UTILISATION OF COVER CROPS: IMPLICATIONS FOR CONSERVATION AGRICULTURE SYSTEMS

by

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Declaration

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Ernst Hendrik Smit

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Uittreksel

Dekgewasse het die potensiaal om sekere beperkings in bewaringslandboustelsels binne ’n meditereënse klimaat aan te spreek. Hierdie beperkings sluit in, maar is nie beperk tot ’n gebrek aan gewasdiversiteit, onkruiddoderweerstandigheid van onkruide, onvoldoende grondbedekking en degradeerde grond nie. Mediterreënse klimaat beperk dekgewasproduksie tot die winterseisoen wanneer kontantgewasse gewoonlik geplant word. Dit verhoog die finansiële koste van dekgewasse, aangesien die implementering van dekgewasse die een seisoen se produksie vervang. ’n Gedeelte van die koste verbonde aan dekgewasproduksie kan deur die benuting van dekgewasse verhaal word. Dit is egter nie duidelik hoe die benutting van dekgewasse die funksionele rol van dekgewasse sal beïnvloed nie. Die doel van hierdie studie is om te ondersoek hoe dekgewasse en die benutting van dekgewasse produktiwiteit van 'n stelsel sal beïnvloed. In die Swartland (met ’n mediterreense klimaat), Suid-Afrika is ’n proef in 2016 uitgevoer. In die eerste jaar van die proef is twee dekgewasmengsels (’n mengsel wat hoofsaaklik graangewasse bevat en 'n ander wat hoofsaaklik peulgewasse bevat) geplant. Elk van die mengsels is op drie maniere benut: i) gesny en verwyder as hooi, ii) bewei deur skape en iii) gerol en onbenut gelaat. In die daaropvolgende jaar (2017) is koring op al die persele geplant en 'n kontrole is ingesluit (koring op persele waar koring vir die voorafgaande twee jaar verbou was). Dekgewasbenutting verminder ($p < 0.05$) die hoeveelheid grondbedekking, maar nie noodwendig ($p > 0.05$) die hoeveelheid minerale in die grondbedekking nie. Daarbenewens het weiding van dekgewasse grond N verbeter ($p < 0.05$). In 'n droë jaar het die verbouing van dekgewasse nie die opvolgende koring-graanproduksie verhoog nie ($p < 0.05$), ongeag die benutting van degewasse in die voorafgande jaar. 'n Hoofsaaklik peuldekgewas mengsel kan egter ($p < 0.05$) die koring-graanproteïeninhoud verhoog. Hierdie resultate dui daarop dat die gebruik van dekgewasse die voedingstofsiklus verbeter. Dekgewasse verbeter nie altyd die produksie van opvolgende kontantgewasse nie, wat die risiko op belegging vir produsente kan verhoog. Die implementering van dekgewasse het kontantgewasgehalte verbeter ($p < 0.05$), maar nie die graanopbrengs ($p < 0.05$) van die kontantgewas nie. Dit dui daarop dat die positiewe effek van dekgewasse op die daaropvolgende kontantgewasse nie altyd sal kan kompenseer vir die finansiële koste verbonde aan dekgewasse verbouing nie. Die enigste negatiewe effek van die weiding van die hoofsaaklik peuldekgewas-mengsel was 'n vermindering ($p < 0.05$) in die hoeveelheid grondbedekking, maar dieselfde behandeling het gelei tot ‘n toename ($p < 0.05$) in grondstikstof. Ten spyte van die vermindering in grondbedekking na benutting, was grond nog voldoende bedek volgens die standaarde van bewaringslandbou. Dit dui daarop dat die gebruik van dekgewasse 'n bykomende inkomste kan genereer en die ekonomiese lewensvatbaarheid van dekgewasproduksie kan verbeter.

Abstract

Cover crops have the potential to address some limitations in conservation agriculture systems with a Mediterranean climate. These limitations include, but are not limited to, a lack in crop diversity, herbicide resistant weeds, insufficient soil cover, and degraded soil. Mediterranean climates restrict cover crop production to the winter growing season when crops are normally planted. This increase the financial cost of cover crops as the implementation of cover crops replace one season's production. In order to salvage some of the costs of cover crop production, the cover crops can be utilised. It is, however, not clear how utilisation of cover crops will influence the functional role of cover crops. This study aims to investigate how cover crops and the utilisation of cover crops affect the productivity of a system. A trial was conducted in 2016 in the Swartland region of South Africa, characterised by a Mediterranean-type climate. In the first year of the trial, two cover crop mixtures (a mixture containing mainly cereal crops and another containing mainly leguminous crops) were planted. Each of the mixtures were utilised in three ways: i) mowed and removed as hay, ii) grazed by sheep and iii) rolled and left unutilised. In the succeeding year (2017), wheat was planted on all the plots and a control was included (wheat on plots where wheat was cultivated for the previous two years). Cover crop utilisation reduced ($p < 0.05$) the quantity of soil cover, but not necessarily ($p > 0.05$) the amount of minerals in the soil cover. In addition to this, grazing of cover crops improved ($p < 0.05$) soil N. In a dry year cover crop cultivation did not increase ($p < 0.05$) the succeeding wheat grain production, irrespective of cover crop utilisation in the previous year. A mainly leguminous cover crop mixture, however, can increase ($p < 0.05$) the wheat grain protein content. The results indicate that utilisation of cover crops improve nutrient cycling. Cover crops do not always improve succeeding cash crop yield, which in turn could increase the risk on investment for producers. The implementation of cover crops improved ($p < 0.05$) cash crop quality, but not ($p < 0.05$) the grain yield of the cash crop. This indicates that the positive effect of cover crops on succeeding cash crops will not always compensate for the financial cost involved in cultivating cover crops. The only negative effect of grazing the mainly leguminous mixture was a reduction ($p < 0.05$) in the quantity soil cover, but the same treatment increased ($p < 0.05$) soil N. Despite the reduction in soil cover following utilisation, soil was still sufficiently covered according to conservation agriculture norms. This indicates that the utilisation of cover crops can generate an additional income and improve the economic viability of cover crop production.

This thesis is in memory of Johan van Huyssteen, a great friend without whose initial motivation I would never have attempted to write this thesis.

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Preface

This thesis is presented as a compilation of five chapters. Each chapter is introduced separately and is written according to the style of a journal manuscript to which the intention is to submit chapters 3 and 4 for publication in a peer-reviewed journal.

