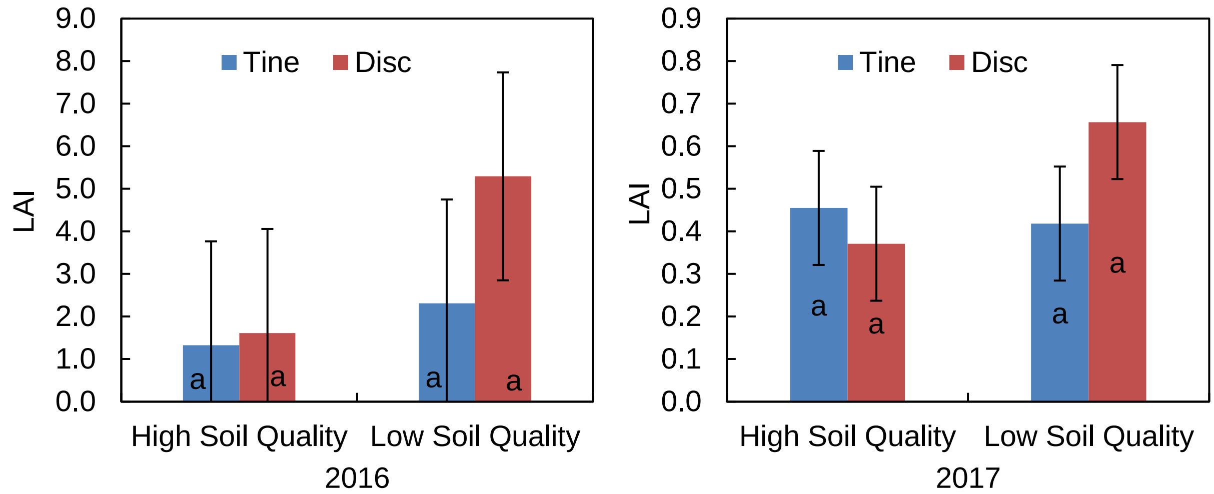

Figure 4.11: Leaf area index 90 days after emergence. Different letters above the vertical bars indicate the treatments with a significant difference (P < 0.05). Error bars indicate the standard error within each treatment.

Although the LAI recorded for the disc opener treatment was lower compared to the tine opener treatment at 30 days after emergence it increased with time and had a higher LAI 90 days after emergence on low quality soil in both 2016 and 2017. Walton et al. (1993) concluded that a LAI of 4 is required to intercept 90% of the incoming solar radiation. LAI is discussed in depth in Chapter 3.

4.4.5 Yield

No significant interaction between opener and soil quality was recorded for either 2016 and 2017 (Table 4.8). In the 2016 production year the treatment with the tine opener tended to have a higher seed yield than the disc opener on both high and low quality soils (Figure 4.12). Similar yields were recorded between the disc and tine openers during the 2017 season. No differences between treatments on high or low quality soil were recorded.

Table 4.8: Main effects and interactions between opener and soil quality for canola yield for both 2016 and 2017.

2016	Effect	Degrees of freedom	F	P-value
	Soil quality	3	0.23	0.66
	Opener	6	0.64	0.46
	Soil quality x Opener	6	0.00	1.00
2017	Soil quality	3	0.02	0.90
	Opener	6	0.05	0.83
	Soil quality x Opener	6	0.05	0.83

