Evaluation of tine and disc openers for wheat production in soils of different qualities and with various crop residue levels.

by

Lulama Magenuka

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Supervisor: Dr Pieter Andreas Swanepoel

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Declaration

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Abstract

The Swartland wheat producing area in the Western Cape is characterised by a Mediterranean-type climate and receives about 80% of the rainfall in winter season, which is particularly favourable for wheat (*Triticum aestivum*) production. Currently, most farmers are implementing conservation agriculture (CA) systems seeking to minimise soil disturbance, increase crop diversity and to retain crop residues on the soil surface. No-till seed-drills are used to establish wheat. Although most farmers rely on tine openers seed-drills to establish wheat, disc openers are becoming more popular due to the belief that discs will disturb less soil when compared to tine openers. The aim of the study was to compare tine and disc openers and the effects of soil quality and crop residue on wheat production, by evaluating establishment, biomass production, leaf area index (LAI), wheat grain yield, thousand kernels mass (TKM), ear-bearing tillers (EBT), Hectolitre mass (HLM) and soil disturbance. The first objective was to evaluate the degree of soil disturbance caused by tine or disc openers in the soils of different qualities. The second objective was to evaluate the establishment of wheat planted with a tine or disc opener in different quality soils with different residue levels. Trials were conducted in 2016 and 2017 at Langgewens Research Farm in the Swartland. In both years, wheat was established in dry soils. The seasonal rainfall for 2017 was lower than for 2016. Contrary to what was expected, soil disturbance did not differ ($P>0.05$) between tine or disc openers, regardless of soil quality. The tine and disc openers performed similarly in the 2016 and 2017 seasons with regard to plant population, LAI, EBT, grain yield, and TKM regardless of soil quality with residue level ($P>0.05$). Biomass production at physiological maturity showed treatment effects ($P<0.05$) in 2016. On low quality soils where disc openers were used, a significant increase in biomass production was recorded compared tine openers on medium residues. In the 2017 season, residue level has caused poor wheat establishment that resulted in lower biomass production compared to 2016. Disc openers achieved the lowest ($P<0.05$) HLM on low quality soils with low residue levels compared to tine openers. Disc openers also resulted in the highest ($P<0.05$) HLM on high soil quality with high residue level. Therefore, either a disc or tine opener can be used by wheat producers for planting wheat in the Swartland. 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.

Uittreksel

Die Swartland koringproduksie-area in die Wes-Kaap word deur ŉ Mediterreënse klimaat gekenmerk en ontvang omtrent 80% van die reënval in die winterseisoen, wat veral gunstig vir koring-(*Triticum aestivum*)-produksie is. Tans implementeer meeste boere bewaringsboerderypraktyke wat minimum-grondversteuring, verhoogde gewasdiversiteit en behoud van oesreste op die grondoppervlak insluit. Geen-bewerkingsaaimasjiene word gebruik om koring te vestig. Alhoewel meeste boere op tandoopmakers staatmaak om koring te vestig, word skyfoopmakers meer populêr omdat daar geglo word dat skyfoopmakers die grond minder as tandoopmakers versteur. Die doel van die studie was op die effek van grondkwaliteit en oesreste op koringproduksie te evalueer, deur vestiging, biomassa-produksie, blaaroppervlakindeks (LAI), graanopbrengs, duisendkorrelmassa (TKM), aardraende halms (EBT), skepelmassa (HLM) en grondversteuring te evalueer. Die eerste objektief was om die hoeveelheid grondversteuring wat deur tand- en skyfoopmakers veroorsaak word in gronde met verskillende kwaliteite, te evalueer. Die tweede objektief was om vestiging van koring wat met tand- of skyfoopmakers geplant word in gronde met verskillende kwaliteite en deur verskillende oesresvlakke, te evalueer. Proewe was in 2016 en 2017 op Langgewens Navorsingsplaas in die Swartland uitgevoer. In beide jare was koring in droë grond gevestig. Die seisoenale reënval vir 2017 was laer as vir 2016. Bo verwagting het grondversteuring nie tussen tand- en skyfoopmakers verskil nie (P>0.05), ongeag grondkwaliteit. Die tand- en skyfoopmakers het in beide 2016 en 2017 soortgelyk in terme van plantpopulasie, LAI, EBT, graanopbrengs en TKM presteer, ongeag grondkwaliteit en oesresvlakke. Biomassaproduksie by fisiologiese rypstadium het behandelingseffekte in 2016 getoon (P<0.05). Waar skyfoopmakers op lae grondkwaliteit gebruik was, was biomassaproduksie hoër as wanneer tandoopmakers deur mediumvlakke van oesreste gebruik was. In 2017 het oesresvlakke ŉ swakker vestiging as in 2016 veroorsaak, wat tot ŉ laer biomassaproduksie gelei het. Skyfoopmakers het die laagste (P<0.05) HLM op lae grondkwaliteit veroorsaak. Skyfoopmakers het ook die hoogste (P<0.05) HLM op hoë grondkwaliteit met hoë oesresvlakke veroorsaak. Daarom kan óf ŉ tand óf ŉ skyfoopmaker deur koringprodusente in die Swartland gebruik word. Verdere navorsing word voorgestel om die ekonomie van tand- en skyfoopmakers te bepaal, om sodoende boere verdere insig te gee wanneer daar tussen die oopmakers gekies moet word.

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Abbreviations:

C Carbon

CA Conservation Agriculture

Ca Calcium

CEC Cation exchange capacity

CO_2 Carbon dioxide

DAP Days after planting

EBT Ear-bearing tillers

HLM Hectolitre mass

K Potassium

LAI Leaf area index

Mg Magnesium

N Nitrogen

Na Sodium

P Phosphorus

PMN Potentially mineralisable Nitrogen

SAR Sodium adsorption ratio

SMAF Soil management assessment framework

SOM Soil organic matter

SQI Soil quality index

TKM Thousand kernel mass

Chapter 1

Introduction

1.1 Context and problem statement

Wheat (*Triticum aestivum*) is the second most important grain crop produced in South Africa following maize (*Zea mays*). The three main wheat producing provinces include the Western Cape (winter rainfall), Free State (summer rainfall) and the Northern Cape (irrigation). The Swartland wheat producing area in the Western Cape are characterised by a Mediterranean-type climate and receives about 80% of the rainfall between April and October, which is particularly favourable for wheat production. Most wheat produced in South Africa is bread wheat, with small quantities of durum wheat (*Triticum durum*) being produced in certain areas and is used to produce pasta. In South Africa, wheat is mainly utilised for human consumption. Low quality wheat seed is used for animal feed (Makgoba, 2013).

The world population is gradually increasing. Currently it stands at more than 7.5 billion. The population in South Africa alone is more than 55 million (Statistics South Africa, 2016). The pressures caused by the high growth rate of the world's population on food demand lead to poor soil quality due to the injudicious management practices to produce more food (Loke *et al*., 2012). Inadequate knowledge of farmers also contributes to the problem and farmers do not necessarily know what the best management practices are. As soil is the foundation of field crop production, soil quality needs to be ensured. Soil quality improves significantly following the adoption of conservation agricultural (CA) practices (Gura, 2016). Karlen *et al.* (1994) defined soil quality as the ability of the soil to function which includes physical, chemical and biological processes.

The use of conventional tillage practices degrade the structure of the soil and also accelerates breakdown of soil organic matter (SOM) (Botha, 2013). Furthermore, concerns have also been raised on the contribution of conventional tillage practices to greenhouse gas emissions and their impact on global warming and climate change (Maraseni and Cockfield, 2011). Exposure of the soil surface (no crop residues) and the disturbance of the soil through conventional tillage increase the susceptibility of soil to erosion (Botha, 2013). These concerns gave rise to the new technologies that form part of conservation agriculture (CA) systems.

Many of the new technologies leads to an improvement of soil quality. Conservation agriculture can be defined as a combination of management practices including reduced tillage, residue or cover crop management and crop rotation. Conservation agriculture can help restore, maintain, or improve soil quality, as well as crop production (Gura, 2016; Botha, 2013; Dumanski *et al*., 2006).

Western Cape wheat producers use to be planting wheat commercially in monocultures (Swanepoel *et al*., 2017). Currently, most producers have adopted CA to increase water and soil conservation. Wheat producers in the Western Cape rely on tine openers to establish wheat. However, tine openers sometimes pull crop residues onto heaps, which obstruct the planter and result in uneven establishment. This is particularly true for production systems, which have followed CA for many years, and have high levels of crop residues on the field.

Due to the success with disc openers in South America and Australia, the interest has increased for using disc openers to establish wheat in the Western Cape region (Swanepoel *et al*., 2017). Disc openers is a new seed-drill technology that has not been scientifically vindicated under the Western Cape conditions. This justifies a study to investigate the effects of the soil quality and residue management on the performance of tine and disc openers for wheat production.

1.2 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 wheat production, by evaluating establishment, biomass production, leaf area index (LAI), wheat grain yield, thousand kernels mass (TKM), ear-bearing tillers (EBT), hectolitre mass (HLM) and soil disturbance.

The first objective was to evaluate the degree of soil disturbance caused by tine or disc openers in the soils of different qualities.

The second objective was to evaluate the success of establishment of wheat planted with a tine or disc openers in different quality soils with different residue levels.

Chapter 2

Literature review

2.1 Methods for wheat establishment

Earlier in the 20th century, soils were tilled using different combinations of ploughing, ripping, and scarifying to prepare a suitable seedbed for wheat (Tolmay *et al*., 2010; Steyn *et al*., 1995). Crops were then established by broadcasting the seed and fertiliser following soil preparation that involved soil tillage (Tolmay *et al*., 2010; Steyn *et al*., 1995). Previously, different tillage systems have been compared in South African wheat production systems including conventional tillage with mouldboard and chisel plough (depth 250 mm) (Steyn *et al*., 1995). A mouldboard plough loosens up the soil to a relatively deep depth (Approximately 200 mm in the Western Cape's shallow soils), compared to shallow tillage systems. Mouldboard ploughing consequently lead to lower initial soil bulk densities, but higher bulk densities in the long-run, as well as increased breakdown of organic matter and higher saturated hydraulic conductivity (Botha, 2013).

In a study conducted by Parvin *et al*. (2014) it was indicated that wheat plant density and crop yield in shallow or no-tillage treatments was higher (3840 kg ha^{-1}) when compared to mouldboard treatment (2480 kg ha^{-1}). Long-term no-tillage practices influences crop performance and yield in a positive manner by enhancing soil quality. In recent years conventional tillage did not fit into the modern set of conservation agriculture (CA) principles, where no-tillage or zero-tillage seed-drill openers (tines and discs) are used to establish wheat. According to Tessier *et al*. (1991) these seed-drill openers are designed in a way that have direct consequences on the soil surface disturbance, furrow opener compaction levels and soil water content in the seed row.

No-tillage farming systems are being followed widely in the Western Cape by wheat farmers. It is particularly important to these farmers because no-tillage leads to improved water use efficiencies and soil conservation under dryland conditions. Altikat *et al*. (2013) lamented that no-tillage systems are of economically importance, because the systems are erosion-controlling plant production systems. Crops are planted into retained plant stubble conditions with no or minimum soil disturbance, which aids in physical protection of soil from wind and water erosion.

Tine openers are currently the most popular seed-drill for no-tillage planting. Tine openers disturb more soil and have less controlled seed placement compared to disc openers (Tessier *et al.*, 1991; Chen *et al.*, 2004; Swanepoel *et al.*, 2017). Both tine and disc openers are considered to be suitable for CA systems. Desbiolles (2011) defined tine openers as technology that is used to loosen soil in furrows and incorporates soil onto the inter row while shaping water harvest furrows. Press wheels ensure good seed-to-soil contact. The seed-drills with tine furrow openers tend to provide a good sowing performance and seed emergence in comparison with the disc-type furrow openers (Altikat *et al*., 2013). The sowing performance and seed emergence under tine openers gave the best results with low standing stubble levels, whereas it decreased with increased stubble levels (Altikat *et al*., 2013). One of the advantages of tine openers is that they have an ability to handle compacted, sticky or stony soils (Choudhari, 2001). 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 (Bahri and Bansal, 1992).

In contrast, disc openers enable direct seeding operations with potentially very low soil and residue disturbance (Desbiolles, 2011). Chen *et al*. (2004) suggested that disc openers result in uniform plant emergence and high biomass production when compared to tine openers. Therefore, the seed-drill disc openers are gaining more ground in the Western Cape, particularly among the long-term no-tillage wheat and canola producers, who are seeking to fine-tune the performance of their conservation farming systems. Disc openers hold several advantages when compared to tine furrow openers. One of the most important advantages include the ability to mechanically handle a high amount of residue without any blockage of the seeding units (Choudhari, 2001). This advantage provides the ability of an opener to seed accurately at a shallow depth than tine openers. Soil structure and soil biological activity may also be improved following the use of disc openers. Desbiolles (2011) mentioned other benefits for using disc openers and include:

- Minimised soil disturbance
- High speed capability with associated efficiencies and cost-savings per hectare
- Ability to handle stones and create minimal field roughness at planting
- Ability to cut and plant unhindered through high stubble levels
- Narrow seed row spacing capability, therefore better seedbed-utility

The performance for a disc openers are associated with good residue cutting, good seeding depth control and uniform placement of seed (Bahri and Bansal, 1992).

Current research shows that the superior seeding accuracy and uniformity expected with disc openers is not always guaranteed (Desbiolles, 2011). This can be experienced when operating in challenging conditions such as sticky and high stone fraction soils. Carter (1994) noted in a review of CA that high intensities of crop residue retained or incorporated into the soil have major constraints to the adoption of CA, because crop residues mechanically hinder with the seedling operations. Therefore, improving seedling equipment or residue removal may be necessary for a good direct drilling practices to establish wheat.

Disc openers have certain disadvantages when used to establish wheat under CA. This include hairpinning where part of the residues are pushed into the opened furrow where it contacted seed and reduced crop emergence (Tessier *et al*., 1991; Choudhari, 2001). However, in the case of tine opener's crop residues are pushed aside. Hairpinning occurs when the openers do not cut or pass through the residue, thus causes ineffective seed placement. When hairpinning occurs, the seed is not placed at a uniform depth and proper establishment will be compromised (Le Roux, 2018). The disc furrow openers created the lowest level of hairpinned stubble and had the highest stubble cutting efficiency with a value of 88.6% at 90 mm operating depth (Ahmad *et al*., 2017).

According to Yao *et al.* (2009) disc openers provide the least soil disturbance which is an important characteristic of this type of furrow opener. Disc openers provide the greatest residue cover and smaller furrow rows than tine openers leading to good wheat and canola establishment (Yao *et al.*, 2009). Disc openers also tend to push the residues into the furrow without being cut and may be less effective in cutting the material, particularly in moist conditions and with high residue cover (Aikins *et al.*, 2017; Chen *et al*., 2004). Consequently, this hairpinning may result in poor seed-to-soil contact, poor seeding establishment thus resulting in poor yields (Aikins *et al.*, 2017).

Both tine and disc openers are designed to allow for simultaneous seeding and fertilising. Placement of fertiliser in the same pass while sowing gives a considerable saving of time. In some cases, seed and fertiliser are applied using separate sets of openers, with fertiliser openers being placed in the front of seed furrow openers (Chen *et al*., 2004; Tessier *et al.*, 1991). Fertiliser placed in close contact with seeds can delay or reduce crop establishment. Placing fertiliser with seed reduced wheat biomass production by 40% at flowering stage, but there was no difference in biomass production at physiological maturity (Hocking *et al*., 2003).

There are commercial disc seeding technologies that are able to split-band (separately apply) seeds and fertiliser. Split-banding with separate disc openers are much more reliable in its ability to separate fertiliser and seed, while still retaining accurate and uniform seed placement (Chen *et al*., 2004). Therefore, split-banding with separate discs might reduce the fertiliser toxicity or chemical seed injury.

2.2 Crop residue management

Crop residues in agricultural systems are primarily derived from plant leaf, stalk and root tissues that remain after harvest. In the early years crop residues were mistakenly regarded as agricultural waste, which was either removed by farmers from the field or used by livestock. Crop residues should not simply be seen as a waste product because of the significant role it plays in sustaining soil organic matter (Lafond *et al.*, 2009). When using no-tillage systems, it is particularly essential to leave crop residue on the soil surface after harvest (Turmel *et al*., 2015). Crop residue management practice forms part of the CA systems. In the long-term, crop residues can decrease soil erosion, runoff, improve soil structure, nutrient cycling, and could be an effective measure of weed control (Karlen *et al*., 1994; Turmel *et al*., 2015) and, prevent evaporation, retains water and buffers soil temperature fluctuations (Altikat *et al*., 2013).

Le Roux (2015) suggested that 30% crop residue cover reduced soil erosion by 80% and with an increase in residue cover there was a further decrease in soil erosion. Hobbs *et al*. (2008) also found that retaining crop residues decreased water and wind erosion and caused less soil surface crusting. Consequently, land with low soil erosion result in the sustainability of the soil and thus have the potential to increase agricultural productivity. Crop residue retention after harvest can therefore be considered critical in soil conservation. According to Turmel *et al*. (2015) crop residue retention have long-term benefits which include the improvement of soil organic matter levels. However, soil organic matter effect may be controlled by the type of soil, climate and management factors. Gura (2016) noted that the removal of crop residue after harvest tend to decline soil organic matter and soil microbial activity which are the major indicators of soil health.

A residue cover of ≥ 30% should be enough to provide enough soil organic carbon to improve and maintain soil organic matter (Kassam *et al*., 2012). Altikat *et al*. (2013) indicated that residue retention on fields are important, but it becomes challenging during sowing. The performance of an opener is affected like blocking furrow openers and preventing seed to soil contact (Altikat *et al*., 2013). It was suggested that tine openers were better adapted than disc openers under high stubble mulch conditions (Choudhari, 2001; Altikat *et al*., 2013).

Crop residues left on the soil surface may decrease soil temperature fluctuations and reduced light penetration, which can both have inhibitory effects on weed germination (Ferreira and Reinhardt, 2010; Turmel *et al.*, 2015). Furthermore, in some cases soil microbial populations, including soil-borne pathogens, are stimulated after soil amendment with fresh plant material (Bruce *et al*., 2001; Ferreira and Reinhardt, 2010). Flower *et al*. (2012) noted that large quantities of crop residues has a beneficial effect on weed suppression. However, weeds that grew through the crop residues were considerably bigger. This mainly include weed like ryegrass (*Lolium rigidum*), which can penetrate easily through the retained or incorporated residues. Herbicide resistance of weeds is one of the major concerns in CA systems, especially ryegrass under wheat production areas of the Western Cape.

The crop residues on the soil surface have a positive effect on the transpiration rate of plants. Transpiration of plants where high residues were maintained were 14 mm higher as compared to low residue level, which indicates that plant takes up more water from the soil (Sommer *et al*., 2012). However, more water used through transpiration may lead to a higher rate of germination and stronger plant growth, which suppresses weeds.

Placement of the crop residue is important for the disc openers operation and wheat seed establishment (Le Roux, 2018; Turmel *et al*., 2015). When using tine openers, residues are cut short with the combine harvester to allow flow of tine opener, but this is not optimum for discs because disc openers cut through residues (Turmel *et al.*, 2015). Optimal residue handling is achieved when the disc interacts least with the residue. Cutforth *et al*. (1997) suggested that, tall, upright stubble will alter the microclimate near the soil surface. When the seedlings are still small, wind speed and solar radiation are reduced by tall upright stubble, which maintains higher air humidity above the seed row and reduces soil temperature and evaporation (Cutforth *et al*., 1997). There are three main residue management options listed in Table 2.1 along with their benefits and potential limitations.

Table 2.1: Advantages and disadvantage analysis of residues related management options (Cutforth et al., 1997; Le Roux 2018).