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List of Abbreviations

ADF	Acid-detergent fibre
ADL	Acid-detergent lignin
Al	Aluminium
B	Boron
C	Carbon
CA	Conservation Agriculture
Ca	Calcium
CF	Crude fibre
CG	Mainly cereal mixture utilised as grazing
CH	Mainly cereal cover crop mixture utilised as hay
CP	Crude protein
Cu	Copper
CU	Mainly cereal mixture unutilised and rolled
Fe	Iron
g	Grams
GE	Gross energy
K	Potassium
L	Litre
LG	Mainly leguminous mixture utilised as grazing
LH	Mainly leguminous mixture utilised as hay
LU	Mainly leguminous mixture unutilised and rolled
ME	Metabolisable energy
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Na	Sodium
NDF	Neutral-detergent fibre
NFE	Nitrogen-free extractives
NH_4^+	Ammonium
NO_3^-	Nitrate
P	Phosphorus
S	Sulphur
TDN	Total digestible nutrients (TDN)
Zn	Zinc

CHAPTER 1: Introduction

The Swartland region, located in the Western Cape of South Africa, has a Mediterranean-type climate where about 80% of rainfall occurs during the months from April to September (Agenbag, 2012). The cool wet winters are ideal for winter cereal and canola production, but summers in the Swartland are hot and dry which complicates summer crop production. Producers can extend the winter growing season by improving soil C content to increase the water holding capacity of soil. Hot and dry summers, and an absence of active growing plants throughout the summer is not conducive to soil C build-up. The fact that soil in this region is prone to surface crusting and erosion adds to the challenges which Swartland producers face (Swanepoel *et al.*, 2016). Despite these challenges the Swartland is one of the main wheat producing areas of South Africa (Basson *et al.*, 2017).

The drive in agriculture for higher production can be stronger than the drive for sustainable production leading to the degradation of the environment. The misuse of land has degraded soils since the start of agriculture and have even led to the downfall of thriving civilisations (Lal, 2009). Wheat production in the Swartland followed the same trend of soil degradation. In the past century wheat was primarily produced in monoculture with occasional variations in the form of a bare fallow field or oats for grazing (Strauss *et al.*, 2010). Producers in the Swartland cultivated wheat on all available land in order to maximise wheat production. Chemical fertilisers and herbicides made production of wheat in monoculture possible, but production decreased over time (Strauss *et al.*, 2010; Swanepoel *et al.*, 2016). Conventional tillage practices in the Swartland have furthermore degraded soil and led to a reduction in soil C (Agenbag, 2012; Swanepoel *et al.*, 2016). Another major challenge caused by improper management, was misuse of herbicides that have led to herbicide resistance in ryegrass (*Lolium rigidum*), the main weed in these systems (MacLaren *et al.*, 2018).

It is clear that there are many challenges to face in these systems, many of which are soil-based. Soil can be protected and soil quality improved with the implementation of conservation agriculture (CA) principals (Hobbs *et al.*, 2008). This is one of the main factors why CA is seen as a more sustainable approach for many of the challenges which Swartland producers face. Increased wheat yields, improved soil N and soil organic C under no-till crop rotation systems support the feasibility of CA in the region (Agenbag, 2012). Some of the CA principles have contributed to improving the degraded soil in the region to varying degrees. Conservation agriculture is based on three main pillars, including minimum soil disturbance, sufficient soil cover and diverse crop rotation systems (Hobbs *et al.*, 2008; Derpsch *et al.*, 2010; Pittelkow *et al.*, 2014). Although crop rotation is one of the three main pillars of CA, it is difficult to have sufficient diversity in a cropping system with cash crop options limited by climatic conditions (Swanepoel *et al.*, 2016).

The hot dry summers in Mediterranean areas make it difficult to retain sufficient material in order to cover the soil throughout the summer (Ward *et al.*, 2012). Cover crops have the potential to provide sufficient diversity and crop residue in Mediterranean cropping systems. The design of CA systems is site-specific, but the three main concepts stay the same (Kassam *et al.*, 2012).The fact that cover crops can be defined as crops planted in order to improve and protect soil between normal crop production periods, indicates that cover crops have more benefits (SSSA, 2008). Until recently the main functions of cover crops was to fix N, protect soil, manage pests and suppress weeds (Blanco-Canqui *et al.*, 2015). The use of cover crops was to serve a single specific function. This viewpoint is changing and now cover crops are viewed as a multifunctional tool in cropping systems. Currently the focus of cover crops is to improve soil C and quality, fodder for livestock, biofuel production and reduce emissions of greenhouse gasses whilst improving the profitability of the system (Blanco-Canqui *et al.*, 2015). It is not a novel concept to use cover crops in order to improve CA systems. Cover crops have successfully been integrated into CA systems in different regions globally (Derpsch *et al.*, 2010; Flower *et al.*, 2012).

When planting cover crops instead of leaving a field fallow, there is a cost and management expense involved (Reeves, 1994; Dabney *et al.*, 2001). As cover crops usually do not generate income, the cost involved should be seen as a future investment in cash crop production. Normally cover crops are planted during a period when fields would be fallow and do not affect the total cash crop production (Dabney *et al.*, 2001). In Mediterranean areas with dry summers, there is not sufficient moisture to grow a cover crop following a cash crop or winter pasture (Ward *et al.*, 2012). This limits the inclusion of a cover crop to the winter production season and thus compete with cash crop- and pasture production. The substitution of cash crops with cover crops elevates the financial implication of cover crops because the producer will lose one season’s income from a cash crop. These financial implications are one of the main reasons why producers in the Swartland are reluctant to incorporate cover crops in their production systems. The utilisation of cover crops as fodder can help producers cover input costs and possibly play a significant part in the inclusion in current cropping systems. When cover crops are utilised sufficient soil cover should be left in order to act as a cover crop. According to Blanco-Canqui *et al.* (2015) cover crop biomass production can be increased with fertilisers in order to have sufficient biomass for utilisation and -soil cover. Derpsch *et al*. (2010) indicated that it is not a common practice to utilise cover crops, because it may decrease the amount of crop residue, but Basson *et al*. (2017) showed that incorporation of livestock into current Swartland CA systems can improve profit and reduce financial risks.

Incorporating cover crops into current CA systems has the potential to improve wheat production by preventing erosion, restoring soil quality and suppressing weeds. Utilising cover crops as fodder for livestock can help producers cover input costs but may reduce the positive effect of cover crops.

This project aims to investigate how cover crops and the utilisation of cover crops affect the productivity of a system. The first objective of this study is to evaluate the effect of cover crop utilisation on soil and the quality- and quantity of the mulch. How cover crops will affect the cropping system and subsequent cash crops is not included in this first objective. The second objective is to determine the effect of cover crops and cover crop utilisation on wheat production and quality.