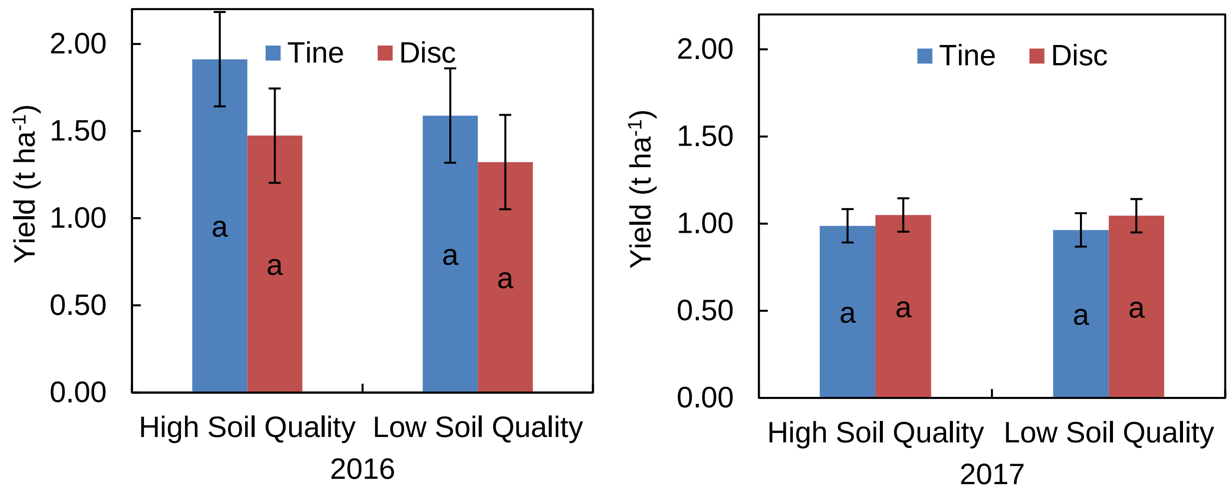

Figure 4.12: Yield obtained during the study. Different letters above the vertical bars indicate the treatments with a significant difference ($P < 0.05$). Error bars indicate the standard error within each treatment.

The lower yield for the disc opener in the 2016 season, although not significant could be attributed to the fertiliser applied with seeding instead of broadcasting the fertiliser before seeding as discussed in depth in Chapter 3. The yields obtained in 2017 were much lower than in 2016 and could be attributed to the dry season where rainfall of only 180.4 mm were measured within the growing season (May – October). Canola needs to be sown timeously to maximise growing time and therefore seed yield (Hocking and Stapper 2001). A strong correlation between biomass production and seed yield can usually be made. However, it was not the norm in this trial as more biomass was produced at physiological maturity in the 2017 season compared to the 2016 season, while the yield was lower. This can be due to higher rainfall in the middle of the season which led to higher biomass production and a drier finish to the season which led poor pod fill and therefore lower yield.

Soil quality had no effect ($P>0.05$) on canola seed yield, contrary to what was expected. In a parallel study on wheat on the same farm by Swanepoel et al. (2017), soil quality made a significant difference to wheat yield. In the latter study, the importance of ensuring soil quality through sound management practices was stressed. It has been reported that the SMAF index is a useful predictor of soil quality, as it translates well into yield of many crops including wheat (Şeker et al. 2017, Masto et al. 2007), cultivated pastures (Swanepoel et al. 2015), sugar beet (*Beta vulgaris*) (Şeker et al. 2017) as well as pea (*Pisum sativum*) and maize (*Zea mays*) (Merrill et al. 2013). The usefulness of SMAF to predict soil quality is therefore not contested. However, the reasons why canola does not respond to soil quality is not clear and warrants further investigation.

4.4.6 Thousand seed mass (TSM)

No significant interaction were recorded between opener and soil quality for both 2016 and 2017 (Table 4.9; Figure 4.12). No differences for TSM was recorded between main treatments for the 2016 season (Figure 4.13). During the 2017 season TSM was higher for the disc opener treatment than the tine opener treatment on high soil quality ($p<0.05$). No differences were recorded between tine and disc openers on low quality soil for the same period.

Table 4.9: Main effects and interactions between opener and soil quality for canola yield for the 2016 and 2017 season.

2016	Effect	F	P-Value
	Soil quality	0.44	0.55
	Opener	0.12	0.74
	Soil quality x Opener	0.39	0.56
2017	Soil quality	1.81	0.27
	Opener	3.56	0.11
	Soil quality x Opener	3.24	0.12