Option	Related advantages	Potential disadvantages
Retain all crop residues with low harvest height	➢ Reduced soil erosion, Increased water infiltration, organic matter increases and potential carbon sequestration ➢ Improved soil microbial activity ➢ Decreases soil moisture evaporation and improved crop water use efficiency ➢ Weeds oppressing and mulch effect on nutrient release to plants.	➢ Increased handling problems at seeding e.g. hairpinning. ➢ May worsen crop sensitivity to incorporative by sowing 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 harvest ability 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 ➢ Better incorporative by sowing herbicide potential in stubble.	➢ High residue can have a negative effect on early cereal and wheat growth ➢ Reduced surface residue ground cover increasing inter-row evaporation and runoff especially under wider row spacing and down slopes ➢ May obstruct the planters on the field when planting
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 precision guidance ➢ Implement tracking stability required

2.3 Wheat establishment

Planting density is one of the main factors influencing yield. A seedling population of 150 to 175 wheat seedlings m^{-2} is optimal in the dryland production systems of the Western Cape and marginal at 120 seedlings m^{-2} (Neethling, 2018). According to Tolmay *et al*. (2010) the response of grain yield to differences in planting density is likely due to the impact of factors such as seasonal rainfall, soil physical properties, nutrient supply, planting time and the genetic make-up of the cultivar. Anderson and Impiglia (2002) suggested that the optimum planting density range for crops with terminal inflorescences and a large capacity to produce culms such as wheat, is often very wide.

To ensure that the plant population is not a limiting factor, the optimum plant population of wheat is proportional to the yield level and that planting density should therefore be increased when higher a grain yield is expected (Anderson and Impiglia, 2002). Planting density experiments by Anderson *et al.* (2004) indicated that optimum plant populations in Australia could vary between 35 to 175 plants m^{-2} for average grain yields of 0.42 to 3.91 ton ha^{-1}. Australian farmers should aim to establish a minimum of 40 plants m^{-2} for every ton of grain yield expected, up to a yield level of 3 ton ha^{-1}. To the contrary, Lafond (1994) found that grain yield did not increase as planting density was increased. For optimal establishment wheat seed required uniform depth placement in a firm, moist seedbed.

The main aim of planting wheat is to place the seed at a certain effective distance from each other and at a specific depth in the seedbed (Burce *et al*., 2013). Therefore, correct planting depth plays a significant role in increasing the rates of the seedling emergence, plant population and crop yield (Burce *et al*., 2013). In terms of planting the depth, disc openers provide a shallower and more uniform seeding depth when compared to tine openers under different levels of crop residue (Chen *et al.*, 2004; Yao *et al*., 2009*)*. Therefore, the seed-drill openers should be able to cut and handle residue, penetrate into soil with a proper planting depth and establish good seed to soil contact. In the current study a row spacing of 300 mm apart was used for both seasons. Potter *et al*. (2001) compared 150 mm and 300 mm row spacing and 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.

2.4 Soil quality

Concerns has been raised about soil degradation or the decrease in soil quality and its effect on the global environment (Arshad and Coen, 1992; Gura, 2016). Soil erosion is one of the most destructive degradation processes and impact soil quality (Arshad and Coen, 1992). Soil quality can simply be defined as the capability of the soil to function for sustainable plant productivity (Karlen *et al.*, 1997). It has raised significant issues concerning soil evaluation and different soil management impacts on chemical, physical and biological properties (Gura, 2016). Plants rely on soil quality to sustain productivity. Soil management systems tend to have negative effect on the quality of the soil (Fuentes *et al.*, 2009). Therefore, policymakers and farmers are required to have an appropriate scientific information to make appropriate soil management decisions.

Zero-tillage with crop residue retentions tend to be a good management technology for farmers producing wheat, resulting in better soil quality and higher yields (Fuentes *et al.*, 2009). Karlen *et al.* (1994) suggested that soil quality indicator is a measurable soil property that affects the capacity of a soil to perform a definite function. Chemical, physical, and biological indicators have been suggested that can show changes over various soil management practices. Principal physical and chemical properties adversely affected by soil degradation processes responsible for the decrease in soil quality (Arshad and Coen, 1992; Karlen *et al.*, 1997), are listed below:

- Soil depth: a decrease in rooting volume and topsoil loss at deep soil depth.
- Water-holding capacity: experience low water holding capacity due to decline in organic matter, fine mineral colloids, aggregation and depth.
- Organic matter: decline in nutrients and nutrient retention capacity, biological degradation.
- Cation exchange capacity: due to soil degradation most reactive colloids are lost, leaving sand and gravel with diminutive nutrient retention capacity.
- Bulk density: more compact and dense horizons exposed due to degraded soils.
- Soil pH: Soil degradation may increase or decrease, depending on primary materials.

Biological indicators illustrated a well-functioning of soil microbial population as well as chemical indictors showed an impact of nutrient management (Swanepoel *et al*., 2015). Arshad and Coen (1992) indicated that soil depth, soil organic matter, and electrical conductivity were significant properties mostly influenced by soil degradation processes.

Selection of indicators that are sensitive to management practices is desirable for evaluation of soil quality (Karlen *et al.*, 1997). Soil quality and its evaluation was developed to address the consequences of high soil erosion rates, soil organic matter loss, depletion in soil fertility and productivity, environmental contamination, and water and air quality degradation (Andrews *et al.*, 2004). Some soil quality indicators and processes that can be affected in the soil are summarised in Table 2.2.

Table 2.1: Selected indicators of the soil quality and some processes they affect (Karlen *et al*., 1997; Gura, 2016).

Soil quality indicators	Process affected
Organic matter	Nutrient cycling, water retention, and soil structure
Aggregate stability	Soil structure, erosion resistance, crop emergence, infiltration
Infiltration	Runoff and leaching potential, plant water use efficiency, erosion potential
pH	Nutrient availability, pesticides absorption and mobility
Microbial biomass	Biological activity, nutrient cycling and capacity to degrade pesticides
Forms of N	Availability to crops, leaching potential, mineralization and immobilisation rates
Bulk density	Plant root penetration, water and air-filled pore space

The assessment tool of soil quality is required for the evaluation and management of soils that were subjected to different management systems. There are several soil quality indices that are used in practices, of which the Soil Management Framework (SMAF) is one of the most widely used indices (Jokela *et al*., 2009; Karlen *et al*., 2008; Karlen *et al*., 2013; Swanepoel *et al*., 2015 Stott *et al*., 2011). It is one of the soil quality assessment tools designed for evaluating all types of soil indicators and if desired, the SMAF can combine all the measured soil indicators into an overall evaluation of the dynamic soil quality (Andrews and Carroll, 2001; Andrews *et al*., 2004*)*. This assessment tool was developed from studies applying principles of systems engineering and ecology to clarify and interpret soil physical, chemical, and biological data collected from studies of soil management systems (Karlen *et al.*, 2008). This tool comprises three steps, namely indicator selection, indicator interpretation and integration into a soil quality index value (Andrews *et al.*, 2004). The first step involves selecting indicators to be measured for the assessment process and the second step involves interpreting the measured indicator data using scoring curves (Figure 2.1). The final step involves integrating the scores of the measured indicators into a single additive index value (Andrews *et al.*, 2004). Jokela *et al*. (2009) used the SMAF to evaluate the impacts of liquid manure applications and cover crops on soil quality in a maize silage system. Stott *et al*. (2011) implemented a soil quality assessment using the SMAF to isolate the field areas with varying performance zones and distinguish specific soil quality indicators that varied with poor canopy development. Karlen *et al*. (2013) also used SMAF to evaluate the soil quality response to long-term and crop rotation practices. Intensive tillage was the primary factor degrading soil quality. Also, it has been reported that the SMAF index is a useful estimator of soil quality correlating with yields of many crops including wheat (Masto *et al*., 2007), cultivated pastures (Swanepoel *et al*., 2015). Low quality soils are characterised as being compact, poor aggregates, and low organic matter content while high quality soil have good aggregate stability. Plots with high quality soil had an overall SMAF score of 63.1%, significantly higher than those plots characterised as having low quality soil with overall SMAF of 57.8% (Swanepoel *et al.*, 2017).

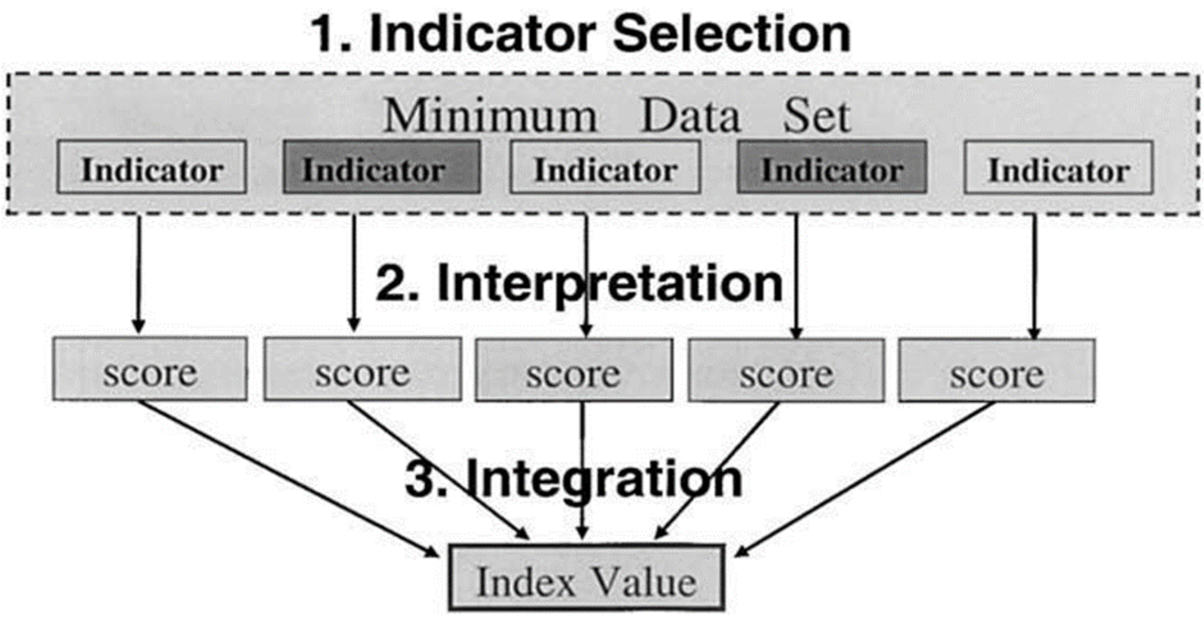


Figure 2.1: Framework illustrating the Soil Management Framework as a three step process (Andrews *et al*., 2004).

Chapter 3

Materials and Methods

3.1 Site and Climate description

The study was conducted on the Langgewens Research Farm of the Western Cape Department of Agriculture during 2016 and 2017. The research farm is situated 18 km north of Malmesbury in the Western Cape Province of South Africa (33°16'34.41" S, 18°45'51.28" E). This region is known as the Swartland dominated by dryland small grain production systems. The climate is typically a Mediterranean climate with hot summers and mild winters. The long-term average annual rainfall is 439.9 mm. Eighty percent of the rainfall occurs during months of April to September. During the 2016 season, the total average annual rainfall was 376.0 mm and in 2017 season received about 238.1 mm (Figure 3.1). In both 2016 and 2017 seasons, May and August were slightly warmer than the long-term mean temperature (Figure 3.1). In this region most of the crops are planted in April or May after the first rain has fallen and harvested from mid-October to November.

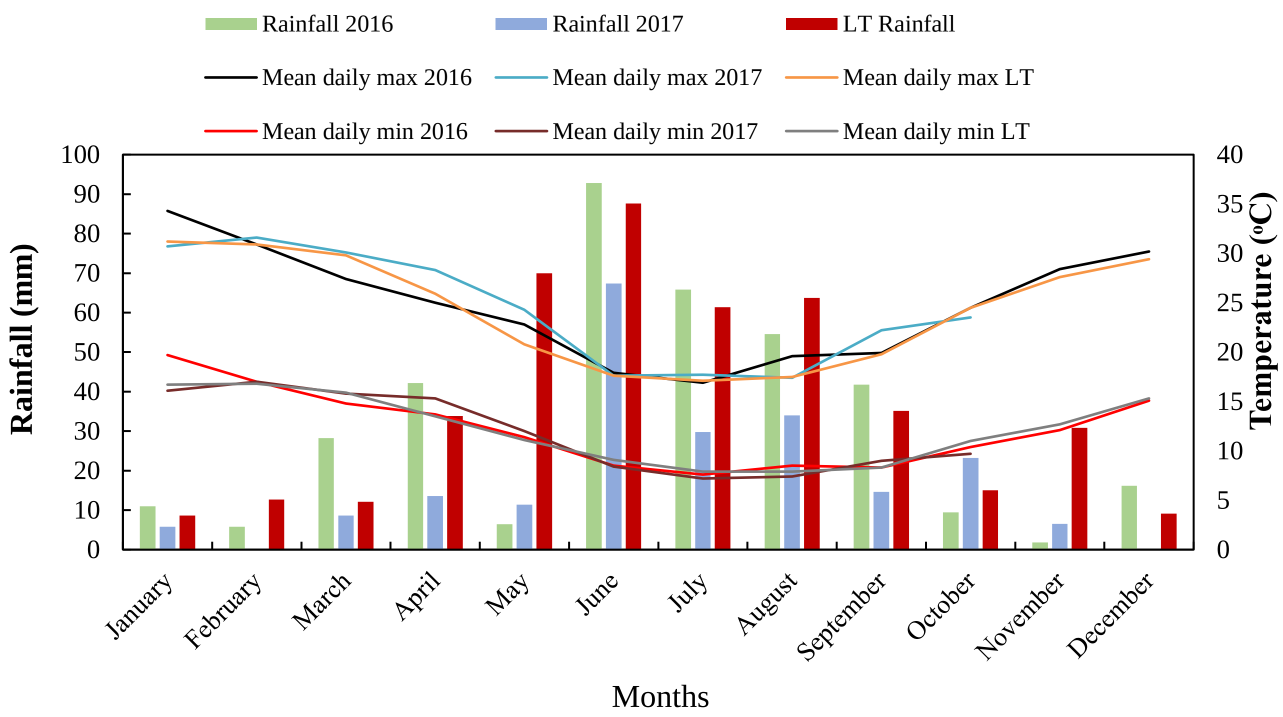


Figure 3.1: Long-term (LT) rainfall (mm), mean minimum and maximum temperatures (°C) of Langgewens Research Farm as well as rainfall, minimum and maximum temperatures recorded monthly for both 2016 and 2017 seasons.

3.2 Experimental design and treatments

The trial was laid out as a split-plot design with three factors, namely; 1) seed-drill openers, 2) soil quality and 3) residue levels, replicated in four randomised blocks. The whole plots comprised the two soils (high and low quality). The sub-plots were assigned to seed-drill openers (tine or disc), and residue levels (high, medium, low) were nested randomly within each sub-plot. An Equalizer no-till seed-drill with interchangeable tine or disc openers was used to plant wheat, which eliminates potential bias of weight differences and seeding efficiency variation between different implements. 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. The rows were spaced 300 mm apart. Soil samples were analysed and SMAF was applied to identify plots with high and low soil qualities. The three crop residue levels were manipulated in each subplot and comprised 55 m^2 in 2016 and 25 m^2 in 2017. For high residue plots wheat residue were applied until no soil was visible (5.1 t ha^{-1} in 2016 and 6.4 t ha^{-1} in 2017) (Figure 3.2). A visually estimated half of the amount applied in high residue level plots was applied on the medium residue level plots (4.3 t ha^{-1} in 2016 and 6.2 t ha^{-1} in 2017). No additional residues were applied to the low residue level plots (1.5 t ha^{-1} in 2016 and 1.9 t ha^{-1} in 2017).

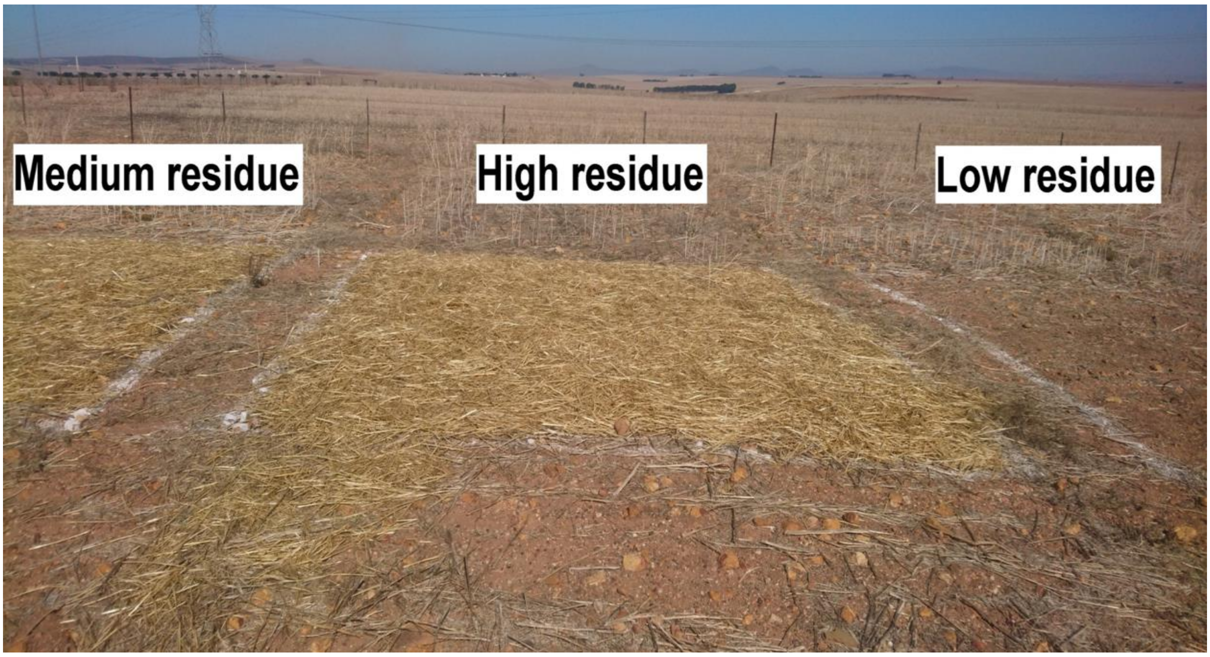


Figure 3.2: Residue treatment levels at Langgewens Research Farm.

3.3 Trial management

In 2016, the trial was planted on 25 May which was towards the end of the recommended planting time for wheat in this region. However, no rain was received before the end of May and the soil was dry with a gravimetric water content of 3.7%. In 2017, the trial was established on 3 May, also in dry soil with a gravimetric water content of 5.7%, and again no rain was received before the end of May. 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 both seasons fertiliser was placed with the seed for both the disc and tine openers. Two to three weeks the wheat emerged, 50 kg N ha^{-1}, 6.2 P ha^{-1} and 7.8 kg S ha^{-1} was applied as a first top dressing. Wheat variety SST056 was used in both years. The cultivar choice was based on wheat cultivar evaluation results from Langgewens Research Farm. For both years, wheat was established at a seeding rate of 80 kg ha^{-1} and a planting depth of approximately 10 mm. Weed and pest control were managed according to recommended guidelines for the Swartland region. The tractor speed in 2016 was 5 km h^{-1} and in 2017 was 9 km h^{-1}.

3.4 Data collection

3.4.1 Soil sampling

Prior to planting, representative soil samples were taken at three depths namely: 0 to 150 mm, 150 to 300 mm, and 300 to 450 mm respectively to determine the soil quality. Soil samples were also taken prior to planting 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. The standard methods were followed as prescribed by the Non-affiliated Soil Analysis Work Committee (1990). The sodium adsorption ratio (SAR) was calculated using the following formula: $SAR = \frac{Na}{\sqrt{0.5 \times (Ca^{2+} + Mg^{2+})}}$

Biological analyses included organic carbon, which was determined with the Walkley-Black procedure (Nelson and Sommers, 1982), β-glucosidase activity was calculated by determining the release of p-nitrophenyl moiety after incubation of soil with p-nitrophenyl glucoside (Dick *et al*., 1996). Potentially mineralisable nitrogen (PMN) was determined through aerobic incubation for seven days following a determination of ammonia and nitrate content (Cataldo *et al*., 1975; Keeney and Nelson, 1982).