CHAPTER 2: Literature Review

2.1 Conservation agriculture

The global adoption of CA enables producers worldwide to manage agro-ecosystems in a more sustainable manner (Derpsch *et al.*, 2010). Despite other benefits of CA, the determining factor for producers is improved profit margins. The global meta-analysis conducted by Pittelkow *et al.* (2014) suggest that the adoption of CA can reduce yields especially when one of the three principals is not applied.

According to Pittelkow *et al.* (2014) CA generally reduces crop production except for rainfed systems in dry regions where CA improves production. A review article focusing on CA in Mediterranean areas concluded that CA has the potential to sustain or increase production and reduce input costs (Kassam *et al.*, 2012). Kassam *et al.* (2012) and Pittelkow *et al.* (2014) agree that CA can improve profits due to lower input costs. Despite these benefits of CA, factors such as the financial implication of crop residues which can be sold as hay may prevent farmers from converting to CA (Lal, 2009). One of the main factors which prevents smallholder farmers in Africa from converting to CA is the competition between livestock and CA for crop residue (Giller *et al.*, 2009).

It is necessary to adapt CA management for every environment, because the design of CA systems is site specific, but the three main concepts stay the same (Kassam *et al.*, 2012). Utilising cover crops as grazing in CA systems can be a multifunctional tool to address challenges like fodder shortage and lack of crop diversity. The risk of incorporating livestock in a CA system is that livestock could have a negative effect on soil cover. Care should be given not to overgraze, and soil should remain covered. Residue retention increases yields under zero-tillage in both monoculture and crop rotation systems relative to the same systems where crop residue is removed (Fuentes *et al.*, 2009). Crop diversity and sufficient residue retention can prevent reductions in yield when farmers convert from conventional tillage to no-tillage systems (Pittelkow *et al.*, 2014). The removal of crop residues leads to lower soil quality and crop yields compared to when crop residue is left as mulch in no-till systems (Fuentes *et al.*, 2009).

The integration of livestock and cash crop systems under no-tillage in southern Brazil was reviewed by de Faccio Carvalho *et al.* (2010). Although the subtropical climate of Brazil is substantially different from the Mediterranean climate of the Swartland, both regions implement CA and integrate livestock with cropping systems. Utilising cover crops as a forage and with strict grazing management, can improve soil quality and increase the systems productivity (de Faccio Carvalho *et al.*, 2010). It is possible that grazing cover crops in the Swartland can have the same effects which it had in Brazil, although management may differ.

2.2 Defining cover crops

Cover crops are not planted with the sole purpose of generating an income but should improve subsequent cash crop production. A crop planted between two cash crop seasons in order to provide ecosystem services can be defined as a cover crop (Dabney *et al.*, 2001; Poeplau and Don, 2015; Wendling *et al.*, 2017). When cover crops are cultivated in a fallow season it can be referred to as inter-crops (Poeplau and Don, 2015). Catch crops is another synonym for cover crops with strong root systems which can utilise nutrients and prevent leaching of nutrients (Poeplau and Don, 2015; Rücknagel *et al.*, 2016). When catch crops break down nutrients are released and made plant available through mineralisation. One of the management practices of cover crops entails tilling cover crops into the soil (Kains, 1973). When cover crops are tilled and incorporated into the soil it is referred to as a green manure (Fageria *et al.*, 2005; SSSA, 2008; Poeplau and Don, 2015). This speeds up the breakdown of organic matter and release of nutrients but reduce soil cover (Turmel *et al.*, 2014). The benefits of a mulch will be lost if soil cover is incorporated into the soil. Despite all the different synonyms and definitions of cover crops the main function of cover crops are to improve sustainability and productivity of a system.

The management and implementation of cover crops are site specific. In Mediterranean regions with hot dry summers cover crops cannot be planted when fields are fallow and will substitute a cash crop (Flower *et al.*, 2012). If cover crops prevent producers from cultivating cash crops the long-term benefits of cover crops must be greater than the loss in cash crop production.

2.3 Potential of cover crops in Mediterranean regions

Cover cops are crops planted to provide a mulch and historically it has been left unutilised (Kains, 1973; Reeves, 1994). The mulch provides soil cover protecting the soil and improves soil fertility, water infiltration and weed suppression (Dabney *et al.*, 2001; Flower *et al.*, 2012). Despite the name “cover crops”, the sole function of cover crops is not just to provide cover. Cover crops are multi-functional and do not just have one specific function (Blanco-Canqui *et al.*, 2015). An effective multifunctional cover crop must be able to addres multiple concerns, which limit production. Because no crop can be cultivated in the dry season in Mediterranean regions, the ideal end result for farmers is an increase in productivity of a cash crop cultivated in the production season following the cover crop (Fageria *et al.*, 2005). In the Swartland, with degraded soils, herbicide resistant weeds and hot dry summers, it is important to have sufficient soil cover to protect and improve soil and suppress weeds.

According to Roth *et al.* (1988) a minimum of 4000 to 6000 kg crop residue ha^{-1} is required in order to effectively reduce runoff. This study was conducted in southern Brazil with different climatic conditions than the Swartland. In a Mediterranean climate with lower rainfall, runoff is still a problem as a result of low infiltration rates. In a case study focusing on literature from no-till cropping systems of southern and western Australia it is suggested that about 1000 kg ha^{-1} cereal residue or about 750 kg ha^{-1} of pasture residue is required as a mulch after grazing in order to prevent wind and water erosion (Fisher *et al.*, 2012). The authors indicated that these values are site specific and that site specific management is needed (Fisher *et al.*, 2012). Indicating that the same values may not apply to the Swartland although the Swartland have similar climatic conditions to southern and western Australia.

2.3.1 Influence on weeds

Cover crops supply producers with alternative ways to control weeds, especially herbicide resistant weeds. Teasdale *et al. (*2007) describe the potential of cover crops to act as a tool to manage weeds without the use of chemicals. The use of cover crops with allelopathic effects can improve weed control (Smith *et al.*, 2014). In the absence of herbicides, cover crops can control weeds by direct competition or as a physical barrier (mulch) after the cover crop growing season (Teasdale *et al.*, 2007).