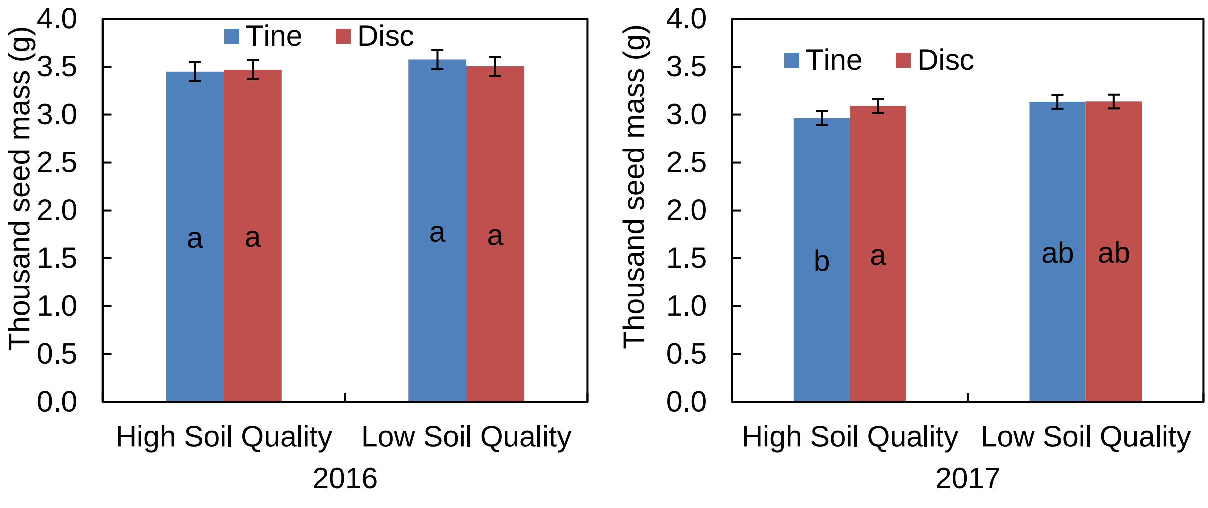

Figure 4.13: Thousand seed mass measured for both the 2016 and 2017 seasons. Different letters above the vertical bars indicate the treatments with a significant difference ($P < 0.05$). Error bars indicate the standard error within each treatment.

Thousand seed mass measured in this study is regarded as normal as similar results were found in a study conducted in Canada (Angadi et al. 2003).

4.5 Conclusion

During the two-year period in which this trial was conducted the rainy seasons was significantly different. The 2016 season's rainfall was close to the long-term mean which can be regarded as normal. However, the 2017 season was dry, receiving only 180.4 mm during the growing season. Overall the treatment with the tine opener seems to have performed better than the disc opener during 2016. The reason for the disc opener not performing as well as the tine opener in 2016 could have been attributed to fertiliser that was applied with the seed with seeding, which might have caused chemical injury. It can also be attributed to the season with the first rainfall of the growing season at the end of May. The treatment with the disc opener had comparable results to that of the tine opener 2017, which was a dry year, possibly since fertiliser was broadcast on the fields before seeding with the disc opener. Contrary to general belief there was no difference between the amount of disturbance caused in terms of surface roughness and furrow width between the tine and disc openers. Thus, it can be regarded that the two openers caused comparable amount of soil disturbance. In the end, similar yields were obtained during both seasons and therefore farmers can choose either a disc or a tine opener to establish canola. Factors that should be considered are maintenance cost of the different openers and running cost with regards to fuel consumption. Further research is suggested which should focus on an economic evaluation of disc and tine openers to give farmers further insight when choosing between the two.

4.6 References

Andrews SS, Karlen DL, Cambardella CA. 2004. The soil management assessment framework. Soil Science Society of America Journal 68: 1945-1962

Angadi SV, Cutforth HW, McConkey BG, Gan Y. 2003. Yield adjustment by canola grown at different plant populations under semiarid conditions. Crop Science 43:1358-1366.

Ashworth M, Desbiolles J, Tola E. 2010. Disc Seeding in Zero-Till Farming Systems: A review of technology and paddock issues. West Australian No-Tillage Farmers Association.

Cooper GD. 2017. Long-term effect of tillage and crop rotation practices on soil C and N in the Swartland, Western cape, South Africa. MSc(Agric) Thesis, Stellenbosch University, Stellenbosch

Dell Inc. 2016. Dell Statistica (data analysis software system), version 13. Software.dell.com

French RJ, Seymour M, Malik RS. 2016. Plant density response and optimum crop densities for canola (*Brassica napus* L.) in Western Australia. Crop & Pasture Science 67: 397–408.

Friedrich T, Kassam, A. 2011. Mechanization and the global development of conservation agriculture. In 23rd Annual SSCA Conference, 13 January, Saskatoon, Canada. FAO pp 1-15

Hocking PJ, Mead JA, Good AJ, Diffey SM. 2003. The response of canola (*Brassica napus* L.) to tillage and fertiliser placement in contrasting environments in southern NSW. Animal Production Science 43: 1323-1335.

Hocking PJ, Stapper M. 2001. Effects of sowing time and nitrogen fertiliser on canola and wheat, and nitrogen fertiliser on Indian mustard. I. Dry matter production, grain yield, and yield components. Australian Journal of Agricultural Research 52:623-634.