For physical analyses, three additional soil samples were taken per plot to a depth of 150 mm one day prior to planting to determine the aggregate stability by wet sieving (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 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 soil quality 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.

The Solvita test did not correlate with plant production parameters or yield, and therefore it was not used to describe soil health. 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 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: Average values of soil indicators for soil quality, and soil quality indices (SQI) of soils classified as having high or low quality for wheat production in 2016 and 2017. CEC = Cation exchange capacity, SAR = Sodium adsorption ratio, PMN = Potential meneralisable nitrogen.

	Soil quality 2016		Soil quality 2017	
	Low	High	Low	High
pH (water)	7.1	6.7	6.8	6.8
Exchangeable Ca (mg kg^{-1})	2384	1078	875	1254
Exchangeable Mg (mg kg^{-1})	152.8	98.8	120	203.7
Exchangeable Na (mg kg^{-1})	47.3	27.8	25.6	145.3
Exchangeable K (mg kg^{-1})	121.5	152.5	154.0	176
CEC (cmol kg^{-1})	12.6	6.9	6.0	9.2
Extractable P (mg kg^{-1})	76.8	83.8	71.3	81.6
Clay (%)	12	9	9	12
Organic C (%)	1.22	1.58	1.06	1.30
Aggregate stability (%)	37.2	47.3	39.0	41.0
Bulk density (g cm^{-3})	1.85	1.75	1.50	1.32
Electrical conductivity (dS^{-1})	0.04	0.00	0.03	0.05
Sodium adsorption ratio	0.07	0.06	0.07	0.29
β-glucosidase activity (μg^{-1} h^{-1})	830	745	1589	1311
PMN (mg kg^{-1})	10.56	11.80	25.50	25.91
CO_2-C burst test (mg kg^{-1})	70.61	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 (%)	55	60	79	92

3.4.2 Soil disturbance

Soil surface disturbance was measured using a pin profile meter to determine surface roughness and the groove width that was created by tine or disc openers in each plot after planting (Moreno *et al.*, 2008). The pin profiler consisted of 42 pins that are spaced 20 mm apart to make 1.0-meter width of the pin profiler and a height of 350 mm. The pin profiler was positioned on the plots perpendicular to the direction of seeding directly after seeding. The pins slide up or down to confirm soil surface irregularities. 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 groove 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 3.3: A pin profile meter at the field used to determine the amount of above ground soil disturbance.

3.4.3 Plant parameters

Plant population was determined 30 days after planting by counting the number of plants in a 0.25 m^2 quadrants per plot. Ten wheat plants were sampled per plot at 30, 60, and 90 days after planting and at physiological maturity to determine the aboveground biomass production (kg dry matter ha^{-1}). The leaves were separated from the stems and leaf area was measured with a LI-COR leaf area meter at 30, 60 and 90 days. The leaf area index was subsequently calculated using the plant population. The same plants were oven dried at 60°C for 72 hours and weighed to determine aboveground biomass production at 30, 60 and 90 days after planting as well as at physiological maturity. The number of ear bearing tillers per m^2 was determined by counting the number of tillers with spikes on all the sampled plants from each plot. Ear bearing tillers was not determined in 2016 season.

The wheat grain was harvested on the 20th of November 2016 and 1st of November in 2017 with a HEGE plot combine harvester. The wheat grain from each plot was cleaned and bagged and the yield was determined by weighing the seeds from each plot. Thousand kernel mass was determined by counting and weighing 1000 seeds. Hectolitre mass was measured using a standard funnel-shaped device that provides a uniform filling in a 500 mL measuring cup and the excess grain was levelled with a wooden scraper. The weighed mass of the grain is divided by five to convert it to kg hL^{-1}.

3.5 Statistical analysis

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 factors at every level, were regarded as fixed terms in the statistical model. Blocks and the cross between blocks and soil quality/opener, with residue levels nestled within whole blocks, were regarded as random terms. Certain parameters only measured for two factors (soil quality and openers) and the model was adapted accordingly. These parameters include soil surface roughness and the groove width. The Bonferroni and 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 performed on the main effects, i.e. soil quality, opener or residue. Residuals were normally distributed and had homogeneous variances. With this 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.

Chapter 4

Results

The results presented in this chapter and their description will focus on the interactions between the soil quality, opener and residue level, except where duly stated otherwise. Only in certain cases where there are no interaction and where it is practically sensible, attention will be given to main effects and the two-way interaction effects.

4.1 Soil disturbance

There were two measurements taken with the pin profiler which were indicators of soil disturbance, namely surface roughness (mm) and groove width (mm). As the pin profiler could only be used on plots where soil is visible (i.e. without residue), only the effects of opener and soil quality is described. During the 2016 season, there was no difference between tine and disc openers for soil surface roughness on either low or high quality soils ($P>0.05$; Table 4.1; Figure 4.1). Similarly, in the 2017 season no interaction effect ($P>0.05$) was noted between openers and soil quality.

Table 4.1: The main effects and the interaction of tine or disc opener and soil quality for soil surface roughness for the 2016 and 2017 seasons.

2016	Effect	F	P-value
	Soil quality	0.11	0.776
	Opener	0.01	0.941
	Soil quality x Opener	1.25	0.296
2017	Soil quality	1.90	0.302
	Opener	2.24	0.172
	Soil quality x Opener	0.94	0.359

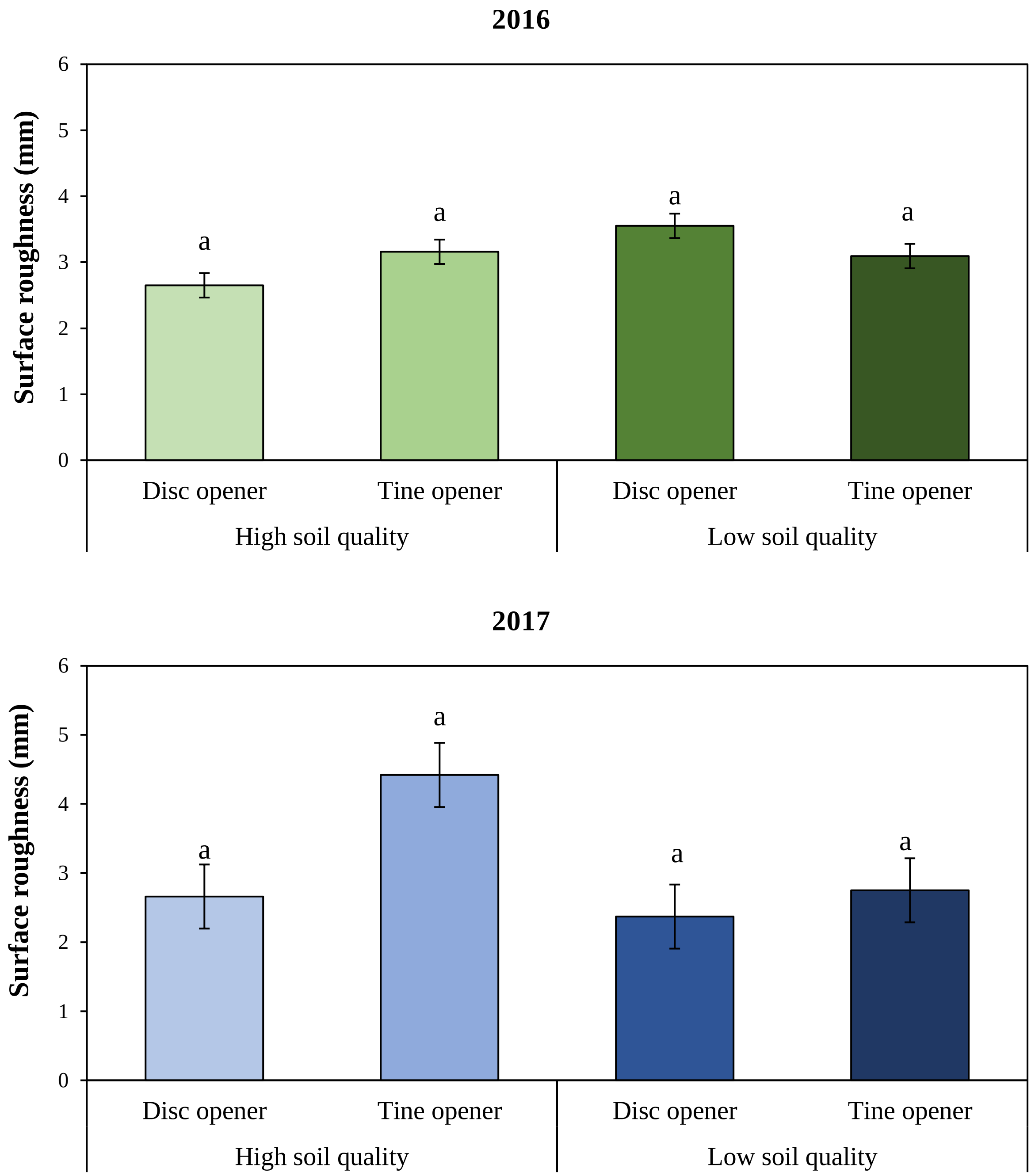
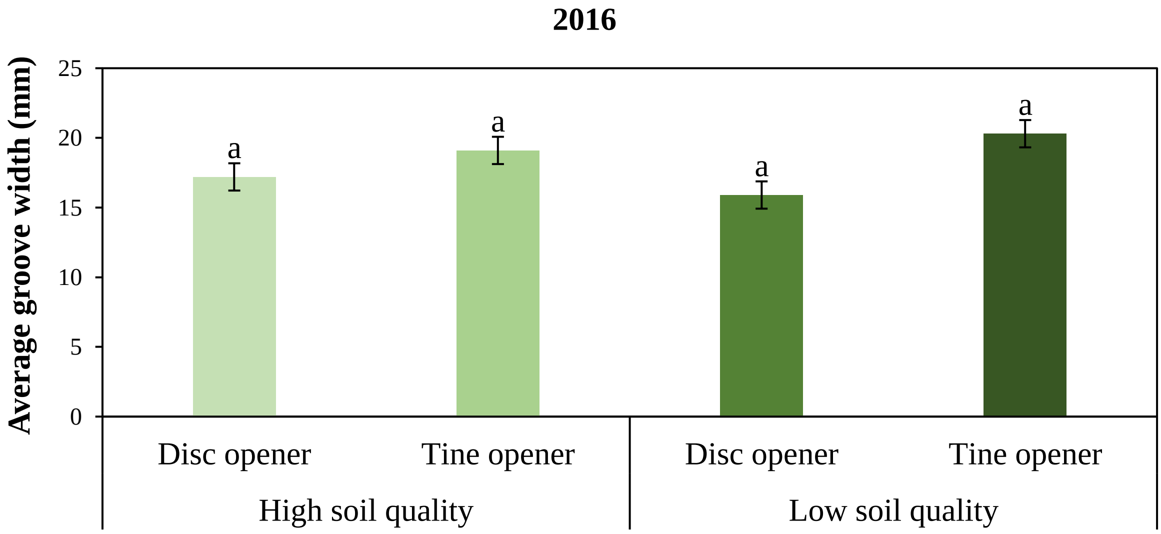


Figure 4.1: Soil surface roughness on high and low soil quality after seeding with a disc or tine opener for the 2016 and 2017 seasons. Bars with different letters indicate significant differences at a 5% level. The error-bars illustrate the standard error within each treatment.

The groove width in the both 2016 and 2017 seasons was not affected (P>0.05) by any treatment (Table 4.2 and Figure 4.2).

Table 4.2: The main effects and interaction of between openers and the soil quality for average groove width for 2016 and 2017 season.

2016	Effect	F	P-value
	Soil quality	0.65	0.456
	Opener	2.68	0.146
	Soil quality x Opener	2.78	0.201
2017	Soil quality	0.23	0.632
	Opener	3.31	0.120
	Soil quality x Opener	0.74	0.423



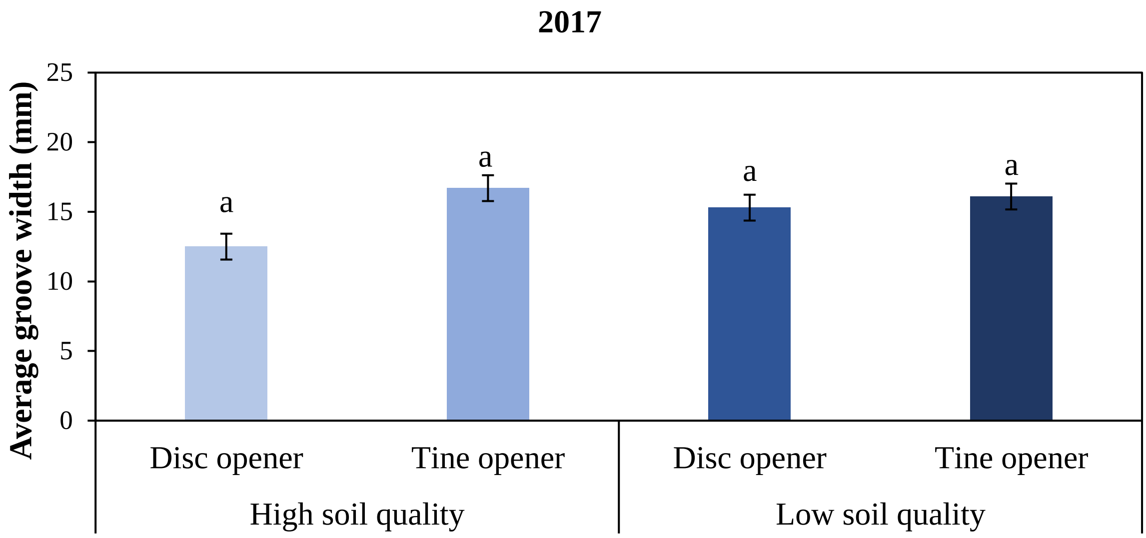


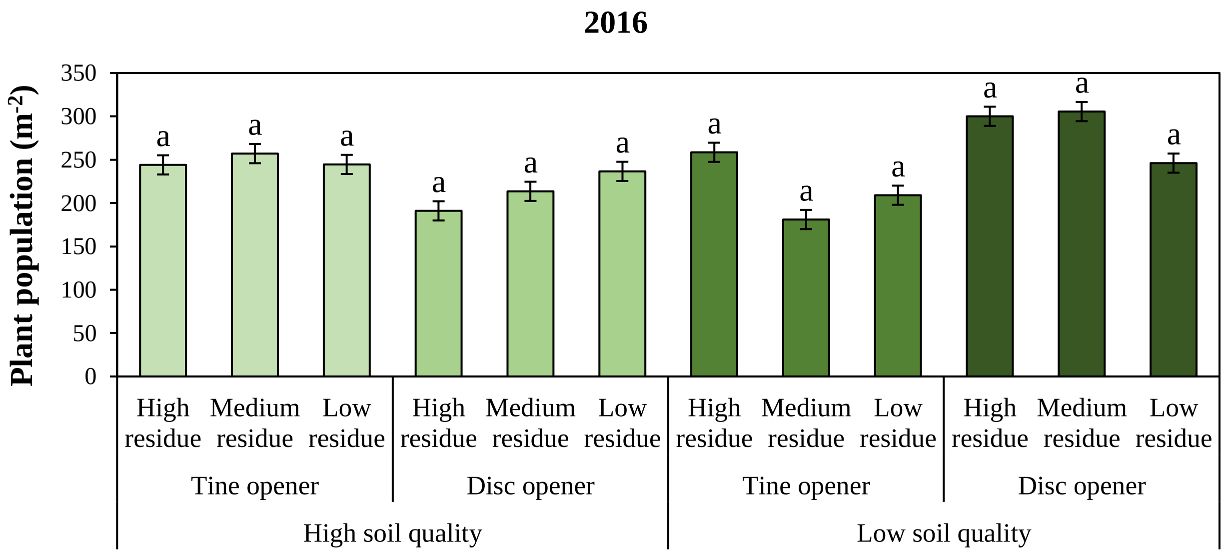
Figure 4.2: The average groove width (mm) created by plating with tine or disc opener under different soil types for the 2016 and 2017 seasons. Bars with different letters indicate significant differences at a 5% level. The error-bars illustrate the standard error within each treatment.

4.2 Plant population

There were no interaction effects (P > 0.05) of soil quality, opener, and residue levels for plant population in 2016 (Table 4.3). No significant effect (P > 0.05) was caused by main effects and neither any of the two-way interactions on plant population (Figure 4.5). Similarly, in the 2017 season, no effect (P > 0.05) caused by the interaction of soil quality, opener, and residue levels observed and neither any of the two-way interaction were different (Table 4.3) with respect to plant population.

Table 4.3: Main effects and interactions between soil quality, opener, and residue level for wheat plant population in the 2016 and 2017 season at 30 DAP.