Cover crops can have a direct or indirect influence on weeds. Firstly, cover crops can directly compete against weeds for water, nutrients, light and space during the growing season (Blanco-Canqui *et al.*, 2015). Dabney *et al*. (2001) conducted winter cover crop trials in South Central Colorado, which is a summer cropping area. During the growing season, cover crops can outcompete weeds for resources like water and nutrients (Dabney *et al.*, 2001; Clark, 2013). The leaf canopy of cover crops use space and light which weeds need in order to survive (Clark, 2013). Cover crops which are allelopathic will increase the direct competition of cover crops on weeds. Ryegrass, winter rye, mustard and subterranean clover are allelopathic and can be used as cover crops (Hartwig and Ammon, 2002; Wendling *et al.*, 2017). It is important that producers ensure that cover crops have the physiological capabilities and growing conditions to outcompete or suppress weeds.

Secondly, cover crops can have an indirect influence on weeds. In this case it is not the active growing cover crops which compete with weeds, but rather the dead residues. After the cover crops have been terminated, the material act as a mulch, which suppresses weeds. When cover crops produce sufficient cover, the mulch layer can control weeds in subsequent cash crops (Dabney *et al.*, 2001; Flower *et al.*, 2012; Büchi *et al.*, 2018). Soil cover is the main predictor of a cover crop's ability to suppress weeds in subsequent cash crops and not necessarily cover crop biomass (Büchi *et al.*, 2018). Cover crop residue can have allelopathic effects improving weed control further (Reeves, 1994; Hobbs *et al.*, 2008). However, cover crop residue is not selective in the sense that the mulch insolates soils and lower soil temperatures which can delay germination and early growth of crops (Dabney *et al.*, 2001). Allelopathic residue is not selective an may have a negative effect on crop production (Fageria *et al.*, 2005). Despite these possible complications, the ability of a cover crop mulch to control weeds enables cover crops to have a long-lasting effect on weeds, even after the cover crop growing season.

Using cover crops to compete with weeds in the growing season and creating a mulch after termination enables cover crops to replace or assist herbicides. When used as an alternative to herbicides, cover crops can enable producers to control herbicide resistant weeds in CA systems. A potential problem is that cover crops can become or act as weeds in subsequent cash crop years. Poor management would be the cause of cover crops becoming weeds. When cover crops are not terminated properly, or at the right time, and set seed, the cover crops might emerge in subsequent crop years and compete with cash crops (Davis, 2010).

2.3.2 Influence on soil quality

The differences and similarities between soil quality and soil health is a controversial topic. Bünemann et al. (2018) conducted a review of soil quality and concepts related to soil quality. The difference between soil health and soil quality was based on principals but have become a matter of preference and can be seen as equal to one another (Bünemann *et al.*, 2018). In this study soil quality refers to soil as a living system but the system as a hole is dependent on soil physical, chemical and biological properties.

2.3.2.1 Soil physical characteristics

Soil quality refers to soil as a living system, the agricultural system as a whole is dependent on soil physical, chemical and biological properties. Physical properties of soil give structure to the soil profile and create the environment in which soil functions take place. The conventional way of improving soil physical properties is by tillage. Abdollahi & Munkholm (2014) compared different tillage systems with and without winter cover crops in the form of a brassica. The structure of soil can be improved by tillage to a depth of 20 cm (Abdollahi and Munkholm, 2014). It must be taken in to account that Abdollahi & Munkholm (2014) conducted their trials in Denmark with different soil and climatic conditions to the Swartland. The implementation of cover crops has a greater effect on reduced tillage systems than in conventional tillage systems (Abdollahi and Munkholm, 2014; Büchi *et al.*, 2018). According to Büchi *et al*. (2018) cover crops play a crucial role in reduced tillage systems and have the potential to alleviate problems associated with reduced tillage. Deep penetrating root systems can act as a biological tine and break compaction layers increasing the volume soil in which cash crops can grow (Clark, 2013; Abdollahi and Munkholm, 2014). Decomposition of cover crop roots creates channels in the soil profile which can improve gaseous exchange and water infiltration. The channels can also be utilised by the roots of subsequent crops. Soil friability can be improved by cover crops specifically in no-till systems (Abdollahi and Munkholm, 2014). Cover crops can help producers convert to no-till and improve current no-till systems in the Swartland. The impact of raindrops and soil surface crusting is reduced if cover crops produce sufficient soil cover to protect the soil surface (Dabney *et al.*, 2001).

2.3.2.2 Soil chemical characteristics

Cover crops have the potential to increase nutrient availability in the soil for crop production. In a three-year cover crop trial conducted in Switzerland the effect of cover crops on soil C was not significant (Büchi *et al.*, 2018). In contrast to this a complementary long-term model Büchi *et al.* (2018) predicted that the use of cover crops in no-tillage and minimum-tillage systems will lead to an increase in soil C. The slow rate of C sequestration in soil can be one of the reasons why long-term models and trial data give different results. Ruis & Blanco-Canqui (2017) conducted a review in order to establish how residue removal and cover crops will affect soil organic C. The use of cover crops can increase soil organic C content, but C production of cover crops is dependent on factors like the length of the cover crop growing season (Ruis and Blanco-Canqui, 2017). For example, brassica winter cover crops can improve K availability in the topsoil after five years (Abdollahi and Munkholm, 2014). Brassicas with strong root systems are able to utilise nutrients other plants cannot utilise. With the ability to fix N, legume cover crops can improve soil N (Dabney *et al.*, 2001; Strauss *et al.*, 2010). Cover crop derived N, has a smaller effect on soil pH compared to some N fertilisers (Mbuthia *et al.*, 2015). When cover crops are terminated and break down, the nutrients can be utilised by subsequent crops. If cover crops improve the nutrient status of soil it will enable producers to reduce fertiliser application.

2.3.2.3 Soil biological characteristics

When cover crops improve chemical and physical properties of soil, it creates an improved environment for soil biology (Turmel *et al.*, 2014). Cover crops can have a direct effect on soil biology with roots creating a favourable environment for microbes and providing them with nutrients in the form of organic matter (Clark, 2013). Mbuthia *et al.* (2015) evaluated the effect of 31 years of tillage, cover crop cultivation and N application. According to Mbuthia *et al*. (2015) the use of cover crops can improve microbial activity in the soil which, in return, improves C and N storage and nutrient cycling ability of the soil. Clark (2013) and Mbuthia *et al*. (2015) focused on cover crops in the United States of America where the standard practice is to plant cover crops during a fallow period. It is not clear whether cover crops replacing a cash crop in a Mediterranean climate will have the same effect as cover crops planted in a fallow season. In a meta-analysis conducted by Venter *et al*. (2015) it was found that microbial richness and diversity in the soil can be improved by diversifying cropping systems. When a cropping system in a Mediterranean climate has limited diversity, cover crops can improve microbial richness and diversity in the soil (Venter *et al.*, 2015). It is difficult to establish the economic impact of improved microbial richness and diversity, but when microbes improve the availability of nutrients it can lead to improved profit. Vetch cover crops can improve soil microbial biomass N and N-cycling but leads to a reduction in mycorrhizae fungi (Mbuthia *et al.*, 2015).