IUSS Working Group WRB. 2006. World reference base for soil resources, 2nd edition. World Soil Resources Report 103, Rome: FAO.

Masto RE, Chhonkar PK, Singh D, Patra AK. 2007. Soil quality response to long-term nutrient and crop management on a semi-arid Inceptisol. Agriculture, Ecosystems & Environment 118(1): 130-142.

Merrill SD, Liebig MA, Tanaka DL, Krupinsky JM, Hanson JD. 2013. Comparison of soil quality and productivity at two sites differing in profile structure and topsoil properties. Agriculture, Ecosystems & Environment 179: 53-61.

Moreno RG, Alvarez MD, Alonso AT, Barrington S, Requejo AS. 2008. Tillage and soil type effects on soil surface roughness at semiarid climatic conditions. Soil and Tillage Research 98: 35-44.

Protein Research Foundation. 2013. Canola Production Guide. SunMedia, Stellenbosch.

Razavi S, Yeganehzad S, Sadeghi A. 2009. Moisture dependent physical properties of canola seeds. Journal of Agricultural Science and Technology. 11: 309-322.

Reicosky DC. 2015. Conservation tillage is not conservation agriculture. Journal of Soil and Water Conservation 70: 103A-108A.

Şeker C, Özaytekin HH, Negiş H, Gümüş İ, Dedeoğlu M, Atmaca E, Karaca Ü. 2017. Assessment of soil quality index for wheat and sugar beet cropping systems on an entisol in Central Anatolia. Environmental Monitoring and Assessment 189(4): 135.

Soil Classification Working Group. 1991. Soil classification: a taxonomic system for South Africa: memoirs on the agricultural natural resources of South Africa No. 15. Department of Agricultural Development, Pretoria, South Africa.

Soil Survey Staff. 2003. Keys to soil taxonomy. Washington, United States of America: Department of Agriculture.

Swanepoel PA, du Preez CC, Botha PR, Snyman HA, Habig J. 2015. Assessment of tillage effects on soil quality of pastures in South Africa with indexing methods. Soil Research 53: 274-285.

Swanepoel PA, Labuschagne J, Hardy M. 2016. Historical development and future perspective of Conservation Agriculture practices in crop-pasture rotation systems in the Mediterranean region of South Africa. In: Ecosystem services and socio-economic benefits of Mediterranean grasslands. Kyriazopoulos, A., Lopez-Francos, A., Porqueddu, C., Sklavou, P. (eds.). Zaragoza: CIHEAM: 2016, 454 (+ xii) p. Options Méditerranéennes, Series A, No 114.

Swanepoel PA, Tshuma, F. 2017. Soil quality effects on regeneration of annual *Medicago* pastures in the Swartland of South Africa. African Journal of Range & Forage Science.1-8.

Tessier S, Saxton KE, Papendick RI, Hyde GM. 1991. Zero-tillage furrow opener effects on seed environment and wheat emergence. Soil and Tillage Research 21: 347-360.

Walton G, Mendham N, Robertson M, Potter T. 1999. Phenology, physiology and agronomy. In 'Canola in Australia: the first 30 years'. pp 9–14.

Walton G, Mendham N, Robertson M, Potter T. 1999. Phenology, physiology and agronomy. Canola in Australia: the first thirty years'.(Eds PA Salisbury, TD Potter, G McDonald, AG Green) pp.9-14.

Chapter 5

Conclusion and Recommendations

5.1 Synopsis

Canola (*Brassica napus* L.) is becoming more and more popular as a crop in the southern Cape and Swartland due to its benefits in a crop rotation system. It is also gaining popularity amongst consumers as it is deemed a healthy oil to use on salads and as cooking oil (Dupont et al. 1989; Opperman 2016). Canola can be difficult to establish due to the small size of the seed. Improving agronomical management practices to improve canola establishment thus ensuring a high yield, is of utmost importance.

The aim of this study was to determine whether the tine or disc seed-drill opener will establish canola the best in varying soil quality and residue levels. The effect from the opener, soil quality and residue on biomass production, leaf area index (LAI), yield and thousand seed mass (TSM) was determined. The information derived from small experimental plots are often not applicable to entire fields in the Western Cape as the soil vary substantially. Therefore, the study was repeated on field scale without the residue factor as it is practically not possible to manipulate the residue on field scale plots. On field scale soil disturbance was determined by measuring soil surface roughness and furrow width with a pin profiler.