	Effect	F	P-value
2016	Soil quality	0.04	0.877
	Opener	0.42	0.634
	Residue levels	0.00	0.999
	Soil quality x Opener	5.67	0.253
	Soil quality x Residue levels	2.60	0.154
	Opener x Residue levels	0.66	0.588
	Soil quality x Opener x Residue levels	1.79	0.213
2017	Soil quality	8.76	0.060
	Opener	6.16	0.089
	Residue levels	1.18	0.370
	Soil quality x Opener	0.07	0.811
	Soil quality x Residue levels	0.63	0.566
	Opener x Residue levels	1.74	0.253
	Soil quality x Opener x Residue levels	3.46	0.100



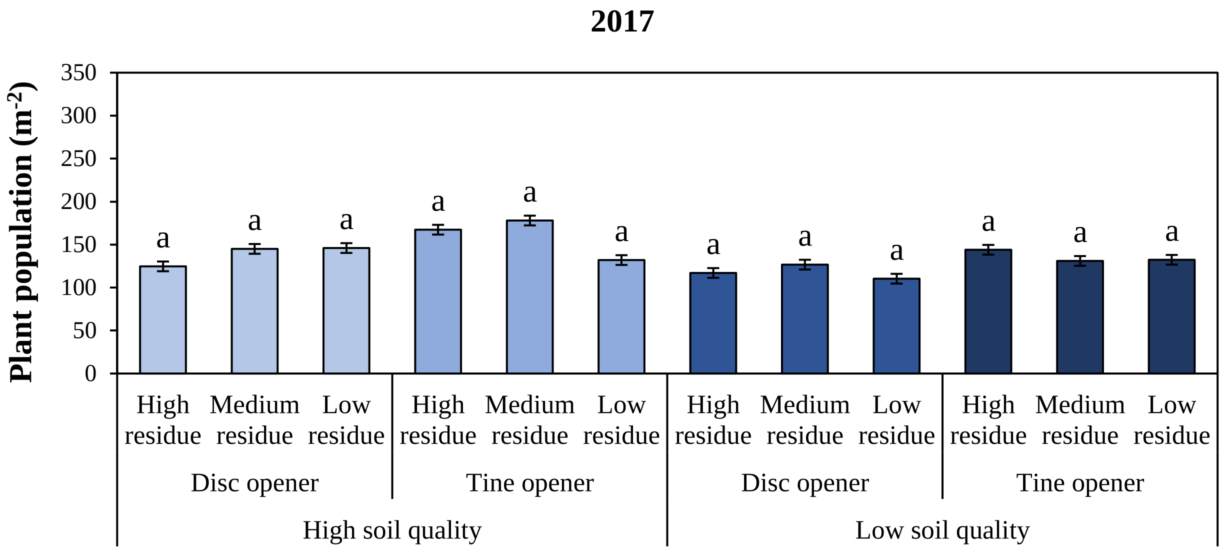


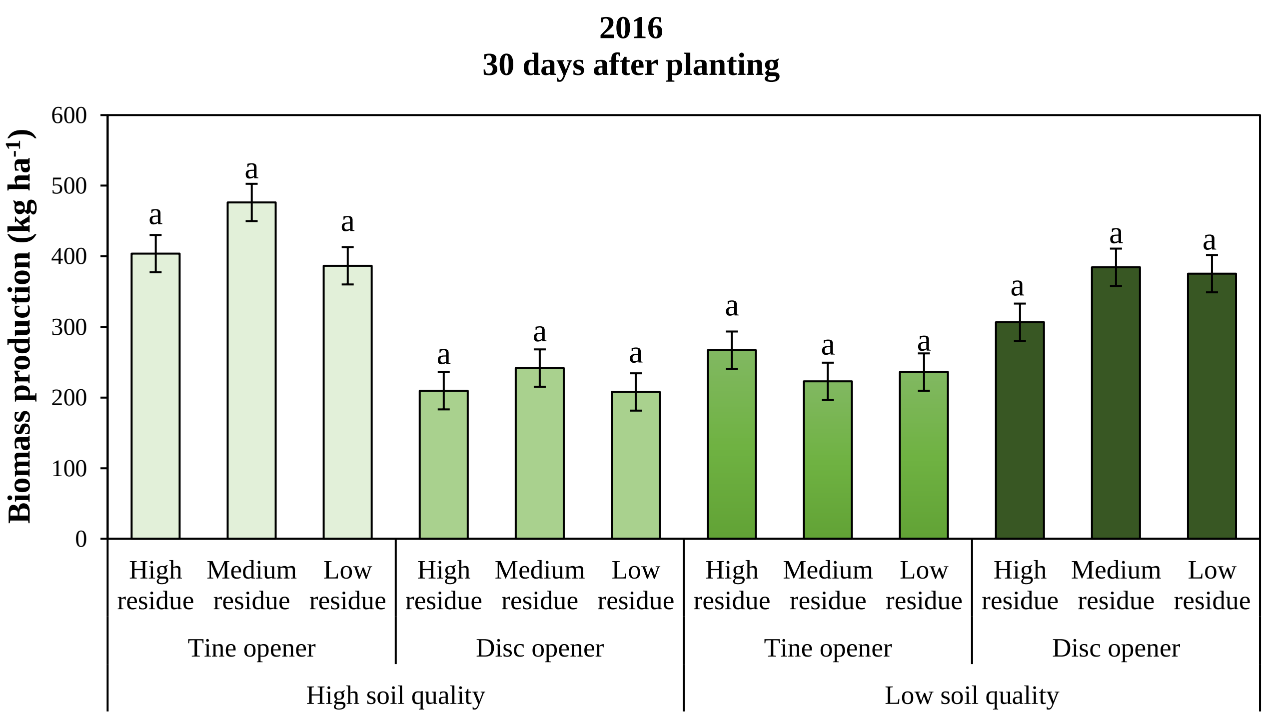
Figure 4.3: Wheat plant population (m^{-2}) on high and low soil quality after the establishment with a disc or tine opener with different residue levels for the 2016 and 2017 seasons. Bars with different letters indicate significant differences at a 5% level. The error-bars illustrate the standard error within each treatment.

4.3 Wheat biomass production

At 30 days after planting of the 2016 and 2017 growing season no significant (P>0.05) interaction effect between soil quality, opener, and residue levels was found with respect to biomass production (Table 4.4 and Figure 4.7). Furthermore, this was also observed on the two-way interactions (soil quality x residues, and opener x residue levels; P>0.05; Table 4.4).

Table 4.4: Main effects and interactions between soil quality opener, and residue level for wheat biomass production in the 2016 and 2017 season at 30 DAP.

	Effect	F	P-value
2016	Soil quality	1.39	0.445
	Opener	0.04	0.881
	Residue levels	0.84	0.514
	Soil quality x Opener	30.96	0.113
	Soil quality x Residue levels	0.15	0.867
	Opener x Residue levels	0.34	0.739
	Soil quality x Opener x Residue levels	2.65	0.115
2017	Soil quality	0.41	0.566
	Opener	0.29	0.625
	Residue levels	0.55	0.601
	Soil quality x Opener	4.19	0.133
	Soil quality x Residue levels	0.21	0.815
	Opener x Residue levels	2.16	0.197
	Soil quality x Opener x Residue levels	0.31	0.743



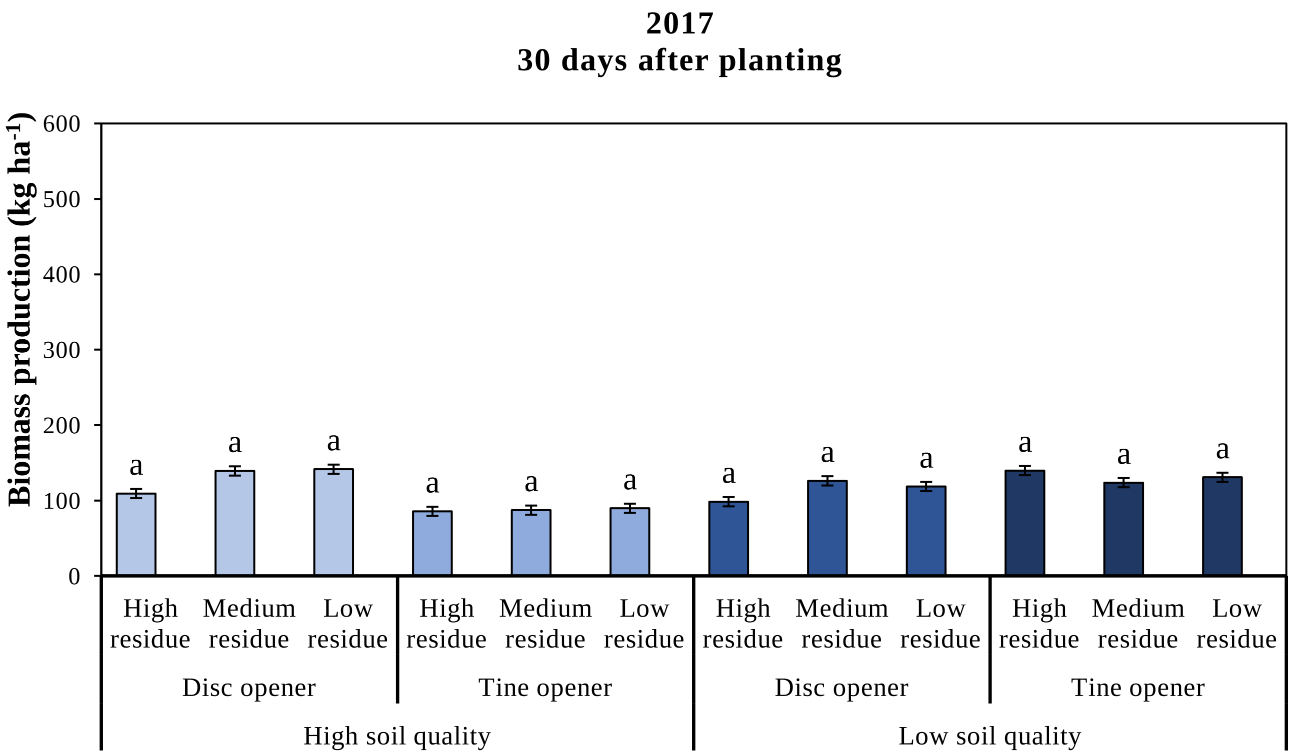
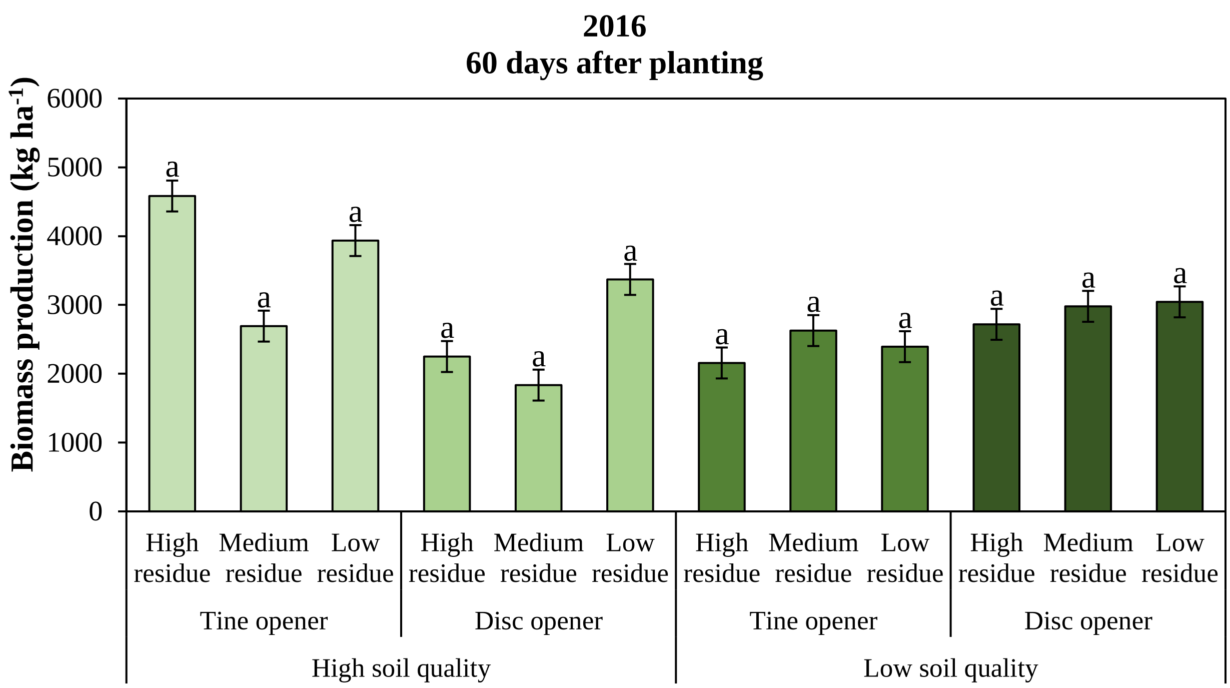


Figure 4.4: Wheat biomass production (kg. ha^{-1}) on high and low soil quality at 30 DAP with a disc or tine opener with different residue levels for the 2016 and 2017 seasons. Bars with different letters indicate significant differences at a 5% level. The error-bars illustrate the standard error within each treatment.

During 2016 at 60 days after planting, there was no difference (P>0.05) between treatments for wheat biomass production (Table 4.5 and Figure 4.5). The main effects and two-way interactions did not differ (Table 4.5). In 2017 season, soil quality, opener, and residue levels had no significant (P>0.05) differences on biomass production at 60 days after planting (Table 4.5 and Figure 4.5).

Table 4.5: Main effects and interactions between, soil quality, opener and residue level for wheat biomass production in the 2016 and 2017 season at 60 DAP.

	Effect	F	P-value
2016	Soil quality	0.58	0.585
	Opener	0.39	0.644
	Residue levels	0.56	0.621
	Soil quality x Opener	2.31	0.371
	Soil quality x Residue levels	1.13	0.384
	Opener x Residue levels	0.31	0.753
	Soil quality x Opener x Residue levels	0.45	0.648
2017	Soil quality	2.13	0.241
	Opener	1.68	0.285
	Residue levels	1.10	0.393
	Soil quality x Opener	2.59	0.206
	Soil quality x Residue levels	0.20	0.828
	Opener x Residue levels	0.74	0.518
	Soil quality x Opener x Residue levels	0.11	0.112



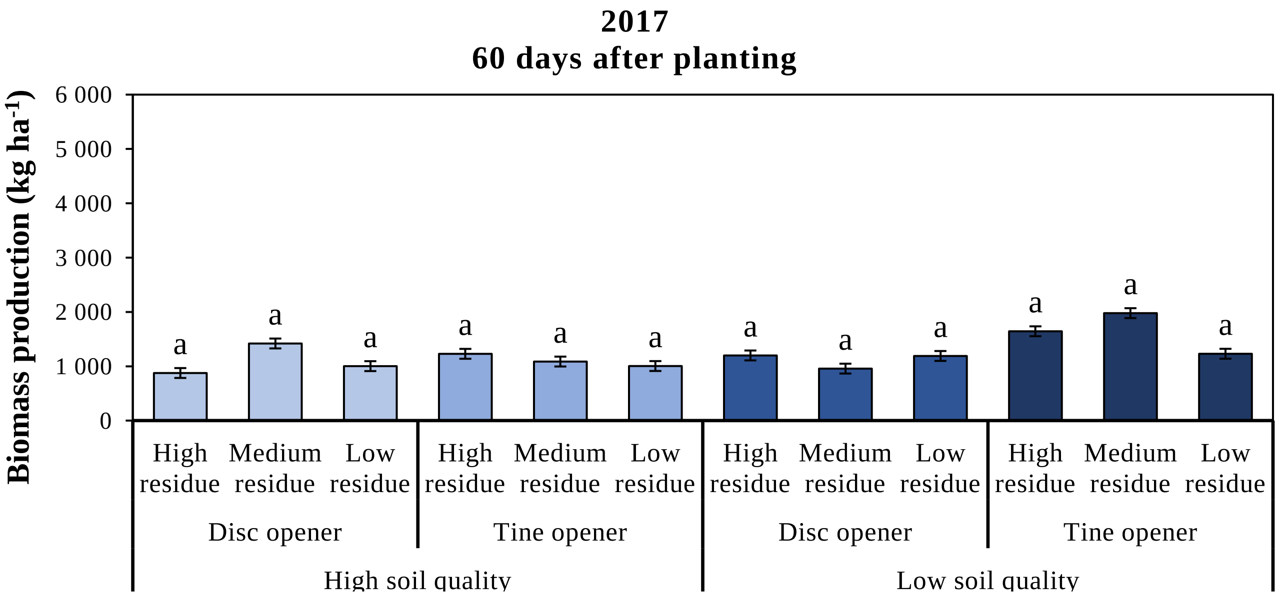
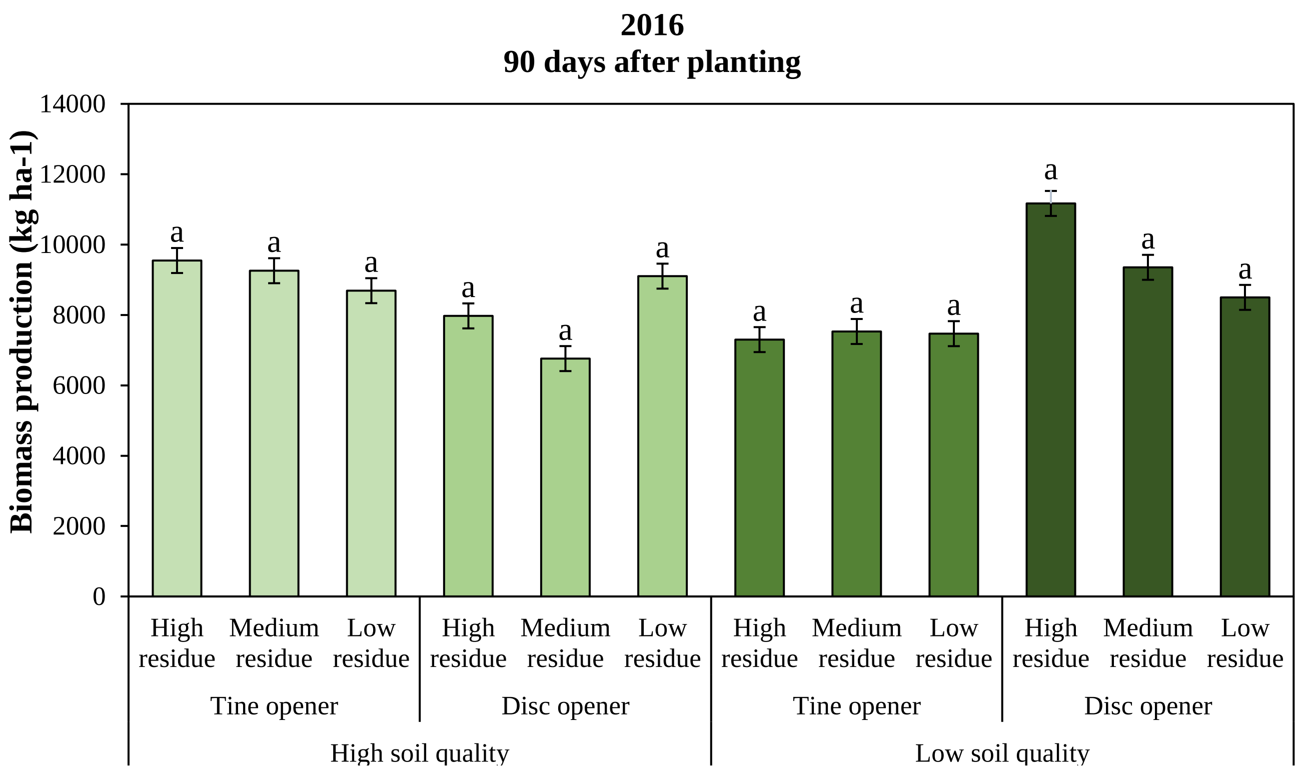


Figure 4.5: Wheat biomass production (kg ha^{-1}) on high and low soil quality at 60 DAP with a disc or tine opener with different residue levels for the 2016 and 2017 seasons. Bars with different letters indicate significant differences at a 5% level. The error-bars illustrate the standard error within each treatment.

The interaction between soil quality, opener, and residue levels was not significant (P>0.05) with respect to the biomass production at 90 days after planting in the 2016 season (Table 4.6). During 2017 season, there were no differences (P>0.05) between soil quality, opener and residues levels on biomass production at 90 days after planting, but residue level as a main effect alone had a significant impact (P<0.05; Table 4.6) (Results not shown). The disc opener produced more wheat biomass than tine opener planted in either high or low quality soils (Figure 4.6).

Table 4.6: Main effects and interactions between soil quality, opener and residue level for wheat biomass production in the 2016 and 2017 season at 90 DAP.