2.3.3 Influence on soil water dynamics

When cover crops improve soil quality, it can lead to improved soil water dynamics, but also have limitations. Cover crops can have a negative effect on soil water dynamics in a cropping system because cover crops need water to grow and due to transpiration, evapotranspiration is increased (Reeves, 1994; Dabney *et al.*, 2001). The impact of cover crops utilising water, on crop production is area specific. In a Mediterranean climate dryland crop production is limited to a single crop during the winter when moisture is available (Flower *et al.*, 2012). The production of a cover crop will replace a cash crop in a Mediterranean climate due to limited moisture between cash crop cycles. Despite the moisture cover crops use to grow, cover crops can improve water infiltration rate and soil water storage in the long term (Dabney *et al.*, 2001).

Water infiltration rates can be increased when cover crops improve soil structure (Lal, 2008; Ruis and Blanco-Canqui, 2017). If cover crops improved friability of the soil and created channels with roots it can improve water infiltration (Ruis and Blanco-Canqui, 2017). According to Lal (2008) and Blanco-Canqui & Lal (2009) soil surface crusting reduce water infiltration but soil cover can absorb the impact of raindrops, reducing soil surface crusting and improving water infiltration. Improved water infiltration can reduce runoff, prevent erosion and reduce evaporation but when soil water holding capacity is low improved water infiltration can lead to leaching.

Improving water holding capacity and reducing evaporation of stored water can improve plant available soil moisture. Water holding capacity can be increased if soil C is increased by cover crops (Dabney *et al.*, 2001; Alonso-Ayuso *et al.*, 2014). Evaporation of stored soil moisture is reduced with sufficient soil cover when soil cover prevents solar energy from reaching the soil (Lal, 2008; Ward *et al.*, 2012; Ranaivoson *et al.*, 2017). The amount of cover needed to reduce evaporation of soil moisture is area specific. However according to Ranaivoson *et al.* (2017) evaporation decreases as soil cover increases. If cover crops improve soil cover it will reduce evaporation. Ward *et al.* (2012) conducted a trial in a Mediterranean climate similar to the Swartland and concluded that cover crops can improve the percentage of soil cover, but not necessarily the quantity of soil cover. The improved percentage of soil cover was because cover crops was rolled and the material was arranged in a horizontal position compared to vertical cash crop residue. Ward *et al.* (2012) also indicated that when potential evapotranspiration is high and rainfall low, cover crops do not have a significant effect on soil moisture during summer months. In a Mediterranean climate with a hot dry summer soil cover can improve the soil moisture after the first winter rain (Ward *et al.*, 2012). Due to the climatic conditions of the Swartland one would not expect cover crops to have an effect on soil moisture during the summer, but may improve soil moisture after the first winter rain. Also, because of the higher water holding capacity that is built through time, and improved pore space, more water could be held at plant-available water tensions, and crops can grow for a longer period towards harvest.

2.3.4 Botanical composition of cover crops

The effect of cover crops is site-specific and dependent on cover crop species or mixtures, cropping systems, cover crop termination, soil texture, tillage and climate (Ruis and Blanco-Canqui, 2017). In order to select site-specific cover crops, desired effects must be matched with the function of different cover crops species. Cover crops can be subdivided into two main groups: Leguminous and cereal cover crops, but other species like brassicas or other herbs can also be included (Dabney *et al.*, 2001). Leguminous cover crops can reduce fertiliser costs due to their ability to fix N (Dabney *et al.*, 2001; Strauss *et al.*, 2010). Legumes produce less material than cereal cover crops, but with the benefit of fixing N (Davis, 2010). All cereals with fibrous root systems can be defined as catch crops and have the ability to scavenge N and other nutrients which previous cash crops did not utilise (Reeves, 1994; Fageria *et al.*, 2005; Clark, 2013). When cereal and legume cover crops are mixed, the different benefits can be combined.

Cover crop mixtures containing cereal and leguminous species increase the positive effects of cover crops in comparison with leguminous or cereal cover crops in pure swards (Fageria *et al.*, 2005; Sainju *et al.*, 2005). The fact that producers can mix cover crops and combine benefits enable them to use cover crops as a multi-functional tool. In one mixture, cereals can scavenge for N and increase the C flux to the soil while legumes fix N (Dabney *et al.*, 2001; Fageria *et al.*, 2005). According to Elgersma & Søegaard (2016) the positive effect of mixtures is not limited to the combining benefits, but improve plant growth and nutrient value of grazing. A cover crop mixture containing a legume and a cereal species produce more biomass, C and N than when the same crops are planted as a monoculture (Sainju *et al.*, 2005).

Despite the previous perception that cover crop mixtures use less water than monoculture crops, Nielsen *et al.* (2015) proved that cover crop mixtures use similar amounts of water as monoculture crops. One of the drawbacks of including legumes and cereals in a mixture is the fact that no selective herbicides can be used to control weeds. Black oats can be used to control weeds as a replacement for herbicides (Flower *et al.*, 2012). It is not clear if black oats in a mixture will be an effective method of weed control because of the competing ability of this type of oats. If the seeding rate of the black oats in a mixture becomes too high it will also suppress the other crops in the mixture thus losing the other benefits. Including herbicide resistant crops in a cover crop mixture can enable producers to use herbicides on mixtures but this can complicate the termination of cover crops.

2.3.5 Termination

Cover crops can be terminated in order to promote decomposition of cover crops (Blanco-Canqui *et al.*, 2015). Nutrients are released as the cover crops decompose after termination. The timing and method of cover crop termination effect the benefits and disadvantages of cover crop cultivation. Termination is critical in order to find the balance between sufficient cover and preventing weeds or cover crops from setting seed (Flower *et al.*, 2012). If cover crops are terminated later it can improve biomass production and improve the C/N ratio of cereal and legume mixtures (Alonso-Ayuso *et al.*, 2014). In a Mediterranean climate where cover crops are cultivated in the same season (but not the same year) as cash crops, it is crucial to prevent cover crops from producing viable seeds. Cover crop seeds can germinate in subsequent cash crops and directly compete with cash crops especially if the cover crops and cash crops have the same growing season. Timing of termination can influence soil N and moisture due to the fact that cover crop use water and N to grow (Blanco-Canqui *et al.*, 2015; Nielsen *et al.*, 2015). Nielsen *et al*. (2015) and Blanco-Canqui *et al.* (2015) both focused on cover crops in regions where cash crops and cover crops are cultivated with no fallow season in-between. Timing of cover crop termination might not have the same effect when there is a fallow season in-between cash crop and cover crop production.