The Equalizer seed-drill used in this trial has interchangeable tines and discs eliminating bias of weight difference using different seed-drills. This allowed evaluation of the true effect of the openers (tine and disc) rather than a comparison of seed-drills, which might have given different results due to differences in weight and seed delivery mechanisms. Similar studies have been done evaluating the difference between tines and discs with different seed-drills, but the actual evaluation was between the seed-drills and not specifically the openers (Labuschagne 2017).

The 2016 season was characterised by late rain at seeding time (May) which resulted in a later than optimal seeding date. Annual rainfall in 2016 was 376 mm with 270.8 mm in the growing season, similar to the long term average. Late rainfall was also experienced in the 2017 season and the annual rainfall was only 214.9 mm (excluding December) with 180.4 mm in the growing season. In both years minimum and maximum temperatures were also similar to the long-term average. The 2017 season also had late rain and much less than the average annual rainfall.

Research question 1: Will a tine or disc opener create a better seedbed for canola?

The tine opener established canola better than the disc opener in the 2016 season regardless of residue level or soil quality. In 2016 fertiliser was applied with seeding which might have caused chemical injury to the seed, hence the lower yield. Fertiliser application was changed in the 2017 season for the disc opener. Prior to seeding with the disc opener fertiliser was broadcast on the fields. The tine and disc opener performed similarly in the 2017 season with regards to results in plant population, biomass production, LAI, yield and TSM. It can therefore be said that the tine opener created a better seedbed in 2016, while similar seedbeds were created by both the tine and disc openers in 2017. Seeding took place in dry soil each year, but when seeding was to take place in soil with an ideal soil moisture content the result might be different.

Research question 2: Does soil quality along with residue level determine whether a tine or disc opener should be used to ensure optimal production of canola?

Residue can become a problem when establishing canola with both the tine and disc openers, and establishment was the best at low residue levels. With regards to disturbance either a tine or disc opener can be used. In this trial tine openers performed better on high quality soil while disc openers performed better on low quality soil with regards to plant population. Similar yields were achieved on both high and low quality soil regardless of the opener used on low residue plots. On medium and high residue plots yields varied between treatments and no treatment could be regarded as superior to the other. In summary a disc or tine opener used in this study can be used for planting canola in the Swartland.

On field scale tests similar results were recorded as on experimental plots, with low residue levels, with regards to plant population, biomass production, LAI, yield and TSM. There was no difference between the amount of disturbance caused in terms of soil surface roughness and furrow width between the tine and disc openers. Thus, it can be regarded that the two openers cause the same amount of soil disturbance, contrary to belief that the disc opener will disturb soil less when soil moisture conditions is ideal.

Canola is not produced in isolation, but rather as part of a crop rotation system. Therefore, it is important to take the parallel wheat trial into consideration when evaluating results of this study (Swanepoel et al. 2017).

5.2 Limitations

The wheat straw was placed on the plots a month prior to planting and should have actually been placed on the plots just after harvest the previous year to get a more accurate effect. The fact that the straw did not decompose to such a extent as in practice is a definite limitation.

Fertiliser was placed with the seed when seeding with the disc opener in the 2016 season which could have caused chemical injury (burning) to the seed. The amount of fertiliser applied differed as the 2017 crop did not receive a second top dressing at the onset of stem elongation due to the dry season experienced. Fertilisation was, however, based on best practice guidelines for the region.

Two different canola varieties were used, i.e. Hyola 559TT in 2016 and Atomic TT in 2017. It is recommended that the same variety is used on the trial to eliminate variables. However, according to cultivar evaluations, both cultivars had a similar production potential in the region.

Field scale tests have its limitations, such as the uncertainty of linking a result to a specific factor and can often only be ascribed to multifaceted and complex interaction of many effects. Despite the limitations, field scale trials are more relevant to farmers' situation.

5.3 Recommendations for future research

Further research is suggested on the economics of tine and disc openers to give farmers further insight when choosing between tine and disc openers. Another factor that has to be considered are the use of pre-emergence herbicide. Farmers with a large grass seedbank on their fields make use of trifluralin which can only be applied with tine openers as it is light sensitive. Research on similar pre-emergence herbicide, (which is as effective as trifluralin) that can be used with disc openers is suggested.