	Effect	F	P-value
2016	Soil quality	0.01	0.933
	Opener	0.13	0.782
	Residue levels	0.03	0.967
	Soil quality x Opener	1.03	0.496
	Soil quality x Residue levels	0.11	0.899
	Opener x Residue levels	0.20	0.832
	Soil quality x Opener x Residue levels	0.81	0.471
2017	Soil quality	0.99	0.393
	Opener	0.53	0.519
	Residue levels	9.25	0.015
	Soil quality x Opener	4.97	0.112
	Soil quality x Residue levels	0.50	0.632
	Opener x Residue levels	0.48	0.643
	Soil quality x Opener x Residue levels	3.01	0.124



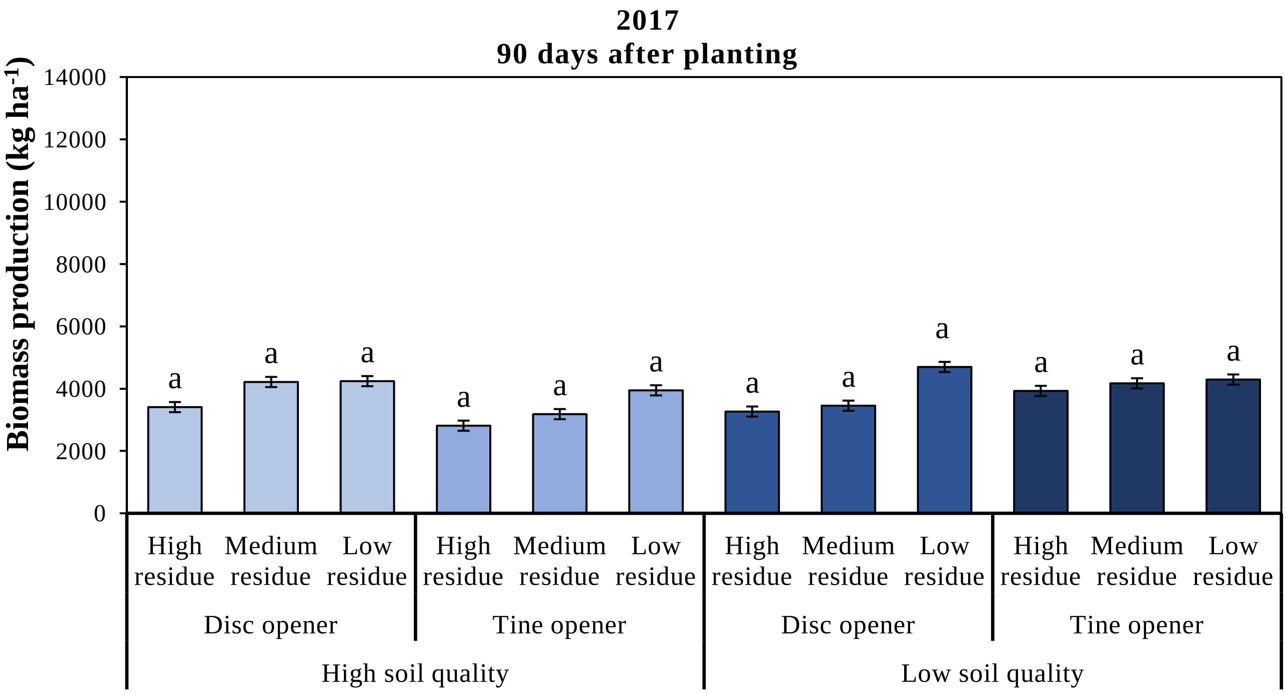
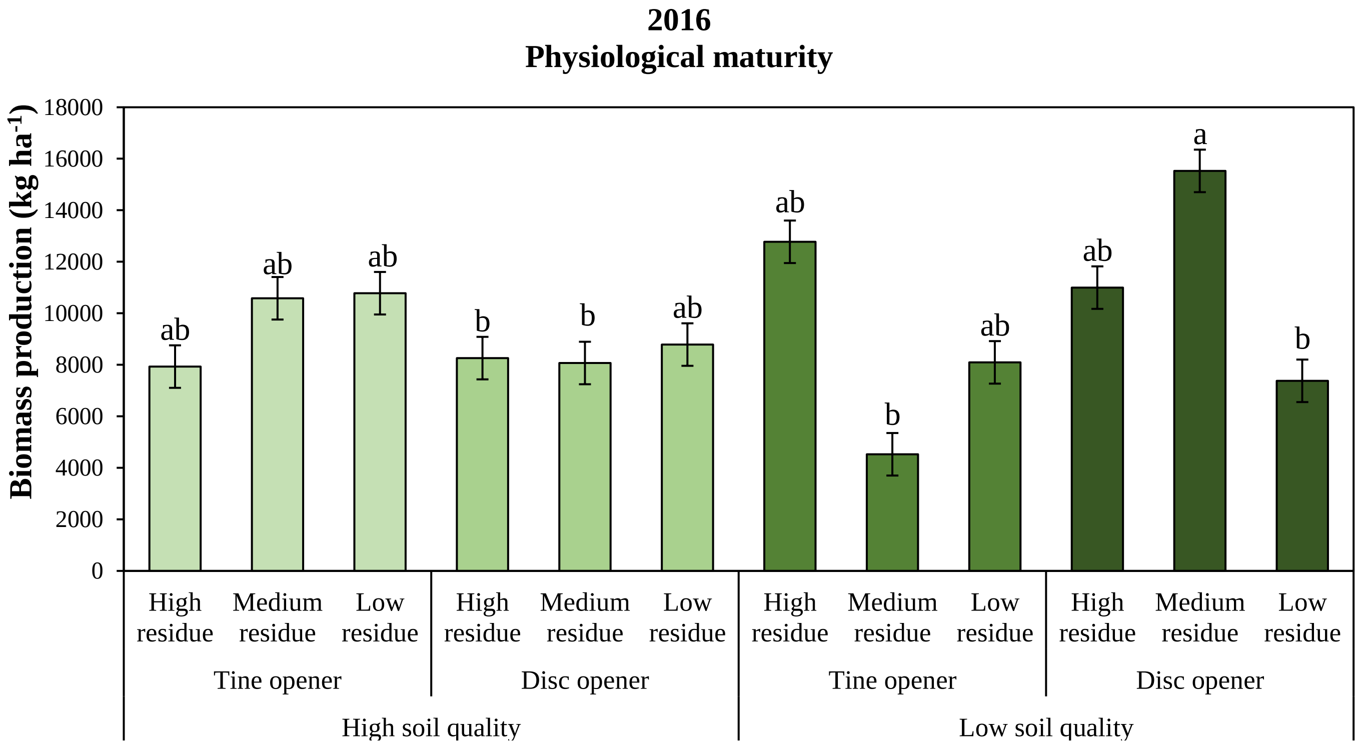


Figure 4.6: Wheat biomass production (kg ha^{-1}) on high and low soil quality at 90 DAP with a disc or tine opener with different residue levels for the 2016 and 2017 seasons. Bars with different letters indicate significant differences at a 5% level. The error-bars illustrate the standard error within each treatment.

During 2016, soil quality, opener, and residue level had an interaction ($P<0.05$) on wheat biomass production at physiological maturity (Table 4.7 and Figure 4.7). No significant ($P>0.05$) effects were observed in the 2017 season for wheat biomass production (Table 4.7 and Figure 4.14).

Table 4.7: Main effects and interactions between soil quality, opener and residue level for wheat biomass production in the 2016 and 2017 season at physiological maturity.

	Effect	F	P-value
2016	Soil quality	0.00	0.972
	Opener	0.17	0.749
	Residue levels	0.02	0.982
	Soil quality x Opener	4.50	0.280
	Soil quality x Residue levels	1.03	0.412
	Opener x Residue levels	1.65	0.329
	Soil quality x Opener x Residue levels	3.82	0.055
2017	Soil quality	0.37	0.586
	Opener	3.95	0.141
	Residue levels	1.42	0.313
	Soil quality x Opener	0.01	0.922
	Soil quality x Residue levels	0.03	0.974
	Opener x Residue levels	1.26	0.349
	Soil quality x Opener x Residue levels	0.71	0.530



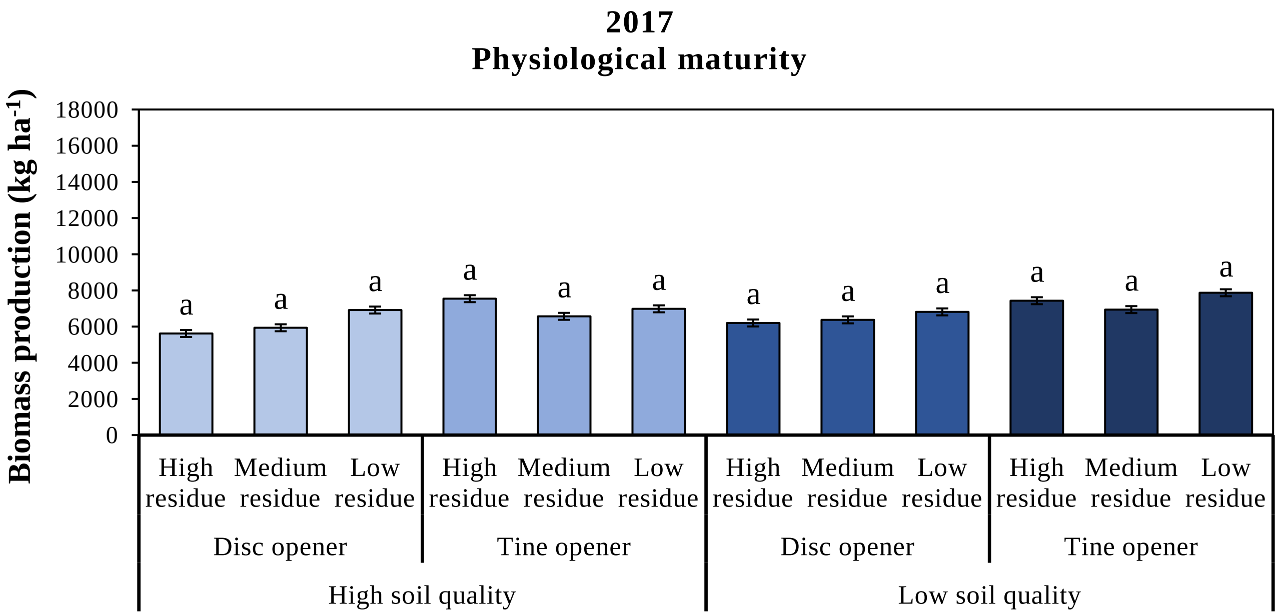


Figure 4.7: Wheat biomass production (kg. ha^{-1}) on a high and low soil quality at physiological maturity with a disc or tine opener with different residue levels for the 2016 and 2017 seasons. Bars with different letters indicate significant differences at a 5% level. The error-bars illustrate the standard error within each treatment.

4.4 Leaf Area Index (LAI)

Leaf area index at 30 days after planting was only determined in 2017 and there was no significant (P>0.05) interaction between soil quality, openers, and residue levels and main effects and neither any of the two-way interactions had a significant effect (P>0.05; Table 4.8 and Figure 4.8).

Table 4.8: Main effects and interactions between opener, soil quality and residue level for leaf area index in the 2017 season at 30 days after planting.

	Effect	F	P-value
2017	Soil quality	0.01	0.935
	Opener	0.07	0.815
	Residue levels	0.36	0.713
	Soil quality x Opener	5.81	0.095
	Soil quality x Residue levels	1.65	0.268
	Opener x Residue levels	0.41	0.680
	Soil quality x Opener x Residue levels	1.28	0.345

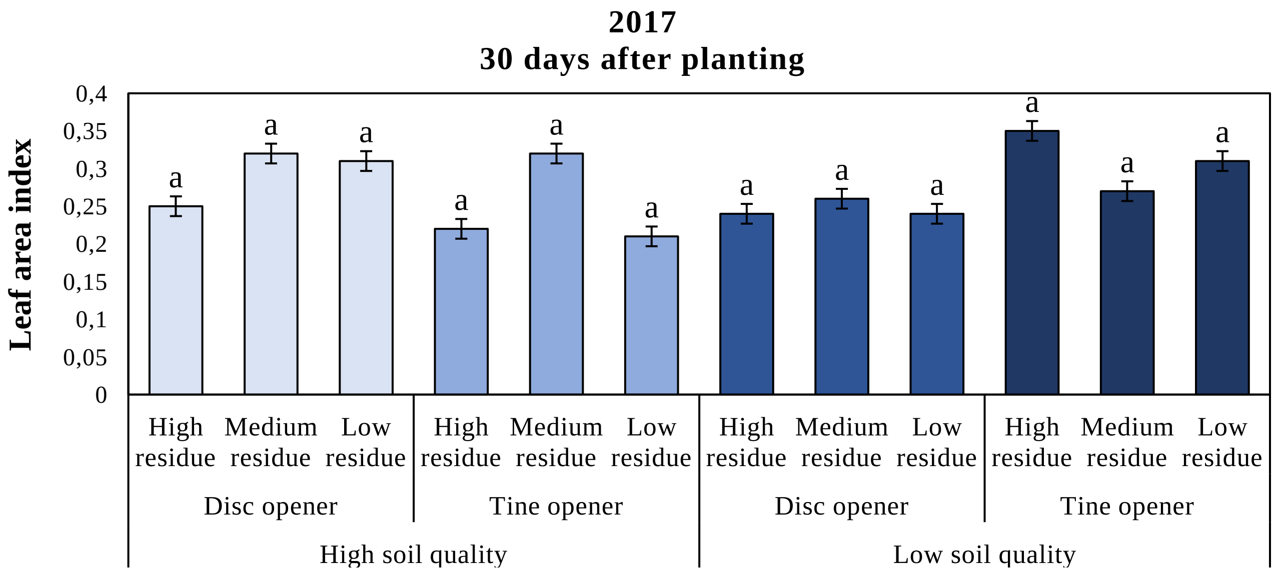
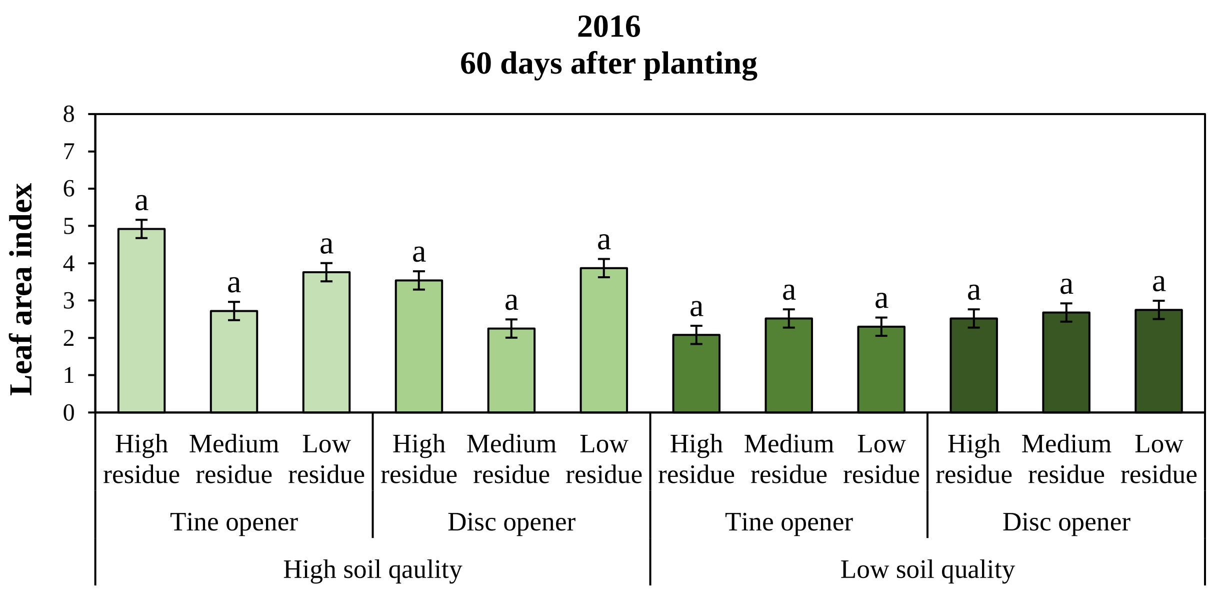


Figure 4.8: Leaf area index (LAI) at 30 days after planting on a high and low soil quality for the tine or disc opener with different levels of residues for 2017 season. Bars with different letters indicate significant differences at a 5% level. The error-bars illustrate the standard error within each treatment.

There was no significant (P>0.05) interaction between soil quality, residue level and opener with regard to LAI at 60 days after planting in the 2016 season (Table 4.9 and Figure 4.9). Similarly, in 2017 season, there were also no significant (P>0.05) interactions between soil quality, opener and residue level (Table 4.9).

Table 4.9: Main effects and interactions between opener, soil quality and residue level for leaf area index in the 2016 and 2017 season at 60 DAP.

	Effect	F	P-value
2016	Soil quality	6.28	0.242
	Opener	0.00	0.979
	Residue levels	0.75	0.543
	Soil quality x Opener	0.67	0.563
	Soil quality x Residue levels	1.38	0.321
	Opener x Residue levels	0.52	0.641
	Soil quality x Opener x Residue levels	0.40	0.680
2017	Soil quality	1.45	0.316
	Opener	0.83	0.430
	Residue levels	0.73	0.521
	Soil quality x Opener	0.13	0.744
	Soil quality x Residue levels	0.67	0.548
	Opener x Residue levels	0.85	0.475
	Soil quality x Opener x Residue levels	1.96	0.221



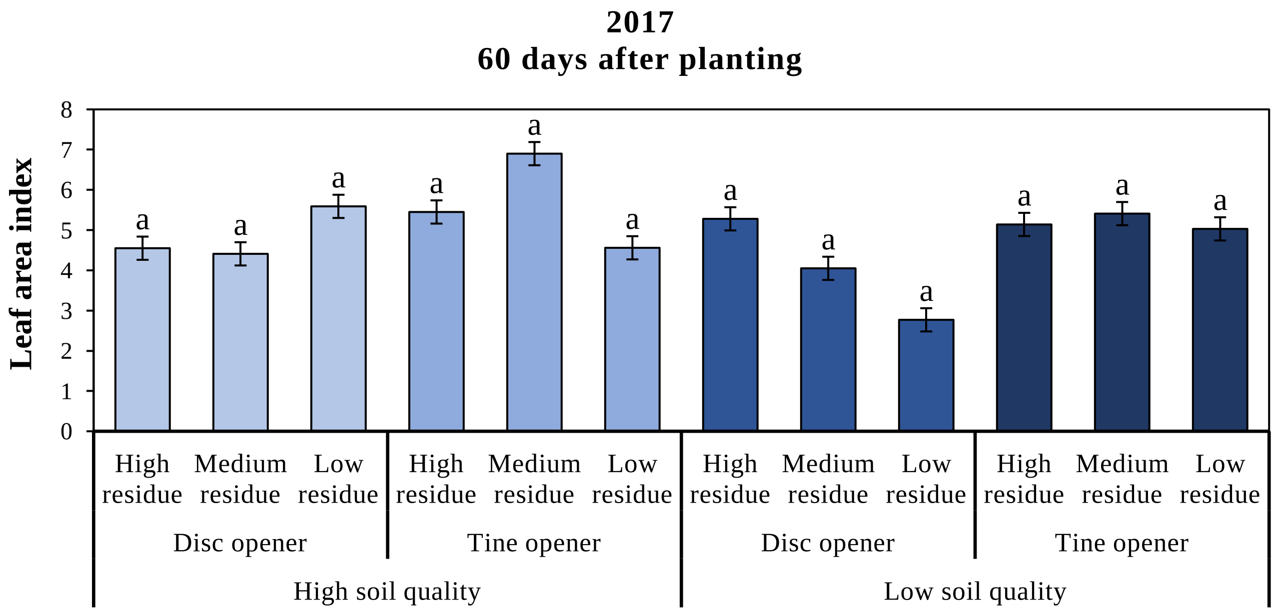
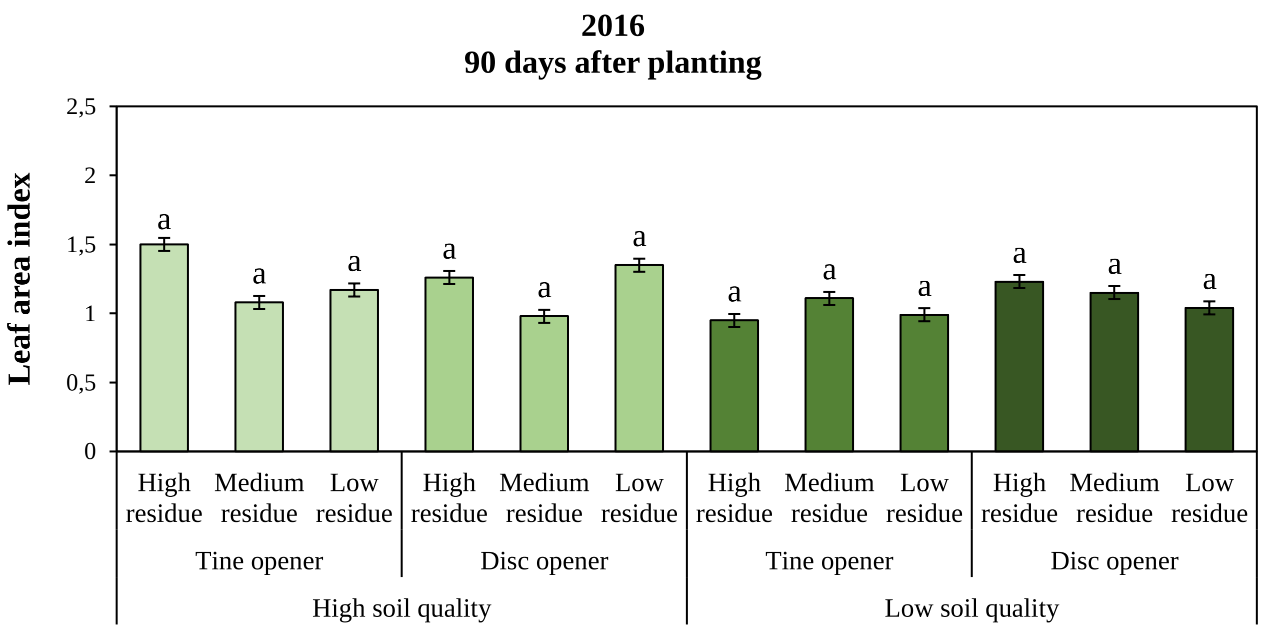


Figure 4.9: Leaf area index (LAI) at 60 days after planting on a high and low soil quality for the tine or disc opener with different level residues for 2016 and 2017 season. Bars with different letters indicate significant differences at a 5% level. The error-bars indicate the standard error within each treatment.