Cover crops can be terminated mechanically or chemically (Dabney *et al.*, 2001; Kornecki *et al.*, 2009). Creamer *et al.* (1995) stated that mechanical cover crop termination is preferred to chemical termination in order to reduce the use of chemicals. Since 1995, consumers have increased pressure on producers to limit the use of chemicals. The perception of consumers and herbicide resistant weeds encourage producers to terminate cover crops mechanically. Mechanical termination can include rolling, mowing and green manuring where cover crops are incorporated into the soil. Rolling and mowing cover crops will create a mulch which will break down and release nutrients over a longer period of time than green manure. In order to maintain sufficient soil cover, rolling or mowing cover crops is the preferred practice rather than green manure when soil cover is essential (Ward *et al.*, 2012). Rolling cover crops is the preferred option as it increases soil cover because residue is arranged horizontally in an even spread over the soil surface (Ward *et al.*, 2012).

Kornecki *et al.* (2009) compared five different rollers as a method of terminating rye cover crops. One of the rollers was used with and without a herbicide application. An untreated plot of rye served as the control and the efficiency of the different treatments was measured by comparing the number of viable plants following treatments with the control plot. In this study Kornecki *et al.* (2009) identified the crimper roller design as an effective roller to terminate cover crops. Davis (2010) obtained similar results and found that a roller crimper can be an effective way to terminate rye but not vetch. According to Davis (2010) cover crop species can complicate mechanical termination and chemical termination of cover crops earlier in the season can improve weed control. Chemical and mechanical termination of cover crops can be combined to improve cover crop termination (Kornecki *et al.*, 2009). Producers are limited by the availability of equipment to terminate cover crops.

2.3.6 Utilising cover crops

Cover crops are normally left unutilised, but it is not a new concept to utilise cover crops. Gardner & Faulkner (1991) concluded that incorporating livestock in cover crop systems is one of the only ways to make cover crop cultivation economically viable. In regions where cover crops substitute a cash crop it is essential for producers to generate an income from the cover crop. According to Blanco-Canqui *et al.* (2015), cover crop biomass removal in the form of hay or grazing for livestock or biofuel production do not have a negative effect on crop production and soil. Utilising cover crop biomass as hay or grazing can improve the profitability of cover crop cultivation.

The utilisation of cover crops as fodder can enable producers to incorporate livestock into cropping systems. Producers can obtain an additional income if cover crops are utilised as fodder. Livestock can improve the economical sustainability of a cropping system with variable climatic conditions and low subsidy support from government (Bell *et al.*, 2014). The addition of livestock in a cropping system achieves this by distributing investments between different commodities (Fisher *et al.*, 2012), simplifying risk management and improving cash flow. From an economical point of view, a producer in a Mediterranean climate can benefit if livestock is incorporated into cropping system (Crookes *et al.*, 2017).

Despite a possible economic benefit, the incorporation of livestock in a cropping system is a controversial topic. In a Mediterranean region with heavy soil, intensive grazing of crop residue during winter and summer can lead to a significant reduction in yields of subsequent crops (Allan *et al.*, 2016). Allan *et al.* (2016) defined intensive grazing as grazing of a pasture in the winter growing season and the following summer. Derpsch *et al.* (2010) indicated that the integration of livestock in to a cropping system may lead to insufficient soil cover. In the case of Derpsch *et al*. (2010) and Allan *et al.* (2016) the negative effect of livestock in a cropping system could have been the result of over grazing. According to de Faccio Carvalho *et al*. (2010), Fernández *et al.* (2015) and Fisher *et al.* (2012) grazing can have a negative or positive effect on production in a cropping system depending on how the grazing is managed.

Managing the amount of residue in an integrated livestock cropping system is important especially in a CA system where sufficient soil cover is required. In the Swartland there is a strong drive towards CA and it is unclear how livestock will fit into the system. Grazing and hay production remove material and both lead to a reduction of crop residue. In a grazing system the animals are on the field, but all undigested material is returned to the soil. Haying can be seen as a harvest but grazing is more complex and can be seen as a form of nutrient cycling (Gardner and Faulkner, 1991). In terms of soil cover the effect of haying and overgrazing is similar and both cases leading to insufficient soil cover. When crop residue is lightly grazed during summer, it has no effect on subsequent crop yields (Allan *et al.*, 2016). Allan *et al.* (2016) indicated that grazing can be managed in a Mediterranean climate in order to prevent negative consequences.

Despite the risk of a reduction in soil cover as a result of integrating livestock into a cropping system, there can be some benefits for a cropping system. The removal of material in the form of grazing does not necessarily mean a reduction in nutrients. Ngatia *et al.* (2015) found that grazing leads to a reduction in plant material but improves foliar P. Despite the perception that grazing has a negative effect on atmospheric C, when grazing is managed correctly it can reduce atmospheric C (Da Silva *et al.*, 2014). Incorporating large herbivores in to systems can have a positive influence on nutrient cycles and soil quality (de Faccio Carvalho *et al.*, 2010). The use of livestock can also play a role in the improvement of diversity in CA cropping systems. Improved diversity can increase microbial richness and diversity (Venter *et al.*, 2015). Venter *et al.* (2015) could not prove that increased microbial richness and diversity led to higher production.

Despite all this information concerning the effect of incorporating livestock in cropping systems it is not clear how cover crops and livestock will influence one another. The combination of cereals and legumes in a cover crop mixture can yield high quality fodder and improve livestock performance. Grazing cover crops do not lead to degradation of soil quality compared to the soil quality of unutilised cover crops (Franzluebbers and Stuedemann, 2008). According to Franzluebbers and Stuedemann (2008) the only negative effect of grazing cover crops is a reduction in infiltration rates. In a similar grazing study Fisher *et al.* (2012) concluded that grazing reduced infiltration rate but it did not influence subsequent crop production. If cash crop production following cover crops is not influenced by lower infiltration rates it is not a major concern.