It is recommended that this study is repeated in the southern Cape since soil and climatic conditions differ substantially from the Swartland. It is also recommended that this study is repeated in other years in the Swartland as the two seasons differed substantially with regards to climatic conditions. The late rainfall in May 2016 and the dry year experienced in 2017 might have had an influence on the results obtained. In both years planting took place in dry soil which is not ideal. It is also suggested that the same opener is used on the same plots each year. Although both the disc and the tine openers are regarded as minimum-tillage they have different mechanical actions. Planting with a disc opener on the same soil each year may hold more benefits. If similar results were to be found in normal rainfall years, economics of tine and disc openers are to be evaluated to give farmers further insight when choosing between tine and disc openers. The economic factors that have to be considered include maintenance cost of the different openers and fuel consumption by tractors pulling these seed-drill openers as tine openers require more power (kW), hence more fuel, than disc openers.

The N application and timing thereof should also be researched in depth as this may have had an influence on emergence and yield. Little research has been done in South Africa on N application and new guidelines for canola are needed as current guidelines are adapted from international literature or guidelines for wheat

(Coetzee 2017). Band placing N with the disc opener also needs further research as in-depth research under South African conditions has not yet been done.

As only aboveground biomass was measured for this trial it is recommended that further studies on root biomass and root elongation are investigated. Root elongation between plants seeded with different seed-drill openers may vary. Root elongation is a vital part of canola establishment as it will determine at what depth the plant will be able to retrieve water from, especially in a dry year. Root biomass is important as there is a correlation between root biomass and aboveground biomass.

Different crop rotation systems can also be researched as the only preceding crops in this trial were wheat and medics, which is the most common rotational system in the Swartland. Different preceding crops could have different influences on establishment and also yield. It is therefore recommended that this trial is repeated over several years on farm scale to be able to evaluate the complete scope of the system.

Results show that low residue is to be advised while farmers strive to retain as much residue as possible for the advantageous effects. Soil cover reduce soil temperature and therefore reduce water loss while it also reduces erosion by wind and rain (Cutforth et al. 1997). Residue management starts when the crop is harvested. More attention should therefore be given to improve choppers and spreaders on combine harvesters as it is important to chop residue short enough and spread it evenly for seed-drills to be able to seed through the residue the following year. Combine manufactures have been improving the choppers and spreaders on the new combine models. There are also chopper and spreader kits available to improve the function of older combine models. Although such new technology will be a great capital expenditure it is important for farmers to strive towards implementing the new technology, as it will improve their Conservation Agriculture (CA) systems. Application of chemicals that stimulate residue break down can also be considered, while partial burning of residue can be implemented although it is not ideal. Livestock also has a role to play in a CA system with regards to residue management (Hunt et al. 2016). Currently South African farmers tend to keep livestock on harvested fields for too long, leaving the soil compacted with little cover. Therefore, further research is suggested on the managing practices of residue in South Africa.

5.4 References

Coetzee A. 2017. Rate and timing of nitrogen fertilisation for canola production in the Western Cape of South Africa. MSc Thesis, Stellenbosch University, South Africa

Cutforth HW, McConkey BG. 1997. Stubble height effects on microclimate, yield and water use efficiency of spring wheat grown in a semiarid climate on the Canadian prairies. Canadian Journal of Plant Science 77: 359-366.

Dupont J, White PJ, Johnston KM, Heggtveit HA, McDonald BE, Grundy SM, Bonanome A. 1989. Food safety and health effects of canola oil. Journal of the American College of Nutrition 8: 360-375.

Hunt JR, Swan AD, Fettell NA, Breust PD, Menz ID, Peoples MB, Kirkegaard JA. 2016. Sheep grazing on crop residues do not reduce crop yields in no-till, controlled traffic farming systems in an equi-seasonal rainfall environment. Field Crops Research 196: 22-32.

Labuschagne J, Langenhoven W, Van Zyl H, Mokwele A. 2017. Influence of degree of soil disturbance on crop productivity, yield, and quality of wheat and canola within cropping systems in the Western Cape. Combined Congress, 24-26 January 2017, ATKV Resort, Bella-Bella, Limpopo.

Opperman M, Benadé AJS, Abrecht CF, Matsheka LL. 2016. South African seed oils are safe for human consumption. South African Journal of Clinical Nutrition 29: 7-11.

Swanepoel PA, Agenbag GA, Strauss JA. 2017. Considering soil quality for choosing between disc or tine seed-drill openers to establish wheat. South African Journal of Plant and Soil 1-4