The interaction of soil quality, opener, and residue levels was not significant (P>0.05) with respect to the leaf area index at 90 days after planting (Table 4.10). Likewise, in the 2017 season, there were no differences recorded (Table 4.10 and Figure 4.10).

Table 4.10: Main effects and interactions between opener, soil quality and residue level for leaf area index in the 2016 and 2017 season at 90 DAP.

	Effect	F	P-value
2016	Soil quality	0.25	0.704
	Opener	0.03	0.893
	Residue levels	0.14	0.878
	Soil quality x Opener	0.20	0.730
	Soil quality x Residue levels	0.52	0.621
	Opener x Residue levels	0.06	0.947
	Soil quality x Opener x Residue levels	0.39	0.686
2017	Soil quality	0.68	0.469
	Opener	0.61	0.492
	Residue levels	1.46	0.304
	Soil quality x Opener	0.32	0.612
	Soil quality x Residue levels	0.38	0.701
	Opener x Residue levels	2.71	0.145
	Soil quality x Opener x Residue levels	1.10	0.393



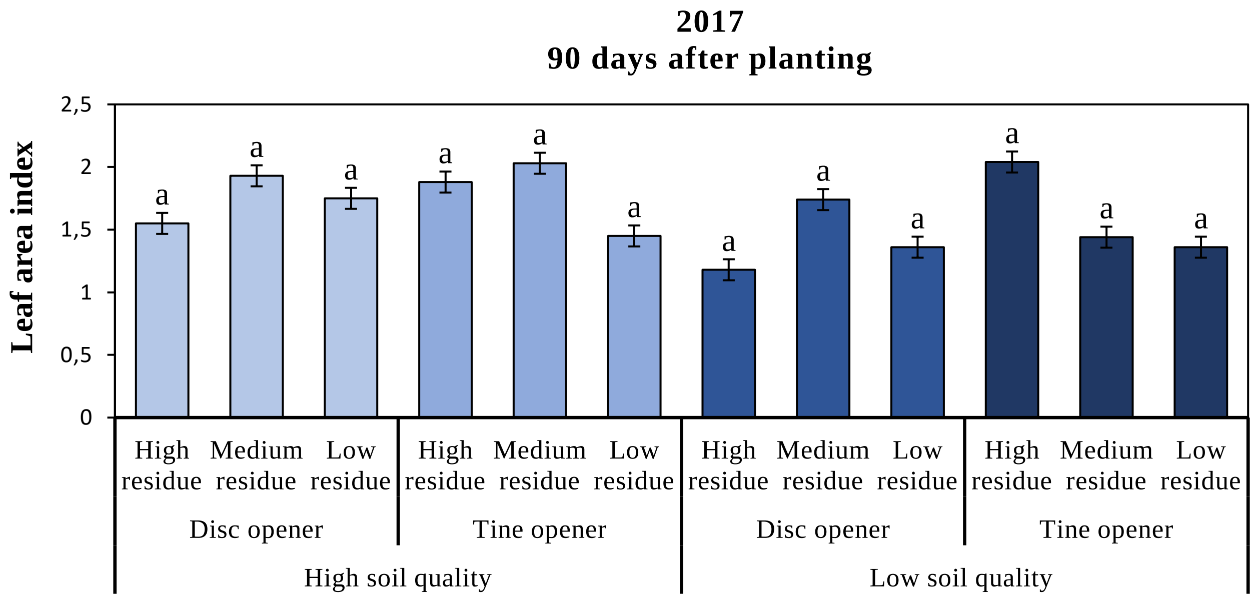


Figure 4.10: Leaf area index (LAI) at 90 days after planting on a high and low soil quality for the tine or disc opener with different level residues for 2017 season. Bars with different letters indicate significant differences at a 5% level. The error-bars indicate the standard error within each treatment.

4.5 Ear bearing tillers (EBT)

The number of EBT were not determined in the 2016 season. There were no differences (P>0.05) between any of the treatments for the 2017 season (Table 4.11 and Figure 4.11).

Table 4.11: Main effects and interactions between opener, soil quality and residue level for ear-bearing tillers for the 2017 season.

	Effect	F	P-value
2017	Soil quality	2.41	0.218
	Opener	2.52	0.211
	Residue levels	1.73	0.256
	Soil quality x Opener	0.04	0.855
	Soil quality x Residue levels	1.99	0.217
	Opener x Residue levels	1.51	0.295
	Soil quality x Opener x Residue levels	0.42	0.677

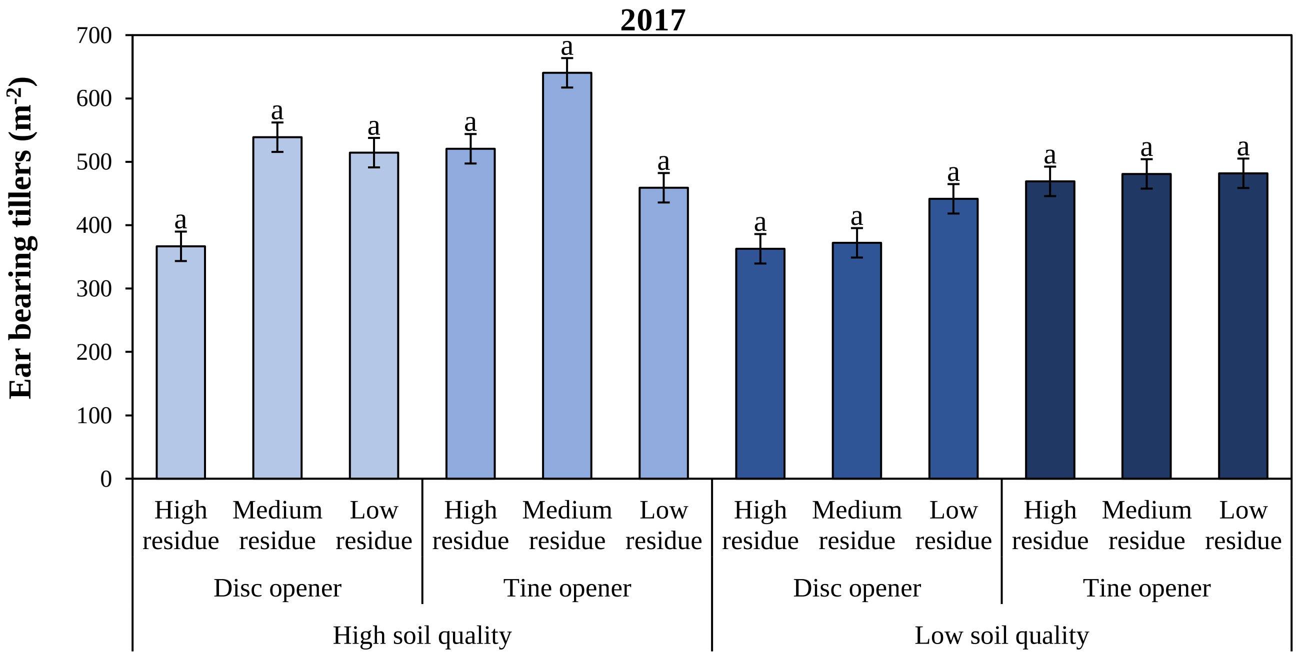


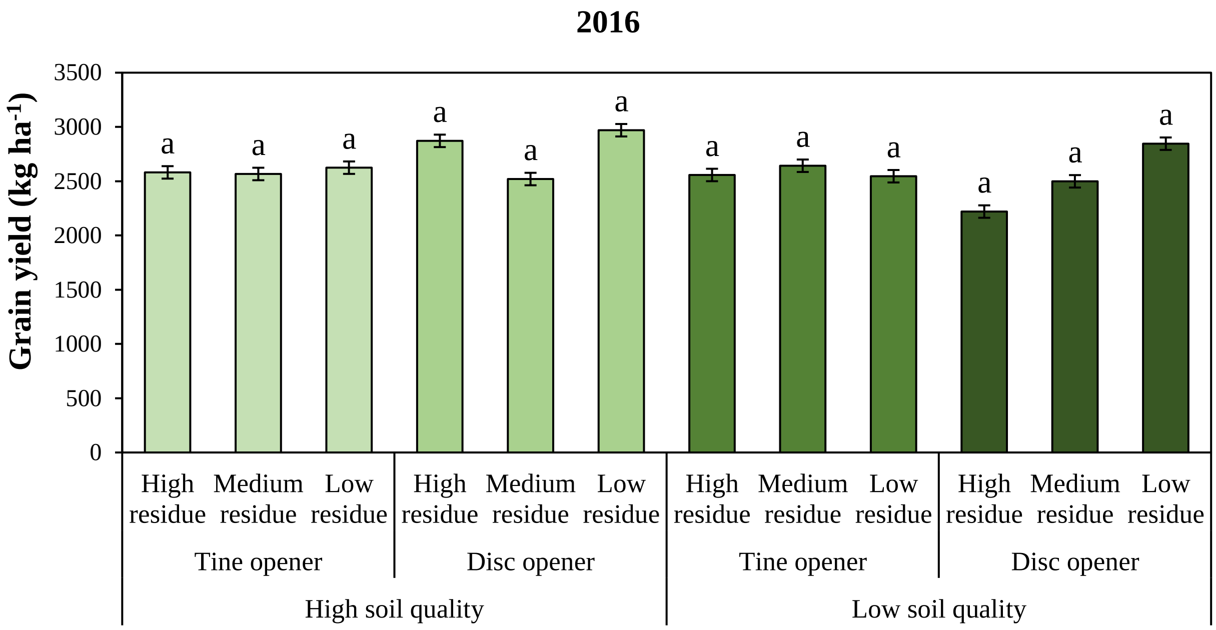
Figure 4.11: Ear-bearing tillers (m^{-2}) in 2017 on high and low soil quality for the tine or disc opener with different level residues. Bars with different letters denote significant differences (P< 0.05). The error-bars indicate the standard error within each treatment.

4.6 Wheat grain yield

During 2016, there were no significant (P>0.05) differences observed in all the treatments (Table 4.12 and Figure 4.12). Furthermore, this was also observed on the main effects and two-way interactions (soil quality x residues, and opener x residue levels; P>0.05; Table 4.12). Similarly, in 2017 season, no significant (P>0.05) effect was caused by the soil quality, opener, and residues levels on the wheat grain yield. All the treatments were similar (Figure 4.12).

Table 4.12: Main effects and interactions between opener, soil quality and residue level for wheat grain yield for the 2016 and 2017 season.

	Effect	F	P-value
2016	Soil quality	0.43	0.632
	Opener	0.04	0.877
	Residue levels	0.48	0.661
	Soil quality x Opener	0.03	0.889
	Soil quality x Residue levels	0.22	0.806
	Opener x Residue levels	0.49	0.653
	Soil quality x Opener x Residue levels	0.57	0.583
2017	Soil quality	0.00	0.995
	Opener	1.14	0.365
	Residue levels	0.14	0.872
	Soil quality x Opener	4.74	0.118
	Soil quality x Residue levels	0.23	0.801
	Opener x Residue levels	1.34	0.329
	Soil quality x Opener x Residue levels	0.98	0.429



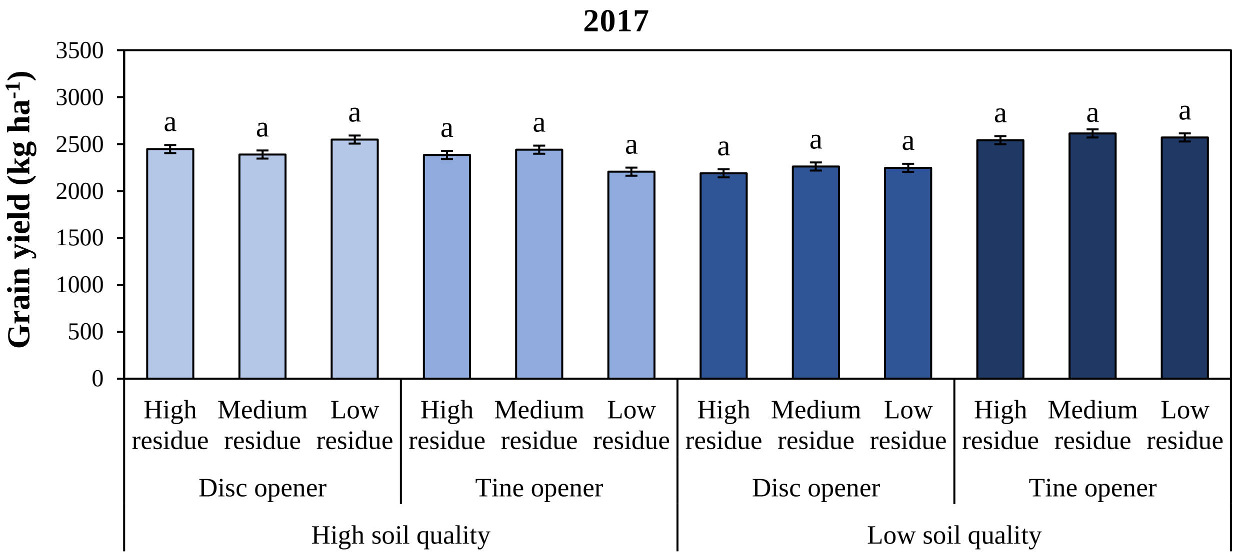


Figure 4.12: Wheat grain yield measured in 2016 and 2017 season on high and low soil quality for the tine or disc opener with different level residues. Bars with different letters denote significant differences at a 5% level. The error-bars indicate the standard error within each treatment.

4.7 Thousand Kernels Mass (TKM)

There were no interactions (P>0.05) observed between soil quality, opener or residue level for TKM during the 2016 season (Table 4.13). During the 2017 season, similar results were observed, as no interactions (P>0.05) were recorded between soil quality, opener and residue level for TKM (Table 4.13 and Figure 4.24). Similar TKM were recorded between all treatments in both seasons.

Table 4.13: Main effects and interactions between opener, soil quality and residue level for TKM for the 2016 and 2017 season.

	Effect	F	P-value
2016	Soil quality	5.25	0.262
	Opener	1.75	0.412
	Residue levels	0.44	0.680
	Soil quality x Opener	0.11	0.795
	Soil quality x Residue levels	0.44	0.664
	Opener x Residue levels	0.44	0.678
	Soil quality x Opener x Residue levels	0.45	0.652
2017	Soil quality	2.23	0.232
	Opener	1.18	0.357
	Residue levels	1.53	0.291
	Soil quality x Opener	0.48	0.538
	Soil quality x Residue levels	1.38	0.320
	Opener x Residue levels	2.70	0.146
	Soil quality x Opener x Residue levels	1.46	0.304

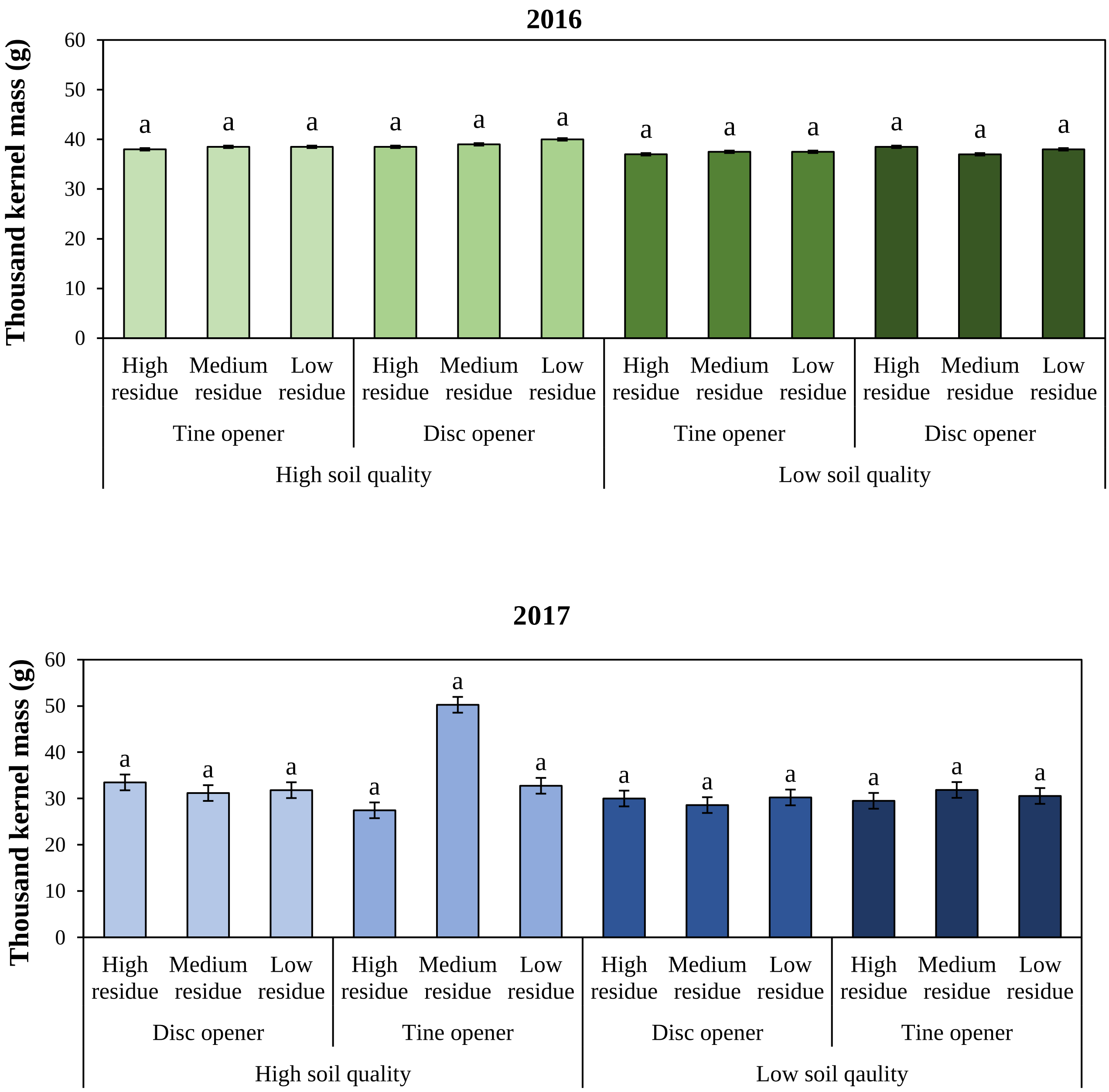


Figure 4.13: TKM (g) measured in 2016 and 2017 season on high and low soil quality for the tine or disc opener with different level residues. Bars with different letters denote significant differences (P< 0.05). The error-bars indicate the standard error within each treatment.