2.4 Wheat following cover crops

The potential of improving wheat production by diversifying production systems can be seen in the effect which a single break crop has on the following wheat crop. Kirkegaard *et al*. (2008) reviewed published studies in order to quantify the effect of a break crop on dryland wheat production in North America, South Australia and northern Europe. According to the studies the average wheat yield increase was 14% in North America, 33% in South Australia and 24% in northern Europe after a break crop. Cover crop mixtures can combine the benefits of different break crops with additional benefits created by the cover crop mulch.

Büchi *et al.* (2018) conducted a trial to explain the role of cover crops in addressing concerns created by reduced tillage and improvement of soil fertility in winter wheat production of Switzerland. Despite different climatic conditions in the Swartland, the information will give an indication of how cover crops can affect wheat production. Büchi *et al.* (2018) compared seven different cover crops and a control (no cover) under no-tillage, minimum-tillage and conventional tillage systems. Cover crops improved soil fertility and reduced weeds in reduced tillage systems and especially in no-tillage systems where cover crops led to the highest increase in wheat yields (Büchi *et al.*, 2018).

2.5 Gaps and opportunities

Cover crops have the potential to overcome some of the limitations in conservation agriculture systems of the Swartland. With limited research conducted on cover crops under Mediterranean climatic conditions, it is not clear whether all the benefits of cover crops observed under other climatic conditions will be the same in a Mediterranean climate. One of the major concerns in a Mediterranean climate is the fact that all crop production is restricted to the winter growing season.

In a Mediterranean climate cover crops replace a cash crop rather than replacing a fallow period. This implies that cover crops in a Mediterranean climate are competing with cash crops and not with a fallow field. It is not clear if cover crops will still have the same effect if a cash crop is replaced rather than a fallow field. In order to make cover crop cultivation financially viable the benefits obtained from cover crops must be greater than the loss in production. Utilising cover crops as fodder can improve the profitability of cover crop cultivation but with no research of cover crop utilisation and the effect thereof on wheat production in the Swartland or under similar climatic conditions.

CHAPTER 3: The Potential of Cover Crop Utilisation

3.1 Introduction

The Swartland region of South Africa, with a Mediterranean climate, has predominantly crop and crop pasture systems (Kemper *et al.*, 1999). Hot and dry summers of this region and varying rainfall restrict crop production to the winter growing season. This limits the diversity of crops in the production systems. The soil is prone to surface crusting and erosion, has poor drainage and is not conducive to C build-up (Swanepoel *et al.*, 2016). The soil was further degraded by previous practices which included tillage, monoculture and fallow fields. Currently producers in the Swartland are adopting conservation agriculture principals in order to address some of the limitations in the Swartland. Conservation agriculture systems, however, are restricted by limited diversity in terms of cash crops and insufficient soil cover. Cover crops have the potential to enhance conservation agriculture systems in the Mediterranean regions by improving diversity and providing soil cover.

Due to Mediterranean climatic conditions, cover crop production is restricted to the winter, when cash crops are normally produced (Allan *et al.*, 2016). This implies that cover crops will replace a pasture or a cash crop, which would have generated an income. Contrary to this, cover crops are normally planted in the fallow season between cash crops and do not substitute cash crops (Dabney *et al.*, 2001; Poeplau and Don, 2015; Wendling *et al.*, 2017). In the Swartland, the financial implication of cover crop cultivation is elevated due to the loss of one season's cash crop income. The utilisation of cover crops as fodder can improve economic viability of cover crop production (Gardner and Faulkner, 1991). However, for the Swartland, it is not clear what the potential production and quality of fodder can be and how the utilisation of cover crops will influence the functional role of cover crops (Blanco-Canqui *et al.*, 2015). The aim of this study is to evaluate the effect of cover crop utilisation on soil and the quality- and quantity of the mulch.

3.2 Materials and methods

3.2.1 Trial site

Trials were conducted on Langgewens Research Farm located in the Swartland, Western Cape South Africa, in the 2016 and 2017 production seasons. The trial was subject to rain-fed conditions as this is the norm for field crop production in the area. The Swartland has a Mediterranean-type climate with an average annual rainfall of 395 mm of which 80% occurs during the cooler half of the year (April to September).

The trial site had a sandy loam soil texture, with 9-17% clay, 8-16% silt and 71-83% sand. Prior to the onset of this trial, crop production management was based on conservation agriculture practices with crop rotation, soil cover and minimum-tillage practices that have been followed for more than 15 years. The previous crop rotation was a three-year rotation system consisting of two years of annual medic pasture (legume) and a single year of wheat. To equalise the site, the entire area was planted with wheat in 2015.

3.2.2 Trial layout for 2016

The current trial was a component trial located within a larger long-term trial that was initiated in 2015. Grain yield and soil data were used to design the trial layout of the long-term trial (Osborne *et al.*, 2017).

The current trial was laid out in a split-plot design with two factors. Factor one was cover crop mixtures, and factor two was different ways of utilising those mixtures. Two different cover crop mixtures were cultivated on 24 whole plots of 450 m^2 each (30 x 15 m). Each whole plot was divided into three different subplots of 150 m^2 each (10 x 15 m) to allow different methods of utilisation. The utilisation methods were as follows: 1) grazed by sheep, 2) removed as hay and 3) left completely as mulch (termination was done by crimping roller). There were 72 subplots in total, which included two cover crop mixtures and three utilisations with 12 replicates each.

3.2.3 Crop establishment

3.2.3.1 Seeding equipment

A 5 m Piket double disc seed-drill (Figure 1) with 20 planting units and a row spacing of 254 mm, was used to plant the crops. The seed-drill was manufactured by *Piket Implements*, a local manufacturer. *Piket Implements* designed the seed-drill (Figure 1) specifically for planting through crop residue with minimal soil disturbance. The planting unit used by this seed-drill (Figure 2) consisted of a single vertical disc to cut through material, followed by a double disc to place the seed in soil.