4.8 Hectolitre mass (HLM)

During 2016, there were no significant (P>0.05) differences observed in all the treatments (Table 4.14 and Figure 4.25) for the hectolitre mass. Furthermore, this was observed on the main effects and two-way interactions (soil quality x residues, and opener x residue levels; P>0.05; Table 4.14 and Figure 4.14). In 2017 season, interaction (P<0.05) effect was initiated by the soil quality, opener, and residues levels on the HLM. However, tine opener achieved the lowest HLM on low quality soils with medium residue levels compared to disc opener, whilst disc opener recorded the lowest HLM on high soil quality with high residue level (Figure 4.25).

Table 4.14: Main effects and interactions between opener, soil quality and residue level for HLM for the 2016 and 2017 season.

	Effect	F	P-value
2016	Soil quality	0.01	0.954
	Opener	034	0.662
	Residue levels	0.15	0.866
	Soil quality x Opener	0.72	0.553
	Soil quality x Residue levels	2.04	0.211
	Opener x Residue levels	0.11	0.900
	Soil quality x Opener x Residue levels	0.01	0.986
2017	Soil quality	0.15	0.720
	Opener	0.65	0.478
	Residue levels	1.47	0.303
	Soil quality x Opener	1.05	0.382
	Soil quality x Residue levels	0.01	0.988
	Opener x Residue levels	1.27	0.347
	Soil quality x Opener x Residue levels	7.48	0.023

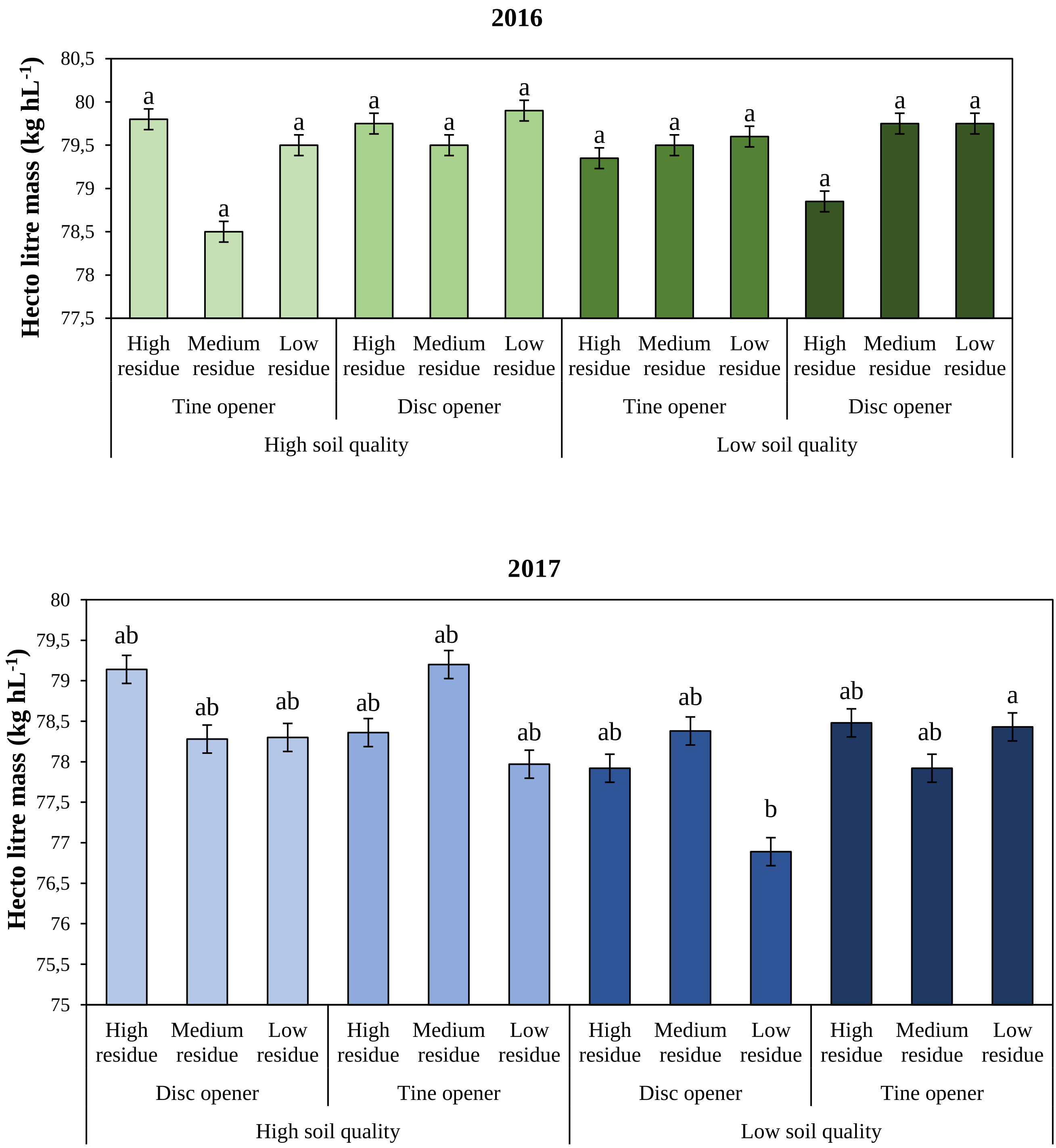


Figure 4.14: HLM (kg hL^{-1}) measured in 2016 and 2017 season on high and low soil quality for the tine or disc opener with different level residues. Bars with different letters denote significant differences ($P < 0.05$). The error-bars indicate the standard error within each treatment.

Chapter 5

Discussion

5.1 Soil disturbance

It was observed during planting that the disturbance of soil and the residue did not cause major problems when disc openers were used. However, occasionally residues blocked the tine or disc openers or prevented proper functioning. In this study, soil surface roughness and groove width were the two indicators used to measure soil disturbance. In both 2016 and 2017 seasons, no significant interaction between openers and soil quality was recorded in terms of soil disturbance ($P>0.05$). This is contrary to literature where it showed that tine openers caused more soil disturbance than disc openers under different soil qualities (Tessier *et al*., 1991; Swanepoel *et al*., 2017). This could be mainly due to a high stone content and dry soil conditions of the 2016 and 2017 seasons, when planting of wheat took place. Swanepoel *et al*. (2014) emphasised that a high stone content decreases the quality of the soil, and stones may affect the efficiency of openers. No rain was received before the end of May 2016, and the soil was still dry with a gravimetric water content of 3.7%. In 2017, the trial was established on 3 May, also in dry soil with a gravimetric water content of 5.7%, and again no rain was received before the end of May. Therefore, both seasons had a dry start, which could have contributed to no soil disturbances observed between tine or disc openers.

One can expect significant variation in results under moist soil conditions, and it is possible that dry soil is more easily disturbed than moist soil. Swanepoel *et al*. (2017) conducted a study under dry soil conditions where tine openers disburbed soil more than the disc openers in low quality soils, but no difference was found on high quality soils. This implies that soil quality might be one of the factors that may have an impact on these results. Several studies have indicated that tine openers create more surface roughness and wider groove widths compared to disc openers (Chen *et al*., 2004; Tessier *et al*., 1991; Swanepoel *et al*., 2017). In a study by Bahri and Bansal (1992) it was reported that tine openers tend to perform well under dry and hard soil conditions while disc openers are more appropriate when seeding in soft and moist soils.

The high stone content may have caused the disc openers to place seed ineffectively at different depths and create more soil disturbance as it displaces stones that are in the way of a planter. Disc openers bounced and created irregularities while tine openers showed uniform seedbed and seedling depth (Bahri and Bansal, 1992). Choudhari (2001) also emphasised that with poor soils (stoney) disc openers tend to have minimum depth variation and create similar disturbance compared to tine openers.

The speed of the tractor is also a factor that might result in soil disturbance by the furrow openers because a slow seeding may disadvantage disc openers, as they will lose the cutting ability through soil. Altikat and Celik (2012) reported that tractor speed had no effect on soil properties and winter wheat establishment when using no-till seeders such as tine and disc openers. Barr *et al*. (2016) measured the effect of speed (8, 12, 16 km h^{-1}) on soil disturbance. There was a potential for disc openers to increase operating speeds up to 16 km h^{-1} thereby minimising soil disturbance and allowing for timely sowing. In the current study, the seeding speed in 2016 was 5 km h^{-1} for both disc and tine opener. In 2017 the seeding speed of the disc opener was increased to 9 km h^{-1}, which is considered to be the best practise. Although a higher speed was expected to cause less soil disturbance, this was not the case as the average groove width and the surface roughness results were similar.

5.2 Residue arrangement

Residue plays an important role in soil health, water conservation and plant growth. Altikat *et al*. (2013) lamented that crop residue covering the rows where wheat was planted decreased the growth of wheat due to physical impact of the straw. Flower *et al*. (2012) noted that large quantities of crop residues has a beneficial effect on weed suppression. The plants grow long as to get through crop residues. Residue might become a problem when establishing wheat with both the tine and disc openers. However, the current study shows that wheat can handle large loads of crop residues well. Large amount of straw may have an impact on wheat at the early stages of development resulting to poor crop establishment and canopy development (Lafond *et al.*, 2009). When crop residue levels are relatively high depending on seasonal conditions, negative impact of residue retention may include physical impairment of seed-drills and also crop establishment (Flower et al., 2017). This may pose challenges for the subsequent crops in rotation.

During planting tine openers pushed large amount of residues aside and block the planter leading to ineffective seed placement on the furrow rows as well as poorer crop establishment.

In the current study residues were manipulated prior to planting and was done by hand. Samples were taken to determine the amount of residue applied. Therefore, the residue applied in 2016 and 2017 were not exactly the same load per specific treatment for the respective years. The residue applied on low and high residue plots were similar, but the residue applied on medium plots differed substantially between years. In 2016, 4.3 t ha^{-1} was applied on medium residue plots and in 2017 and 6.2 t ha^{-1}. Therefore, the results obtained between medium and high residue plots on both high and low quality soil during the 2017 season was expected to be similar.

5.3 Plant population

Planting density is one of the main factors that can influence yield. A plant population of 150 to 175 wheat plants m^{-2} is optimal in the dryland production systems of the Western Cape and marginal at 120 plants m^{-2} (Neethling, 2018). To ensure that the plant population is not a limiting factor, the optimum plant population of wheat is related to the yield and that planting density should therefore be increased when higher grain yield is expected (Anderson and Impiglia, 2002). Anderson (1986) investigated the relationship between plant populations, yield components and grain yield. There was a tendency for larger optimum plant populations to achieve higher wheat grain yields. In this regard, both 2016 and 2017 seasons, had no difference between plant populations measured between the tine and disc openers on either low or high quality soils with residue levels. In the current study, a similar plant population resulted for all the treatments. This was in agreement with Doan *et al*. (2005) as tine and disc openers resulted in similar plant populations. During 2016 and 2017 seasons both tine and disc openers achieved the optimum plant population on low and high quality soils with different residue levels. In 2016 plant population from tine openers ranged from 181 to 259 m^{-2} where disc openers range from 191 to 306 m^{-2} and in 2017 tine openers ranged from 131 to 178 m^{-2} while disc openers ranged from 110 to 146 m^{-2} ($P>0.05$), these were a bit higher in 2016 but better in 2017 season. During 2017, plant populations achieved was lower than in 2016 season. The impact on plant population for both seasons may be due to late onset of rainfall in 2016 and even later onset of rainfall in 2017. This could be the reason for the similar results on crop establishment and consequently an impact on yield, especially in 2017 season. This agrees with the study conducted by Swanepoel *et al*. (2017) that plant population was similar between the soil quality and seed-drill openers following the establishment of wheat.

5.4 Wheat biomass production

Tessier *et al*. (1991) mentioned that disc openers resulted in a significantly faster wheat emergence and plant population than tine openers leading to high plant density and biomass production at the early stages of growth. Within the early stages after planting, biomass production is quite low as the plants and their leaves are still small which means their photosynthetic capacities are incomplete. The water stress during both planting seasons may have impacted the biomass production leading to lower yields. Bahri & Bansal (1992) indicated that using disc or tine openers under dryland conditions tend to reduce plant population leading to low biomass throughout the production cycle, mainly because of a prolonged drought.

The interaction of soil quality, opener, and residue levels was not significant (P>0.05) on biomass production during both seasons at 30, 60, and 90 days after planting, with the only difference found in 2016 at physiological maturity. On low quality soils where disc openers were used, a significant increase (P<0.05) in biomass production was recorded compared tine openers on medium residues in 2016 season (Figure 4.7). Even though 2016 received more rain than 2017 (Figure 3.1), the amount of rainfall during the growing season was considered low for both seasons compared to long-term rainfall data. The low rainfall could have influenced biomass production to such an extent that the tine openers under low quality soils produced low biomass production. The tine openers performed well throughout the production cycle under high quality soils from 30 days after planting until 90 days after planting regardless of residue levels. During the 2017 season, residue level seems to have caused poor wheat establishment that resulted in lower biomass production (P < 0.05; Table 4.6). In this regard, disc openers produced more biomass than tine openers regardless of the type of soil and residue level. When crop residue levels are relatively high depending on seasonal conditions, negative impact of residue retention may include physical impairment of seed-drills and also crop establishment (Flower *et al*., 2017). This may pose challenges for the subsequent crop in rotation.

The reason may be due to the fact that during planting tine openers push large amount of residues aside leading to ineffective seed placement on the furrow rows as well as poorer crop establishment. Another reason for low biomass production could be the high stone fraction causing the seed-drill to seed at uneven depths and some of the seed deposited on top of the soil.

5.5 Leaf Area Index

LAI defines the potential surface area of leaves available for capturing light interception and thus photosynthetic capacity. The LAI decreases from late flowering to physiological maturity as plants shed their leaves. According to Mahdi *et al*. (1998) initial crop establishment is one of the major constraints to wheat production in some environmental conditions. This can be assessed in terms of LAI during early growth. Therefore, a high LAI gives a plant the capacity for higher biomass production and yield potential (Viña *et al*., 2011; Breda, 2003). Mahdi *et al*. (1998) mentioned the impact of using different no-till systems at varying sowing depth, where results showed that there was a reduction caused by increasing depths in tiller numbers, leaf area index, and the grain yield.

In this study, no differences ($P > 0.05$) were recorded throughout the production cycle from 30 days after planting to 90 days after planting for leaf area index. The early part of the growing season experienced slight higher temperatures (Figure 3.1), which may have shortened the duration of the vegetative growth stage. Hocking and Stapper (2001) emphasised the importance of timely sowing to allow facilitate a longer growing period to maximise yield. The delay in onset of the rainy season and the fact that it took a long time for the plants to emerge may have affected LAI and biomass production negatively, even though similar results were obtained for 2016 and 2017 seasons. This is one of the limitations of production systems in areas with a Mediterranean-type climate. Therefore, both seasons experienced water stress especially towards the flowering stage where plants demand more water, which certainly may have a negative effect on duration of the development stages of the wheat crop. A study by Tesfamariam *et al.* (2010) suggested that the drought during the vegetative and flowering stages of the plant have a major impact on the LAI. They have indicated that sufficient plant available water throughout the season have resulted in a higher LAI and biomass leading to high yields.

5.6 Ear-bearing tillers

The final number of wheat ear-bearing tillers (m^{-2}) is a good indicator of grain yield potential. Van Zyl (2017) found that the number of ear-bearing tillers was significantly higher when no-tillage seed-drills were used. It was found that the higher amount of wheat ears could be because of higher seed survival rates, LAI and higher biomass production. It was also found that a higher number of wheat seedlings per square metre increased the number of ear-bearing tillers. In the current study there were no significant differences (P>0.05) between any of the treatments (Table 4.11 and Figure 4.11) in terms of ear-bearing tillers. For the disc openers, number of ear-bearing tillers ranged from 367 m^{-2} to 539 m^{-2} under high quality soils while on low quality soil ranged from 363 m^{-2} to 442 m^{-2} regardless of residue levels. This indicates importance of maintaining soil quality through good agronomical management practices.

5.7 Wheat grain yield

During 2016, there were no significant (P > 0.05) grain yield differences between any of the treatment factors (Table 4.12 and Figure 4.12). Similarly, in 2017 season no impact was caused by the soil quality, opener, and residue level. This was contrary to the findings by Swanepoel *et al*. (2017) where wheat establishment with disc openers resulted in superior yields when compared to tine openers, regardless of soil quality. It implies that wheat was not sensitive to residue loads. The reason for similar yields might be attributed to fertiliser placement with the seed when planting with the disc opener, which could lead to lower emergence resulting to poor yields. The dry conditions experienced during both seasons, causing potential stress on the crop developmental stages (Figure 3.1) may have had an impact on the yield components and consequently on the final yields.

Robertson *et al*. (2016) found that wheat yield was positively correlated with biomass production if temperatures are at optimum levels and no water stress existed. The late onset of the rainy season might have a negative effect on the wheat grain yield as Hocking and Stapper (2001) emphasised the importance of timely sowing to allow longer photoperiod to maximise yield.

5.8 Thousand kernel mass

The thousand kernel mass is a good indicator that depict soil and environmental factors by influencing crop growth after flowering period of a plant (Wiatrak *et al*., 2006; Van Zyl, 2017). In both 2016 and 2017 seasons no significant differences (P > 0.05) were observed for all the treatments on thousand kernel mass. Similar results were found by Van Zyl (2017), where no significant changes were obtained in the thousand kernels mass due to the different tillage practices and residues. This may be related to the weather conditions (rainfall distribution and the temperatures), which might have reduced the duration of grain filling period during the growing season.

5.9 Hectolitre Mass

Hectolitre mass (HLM) is defined as the weight of a standard volume of wheat and also a function of wheat density (Manley *et al.*, 2009). It is one of the aspects used in wheat grading and serves as a guide to a combination of characteristics, including wheat flour yield (Manley *et al.*, 2009). Hectolitre mass was not influenced by any of the treatments in 2016 (Table 4.14; Figure 4.14) as this was in agreement with the study done by (Neethling, 2018) on Langgewens Research Farm in 2016. In the 2017 season, interaction effects between soil quality, opener, and residues levels on the HLM were significant ($P<0.05$). Disc openers achieved the lowest HLM on low quality soils with low residue levels compared to tine openers. Also disc openers recorded the highest HLM on high soil quality with high residue level (Figure 4.25). This, however might be due to the effect of drought during the 2017 season. Van Zyl (2017) reported that the significant higher mean HLM could have been the effect of drought where no-till systems conserved more water in the profile. Hectolitre mass that will ensure high quality wheat normally range from 70 to 80 kg hL^{-1}, but can vary due to the climatic conditions and insect or disease damage (Manley *et al.*, 2009; Neethling, 2018). In 2016 hectolitre mass from both tine and disc openers ranged from 79 to 80 kg hL^{-1} and in 2017 tine openers ranged from 78 to 79 kg hL^{-1}while disc openers ranged from 77 to 79 kg hL^{-1} ($P>0.05$), the hectolitre mass for all the treatments were at optimum levels for both seasons.

Chapter 6

Conclusion and recommendations

6.1 Synopsis

The Western Cape's Swartland region is one of the most important wheat producing regions in South Africa. Wheat is cultivated in dryland conservation agriculture systems with canola and annual medics as the most popular rotation crops. In the past two decades there has been a rapid increase in the adoption of CA practices in South Africa, with the Western Cape Province having the highest adoption rate (Basson *et al*., 2017). Wheat producers have been relying on tine openers to establish their crops. In the past five years the interest in using disc openers is rapidly increasing due to the success in South America and Australia. The disc opener is a new technology that has not been scientifically vindicated under the Western Cape conditions.

The aim of this study was to compare tine and disc openers and the effects of soil quality and crop residue on wheat production, by evaluating establishment, biomass production, leaf area index (LAI), wheat grain yield, thousand kernels mass (TKM), ear-bearing tillers (EBT), hectolitre mass (HLM) and soil disturbance. The trials were conducted at the Langgewens Research Farm of the Western Cape Department of Agriculture in the Swartland. Three factors were investigated in the study including 1) openers (tine or disc), 2) residue level (high, medium, low), and 3) soil quality (high or low). An Equalizer no-tillage seed-drill with interchangeable tine or disc openers was used, which eliminates potential bias of weight differences and seeding efficiency of using different seeding implements. This allowed evaluation of the true effect of the tine and disc openers themselves. The study was conducted over two growing seasons (2016 and 2017), both of which were relatively dry.

6.1.1 Objective 1: The first objective was to evaluate the degree of soil disturbance caused by tine or disc openers in the soils of different qualities.

In both 2016 and 2017 seasons, no significant difference between tine or disc openers, and soil quality was recorded with regard to soil disturbance. Similar results might due to a high stone content on the field and the dry soil conditions of 2016 and 2017 seasons. The tractor speed might also be a factor that contributed to similar soil disturbance by the openers as slower seeding will disadvantage disc openers as they will lose the cutting ability through soil. Therefore, it can be regarded that the two openers cause the same amount of soil disturbance. This was contrary to the general belief that the disc openers will disturb soil less compared to tine openers. One can expect significant variation in results under soil moist conditions, and it is possible that dry soil is more easily disturbed than moist soil. However, in the current study showed that stone content was the most important factor causing similar results.

6.1.2 Objective 2: To evaluate the success of establishment of wheat planted with a tine or disc openers through different quality soils with different residue levels.

In the current study, the tine and disc openers performed similarly in the 2016 and 2017 seasons with regard to plant population, leaf area index, ear-bearing tillers, grain yield, and thousand kernels mass regardless of soil quality and residue level. The only difference was found in 2016 at physiological maturity in terms of biomass. On low quality soils where disc openers were used, a significant increase in biomass production were recorded compared tine openers on medium residues in 2016 season. Wheat was planted in dry soil in both 2016 and 2017 (Figure 3.1). During the 2017 season, residue level seems to have caused poor wheat establishment that resulted in lower biomass production. Residues can become a challenge when establishing wheat with both tine and disc openers, and crop establishment was the best at low residue levels.

6.2 General conclusion

The 2016 and 2017 seasons climatic conditions in which the trials were conducted differed substantially, although for both years the wheat was planted in dry soils. The average 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 238.1 mm was recorded. In both 2016 and 2017 treatments did not affect the degree of soil disturbance. Wheat planted with the tine opener on high quality soils performed well throughout the production cycle when biomass is considered regardless of residue level. A similar yield and yield components were obtained in both years. This shows that one can expect significant variation in results between seasons, and that the season dictates production potential of wheat. In the end, similar yields were achieved during both 2016 and 2017 seasons and therefore either a disc or tine openers used in this study can be used by wheat producers for planting wheat in the Swartland. Farmers need to keep track of the tractor speed for these different openers and also factors such as maintenance cost and fuel consumptions should be considered when utilising the openers.

6.3 Limitations of the study

The study was undertaken within the two years which were relatively dry at the time of planting. Due to the lack of rainfall for about four weeks after planting, a delay in crop emergency was experienced which could have contributed to the results obtained in the study.

Residues might become a challenge when establishing wheat with both the tine and disc openers. However, the current study shows that wheat can handle large loads of crop residues well. The opener have a limit regarding the amount of residue it can handle, as too much residue blocks the seeder. In the study residues were placed on the plots a month prior to planting and should have actually been placed on the plots just after the harvest of the previous crop to allow for decomposition and to get a more accurate effects of residues.

Both tine and disc openers are designed to allow for simultaneous seeding and fertilising. Fertiliser was placed with the seed when seeding with the disc openers which could have caused chemical injury to the seed and delay or reduce crop establishment.

6.4 Recommendations for future research

In the current study wheat was planted in dry soil using tine and disc openers, but we do not know how these two openers will perform when planting in wet soils. Therefore, it is recommended that this study is repeated in other years in the Swartland region and Southern Cape as the soils and climatic conditions are different between these regions. Further research is also suggested which should focus on an economic evaluation of disc and tine openers to provide producers further insight in choosing between the two openers.

The high stone fractions resulted the seed-drills to seed at uneven depths and some of the seed deposited on top of the soil, therefore one should look at the uniformity of seed placement (depth) by these different seeders. Residue management should begin when plants are harvested. More attention should 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-drill openers to be able to seed through the residue the following season.

More research on soil disturbance needs to be done, as the current study only measured surface roughness and groove width with a pin profiler that only measures surface irregularities on the furrows. Therefore, one should look at the soil disturbance deeper into the soil profile. Root biomass is important as there is a correlation between root biomass and aboveground biomass production. In the current study only aboveground biomass production was measured, therefore one should investigate root elongation between the plants seeded with disc or tine openers. The study should be done in sandy soils with low stone content. These future researches would contribute further to the development and success of wheat production in the Western Cape South Africa.

6.4 References

Ahmad, F., Weimin, D., Qishou, D., Rehim, A. and Jabran, K. 2017. Comparative Performance of Various Disc-Type Furrow Openers in No-Till Paddy Field Conditions. *Sustainability*, *9*(7), p.1143.

Aikins, K.A., Antille, D.L. Jensen, T.A. and Blackwell, J. 2017. Advances in residue management mechanisms of zero-tillage planters. In *2017 ASABE Annual International Meeting* (p. 1). American Society of Agricultural and Biological Engineers.

Altıkat, S. and Celik, A. 2012. Effects of different no-till seeders and tractor forward speeds on the soil physical properties and seed emergence of summer vetch and winter wheat. *Tarım Bilimleri Dergisi*, *18*(1).

Altikat, S., Celik, A. and Gozubuyuk, Z. 2013. Effects of various no-till seeders and stubble conditions on sowing performance and seed emergence of common vetch. *Soil and Tillage Research*, *126*, pp.72-77.

Anderson, W.K. 1986. Some relationships between plant population, yield components and grain yield of wheat in a Mediterranean environment. *Australian Journal of Agricultural Research*, *37*(3), pp.219-233.

Anderson, W.K. and Impiglia, A. 2002. Management of dryland wheat. *FAO Plant Production and Protection Series (FAO)*.

Anderson, W.K., Sharma, D.L., Shackley, B.J. and D'Antuono, M.F. 2004. Rainfall, sowing time, soil type, and cultivar influence optimum plant population for wheat in Western Australia. *Australian Journal of Agricultural Research*, *55*(9), pp.921-930.

Andrews, S.S. and Carroll, C.R. 2001. Designing a soil quality assessment tool for sustainable agroecosystem management. *Ecological Applications*, *11*(6), pp.1573-1585.

Andrews, S.S., Karlen, D.L. and Cambardella, C.A. 2004. The soil management assessment framework. *Soil Science Society of America Journal*, *68*(6), pp.1945-1962.

Arshad, M.A. and Coen, G.M. 1992. Characterization of soil quality: physical and chemical criteria. *American Journal of Alternative Agriculture*, *7*(1-2), pp.25-31.

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

Barr, J.B., Desbiolles, J.M. and Fielke, J.M. 2016. Minimising soil disturbance and reaction forces for high speed sowing using bentleg furrow openers. *Biosystems Engineering*, *151*, pp.53-64.

Basson, C.H., 2017. A financial analysis of different livestock management approaches within different crop rotation systems in the Middle Swartland (Doctoral dissertation, Stellenbosch: Stellenbosch University).

Blake, G.R. 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. 374 – 390.

Botha, P.B. 2013. The effect of long-term tillage practices on selected soil properties in the Swartland wheat production area of the Western Cape. MSc Thesis, Stellenbosch University, South Africa.

Bréda, N.J. 2003. Ground-based measurements of leaf area index: a review of methods, instruments and current controversies. *Journal of experimental botany*, *54*(392), pp.2403-2417.

Bruce, S., Ryan, M., Kirkegaard, J. and Pratley, J. 2001. Wheat stubble and canola growth-identifying and overcoming limitations. In: Proceedings of the 12th Australian Research Assembly on Brassicas, 25 October 2001, Geelong, Victoria. pp 181-185

Burce, M.E.C., Kataoka, T., Okamoto, H. and Shibata, Y. 2013. Seeding Depth Regulation Controlled by Independent Furrow Openers for Zero Tillage Systems. *Engineering in Agriculture, Environment and Food*, *6*(1), pp.13-19.

Carter, M.R. 1994. A review of conservation tillage strategies for humid temperate regions. *Soil and Tillage Research*, *31*(4), pp.289-301.

Cataldo, D.A., llaroon lll, Schrader, L.E. and Youngs,V.L. 1975. Rapid colormetric determination of nitrate in plant tissue by nitration of salicylic acid. *Communications in Soil Science and Plant Analysis* 6:71-80.

Chen, Y., Tessier, S. and Irvine, B. 2004. Drill and crop performances as affected by different drill configurations for no-till seeding. *Soil and Tillage Research*, *77*(2), pp.147-155.

Choudhari, D. 2001. Performance evaluation of various types of furrow openers on seed drills. *Journal of Agricultural Engineering Research*, *79*(2), pp.125-137.

Cutforth, H.W. and McConkey, B.G. 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*(3), pp.359-366.

Day, P.R. 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

Desbiolles, J. 2011. Disc seeders in conservation agriculture: An Australian survey. In *Proceedings of the 5th World Congress on Conservation Agriculture* (pp. 26-9).

Dick, R.P., Breakwell, D.P, and Turco, R.F. 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.

Doan, V., Chen, Y. and Irvine, B. 2005. Effect of oat stubble height on the performance of no-till seeder openers. *Canadian Biosystems Engineering*, *47*(2), pp.37-44.

Dumanski, J., Peiretti, R., Benetis, J., McGarry, D., and Pieri, C. 2006. The paradigm of conservation tillage. Proceedings of World Association of Soil and Water Conservation, FAO, Rome, pp 58–64.

Ferreira, M.I. and Reinhardt, C.F. 2010. Field assessment of crop residues for allelopathic effects on both crops and weeds. *Agronomy journal*, *102*(6), pp.1593-1600.

Flower, K.C., Cordingley, N., Ward, P.R. and Weeks, C. 2012. Nitrogen, weed management and economics with cover crops in conservation agriculture in a Mediterranean climate. *Field Crops Research*, *132*, pp.63-75.

Flower, K.C., Ward, P.R., Cordingley, N., Micin, S.F. and Craig, N. 2017. Rainfall, rotations and residue level affect no-tillage wheat yield and gross margin in a Mediterranean-type environment. *Field Crops Research*, *208*, pp.1-10.

Fuentes, M., Govaerts, B., De León, F., Hidalgo, C., Dendooven, L., Sayre, K.D., and Etchevers, J. 2009. Fourteen years of applying zero and conventional tillage, crop rotation and residue management systems and its effect on physical and chemical soil quality. *European Journal of Agronomy*. *30(3)*, 228-237.

Gura, I. 2016. Crop rotation and crop residue management effects under no-till on the soil quality of two ecotopes in the Eastern Cape. MSc Thesis, University of Fort Hare, South Africa.

Hobbs, P.R., Sayre, K. and Gupta, R. 2008. The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *363*(1491), pp.543-555.

Hocking, P.J. and 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*(6), pp.623-634.

Hocking, P.J., Mead, J.A., Good, A.J. and Diffey, S.M. 2003. The response of canola (Brassica napus L.) to tillage and fertiliser placement in contrasting environments in southern NSW. *Australian Journal of Experimental Agriculture*, *43*(11), pp.1323-1335.

Jokela, W.E., Grabber, J.H., Karlen, D.L., Balser, T.C. and Palmquist, D.E. 2009. Cover crop and liquid manure effects on soil quality indicators in a corn silage system. *Agronomy Journal*, *101*(4), pp.727-737.

Karlen, D.L., Andrews, S.S., Wienhold, B.J., and Zobeck, T.M. 2008. Soil Quality Assessment: Past, Present and Future. Electronic Journal of Integrative Biosciences.

Karlen, D.L., Cambardella, C.A., Kovar, J.L. and Colvin, T.S. 2013. Soil quality response to long-term tillage and crop rotation practices. *Soil and Tillage Research*, *133*, pp.54-64.

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F. and Schuman, G.E. 1997. Soil quality: a concept, definition, and framework for evaluation (a guest editorial). *Soil Science Society of America Journal*, *61*(1), pp.4-10.

Karlen, D.L., Wollenhaupt, N.C., Erbach, D.C., Berry, E.C., Swan, J.B., Eash, N.S. and Jordahl, J.L. 1994. Long-term tillage effects on soil quality. *Soil and Tillage Research*, *32*(4), pp.313-327.

Kassam, A., Friedrich, T., Derpsch, R., Lahmar, R., Mrabet, R., Basch, G., González-Sánchez, E.J. and Serraj, R. 2012. Conservation agriculture in the dry Mediterranean climate. *Field Crops Research*, *132*, pp.7-17.

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

Kemper, W.D., and Rosenau, R.C. 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.

Lafond, G.P. 1994. Effects of row spacing, seeding rate and nitrogen on yield of barley and wheat under zero-till management. *Canadian Journal of Plant Science*, *74*(4), pp.703-711.

Lafond, G.P., Stumborg, M., Lemke, R., May, W.E., Holzapfel, C.B. and Campbell, C.A. 2009. Quantifying straw removal through baling and measuring the long-term impact on soil quality and wheat production. *Agronomy Journal*, *101*(3), pp.529-537.

Le Roux, A.A. 2015. The effect of soil residue cover on medicago pasture establishment and production under conservation agricultural practices. MSc Thesis, Stellenbosch University, South Africa.

Le Roux, P.J.G. 2018. Establishment, growth and yield of canola (*Brassica napus* L.) as affected by seed-drill opener, soil quality and crop residue in the Swartland. MSc Thesis, Stellenbosch University, South Africa.

Loke, P.F., Kotzé, E. and Du Preez, C.C. 2012. Changes in soil organic matter indices following 32 years of different wheat production management practices in semi-arid South Africa. *Nutrient Cycling in Agroecosystems*, *94*(1), pp.97-109.

Mahdi, L., Bell, C.J. and Ryan, J. 1998. Establishment and yield of wheat (Triticum turgidum L.) after early sowing at various depths in a semi-arid Mediterranean environment. *Field Crops Research*, *58*(3), pp.187-196.

Makgoba, S.S. 2013. Evaluation of different South African wheat cultivars under irrigation for quality and yield parameters in Limpopo Province, MSc Thesis, University of Limpopo, South Africa.

Manley, M., Engelbrecht, M.L., Williams, P.C. and Kidd, M. 2009. Assessment of variance in the measurement of hectolitre mass of wheat, using equipment from different grain producing and exporting countries. *Biosystems engineering*, *103*(2), pp.176-186.

Maraseni, T.N. and Cockfield, G. 2011. Does the adoption of zero tillage reduce greenhouse gas emissions? An assessment for the grains industry in Australia. *Agricultural Systems*, *104*(6), pp.451-458.

Masto, R.E., Chhonkar, P.K., Singh, D. and Patra, A.K. 2007. Soil quality response to long-term nutrient and crop management on a semi-arid Inceptisol. *Agriculture, Ecosystems & Environment*, *118*(1-4), pp.130-142.

Moreno, R.G., Alvarez, M.D., Alonso, A.T., Barrington, S., and Requejo, A.S. 2008. Tillage and soil type effects on soil surface roughness at semiarid climatic conditions. *Soil and Tillage Research 98*: 35-44.

Morrison, M.J., McVetty, P.B.E. and Scarth, R. 1990. Effect of row spacing and seeding rates on summer rape in southern Manitoba. *Canadian Journal of Plant Science*, *70*(1), pp.127-137.

Neethling, P.J. 2018. Developing nitrogen fertiliser management strategies for wheat (*Triticum aestivum*) under conservation agriculture practices within the Western Cape. MSc Thesis, Stellenbosch University, South Africa.

Nelson, D.W., and Sommers, L.E. 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.

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.

Parvin, N., Parvage, M.M. and Etana, A. 2014. Effect of mouldboard ploughing and shallow tillage on sub-soil physical properties and crop performance. *Soil Science and Plant Nutrition*, *60*(1), pp.38-44.

Potter, T.D., Kay, J.R., Ludwig, I.R. and Frischke, B.M. 2001. Effect of row spacing and sowing rate on canola cultivars in low rainfall areas. *Seeds*, *1000*, p.2.

Robertson, M., Kirkegaard, J., Rebetzke, G., Llewellyn, R. and Wark, T. 2016. Prospects for yield improvement in the Australian wheat industry: a perspective. *Food and Energy Security*, *5*(2), pp.107-122.

Sommer, R., Piggin, C., Haddad, A., Hajdibo, A., Hayek, P. and Khalil, Y. 2012. Simulating the effects of zero tillage and crop residue retention on water relations and yield of wheat under rainfed semiarid Mediterranean conditions. *Field Crops Research*, *132*, pp.40-52.

Statistics South Africa. 2016. Mid-year population estimates

Steyn, J.T., Tolmay, J.P.C., Human, J.J., and Kilian, W.H. 1995. The effects of tillage systems on soil bulk density and penetrometer resistance of a sandy clay loam soil. *South African Journal of Plant and Soil 12*: 86-90.

Stott, D.E., Cambardella, C.A., Tomer, M.D., Karlen, D.L. and Wolf, R. 2011. A soil quality assessment within the Iowa River South Fork watershed. *Soil Science Society of America Journal*, *75*(6), pp.2271-2282.

Swanepoel, C.M., Swanepoel, L.H. and Smith, H.J. 2017. A review of conservation agriculture research in South Africa, *South African Journal of Plant and Soil*, 1862, pp. 1–10. doi: 10.1080/02571862.2017.1390615.

Swanepoel, P.A., Agenbag, G.A. and Strauss, J.A. 2017. Considering soil quality when comparing disc and tine seed-drill openers for establishing wheat. *South African Journal of Plant and Soil*, pp.1-4.

Swanepoel, P.A., du Preez, C.C., Botha, P.R., Snyman, H.A. 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, P.A., Du Preez, C.C., Botha, P.R., Snyman, H.A. and Habig, J. 2014. Soil quality characteristics of kikuyu–ryegrass pastures in South Africa. *Geoderma*, *232*, pp.589-599.

Tesfamariam, E.H., Annandale, J.G. and Steyn, J.M. 2010. Water stress effects on winter canola growth and yield. *Agronomy Journal*, *102*(2), pp.658-666.

Tessier, S., Saxton, K.E., Papendick, R.I. and Hyde, G.M. 1991. Zero-tillage furrow opener effects on seed environment and wheat emergence. *Soil and Tillage Research*, *21*(3-4), pp.347-360.

Tolmay, J.P.C., Agenbag, G.A. and Hardy, M.B. 2010. The influence of row width, planting density and cultivars on seedling establishment of no-till spring wheat (Triticum aestivum L.) in Western Cape, South Africa. *South African Journal of Plant and Soil*, *27*(2), pp.168-178.

Turmel, M.S., Speratti, A., Baudron, F., Verhulst, N. and Govaerts, B. 2015. Crop residue management and soil health: A systems analysis. *Agricultural Systems*, *134*, pp.6-16.

Van Zyl, J. G. 2017. Response of wheat (*Triticum aestivum L*.), Canola (*Brassica Napus*) and Medic (*Medicago*) to a once-off mouldboard and deep tine tillage in the Swartland sub-region of the Western Cape. MSc Thesis, Stellenbosch University, South Africa.

Viña, A., Gitelson, A.A., Nguy-Robertson, A.L. and Peng, Y. 2011. Comparison of different vegetation indices for the remote assessment of green leaf area index of crops. *Remote Sensing of Environment*, *115*(12), pp.3468-3478.

Wiatrak, P.J., Wright, D.L. and Marois, J.J. 2006. The impact of tillage and residual nitrogen on wheat. *Soil and Tillage Research*, *91*(1-2), pp.150-156.

Yao, Z., Zheng, X., Xie, B., Mei, B., Wang, R., Butterbach-Bahl, K., Zhu, J. and Yin, R. 2009. Tillage and crop residue management significantly affects N-trace gas emissions during the non-rice season of a subtropical rice-wheat rotation. *Soil Biology and Biochemistry*, *41*(10), pp.2131-2140.