Figure 1: Piket double disc seed-drill planting through cover crop residue

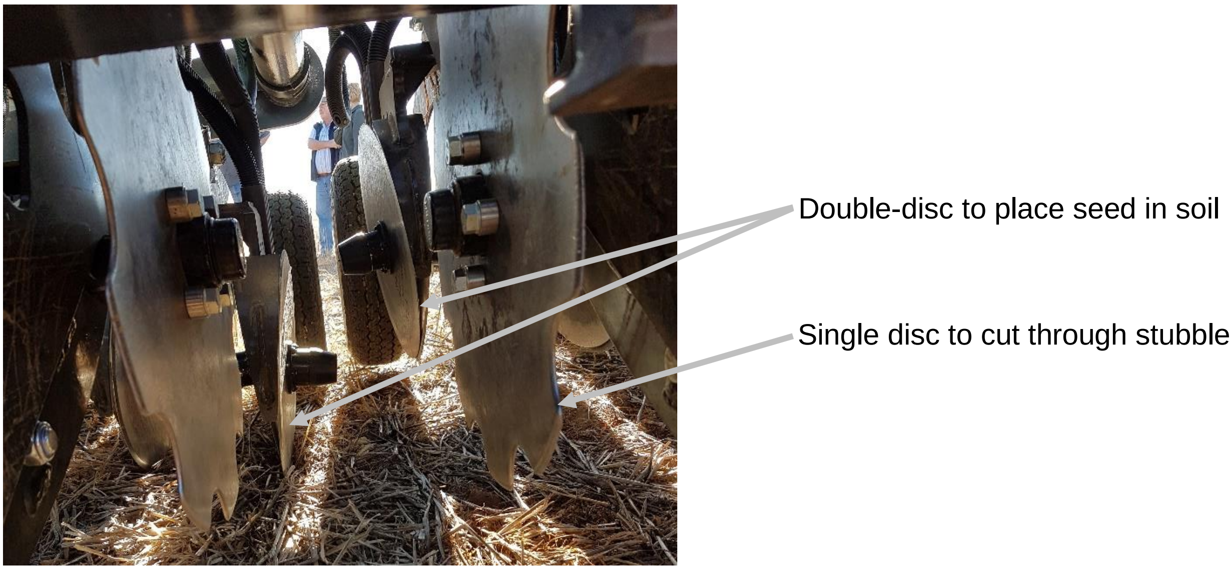

Figure 2: Planting unit of the Piket double disc seed-drill

3.2.3.2 Cover crop planting procedure

Twenty-one days prior to planting (12 May 2016), plots were sprayed with a non-selective herbicide (720 g glyphosate ha^{-1}), with an adjuvant, in order to kill weeds and volunteer crops which germinated prior to planting. Fertiliser was applied in the row with the seed-drill at 2.46 kg N ha^{-1}, 10.01 kg P ha^{-1} and 4.93 kg K ha^{-1}. The cover crops did not receive additional fertiliser during the rest of the season.

3.2.4 Cover crop mixtures

The two cover crop mixtures consisted of a mainly leguminous and a mainly cereal mixture (Table 1). The composition of the mainly leguminous mixture was aimed at achieving a botanical composition of 70% legumes and 30% cereals. The mainly cereal mixture was composed to achieve a botanical composition of 70% cereals and 30% legumes.

Table 1: Composition of the mainly leguminous, and mainly cereal cover crop mixture, presented with the respective seeding rates of each component

Crop	Species name	Cultivar	Seeding rate (kg ha^{-1})
	Mainly leguminous mixture		
Forage barley	*Hordeum vulgare*	SVG 13	6
Forage barley	*Hordeum vulgare*	Moby	6
Triticale	*x Triticosecale*	US 2014	12.5
Peas	*Pisum sativum*	Arvika	35
Vetch	*Vicia sativa*	Haymaker	3
Arrowleaf clover	*Trifolium vesiculsum*	Zulu II	1
Berseem clover	*Trifolium alexandrinum*	Elite	2
Subterranean clover	*Trifolium subterraneum*	Woogenellup	2
Biserrula	*Biserrula pelecinus*	Casbah	1
	Mainly cereal mixture		
Forage barley	*Hordeum vulgare*	SVG 13	25
Triticale	*x Triticosecale*	US 2014	50
Peas	*Pisum sativum*	Arvika	20
Vetch	*Vicia sativa*	Haymaker	3
Arrowleaf clover	*Trifolium vesiculsum*	Zulu II	2

Legume seeds of both mixtures were inoculated less than 24 hours prior to planting. Each legume received its host-specific *Rhizobium* inoculant, as specified by the seed supplier. After inoculation, the mixtures were composed according to the composition given in Table 1. Each mixture was thoroughly blended in order to ensure an even distribution of the different seeds. Both mixtures were planted on 2 June 2016. The mainly leguminous mixture was planted at a seeding rate of 68.5 kg ha^{-1}, and the mainly cereal mixture at a seeding rate of 100 kg ha^{-1}.

3.2.5 Cover crop utilisation

3.2.5.1 Grazing

Prior to grazing, a Bonnox fenced pen was assembled on each subplot (24 in total) subjected to grazing. Cover crops were grazed by sheep for 10 days when the cereals in the mixtures reached the flag leaf growth stage (Figure 3). Two adult SA Mutton Merino ewes with an average body weight of 75 kg were allocated to each grazing subplot (133 ewes ha^{-1}) from 26 August to 9 September 2016. Pens were removed following the grazing period and cover crop regrowth was allowed. When the regrowth from grazing plots reached the ear forming stage 400 g ha^{-1} paraquat was applied in order to prevent seed set.

Figure 3: Cover crops grazed for ten days by two SA Mutton Merino ewes

3.2.5.2 Hay production

The cover crop mixtures were mowed with an Agria ESM when the cereals in the cover crop mixtures reached the soft dough stage (Figure 4). On 29 September 2016, hay subplots were mowed and the material was left on the field to dry. All the material was raked and removed from the subplots and weighed to determine the removed biomass yield on dry matter basis for each subplot.

Figure 4: Mowing of cover crops with an Agria ESM

3.2.5.3 Mulching

Cover crops in the mulch subplots were rolled with a crimping roller at the same growth stage at which hay was mowed (Figure 5). This was done to prevent cover crops and weeds from setting seeds. Biomass produced was left on the field as a mulch.

Figure 5: Cover crops being rolled with a crimping roller

3.2.6 Cover crop samples and measurements

Cover crop biomass samples were collected by cutting biomass at the soil surface from three 0.25 m^2 quadrants. Samples for each plot were pooled into one sample and the sample was then fractionated into the following four groups: leguminous cover crops, cereal cover crops, weeds and wheat stubble (left standing from previous season). Samples were dried in an oven at 60°C for a week in order to report biomass data on a per dry matter (DM) basis. After the samples were dried, the four groups were weighed in order to determine the proportional composition of biomass. Due to a limitation in labour and funds, the three different groups could not be analysed for quality individually. After the mass of the samples had been determined, the three different groups were combined in order to have one composite sample for quality analyses. Samples were milled until particles could fit through a one-millimetre sieve.

Elsenburg Laboratories (Western Cape Department of Agriculture) analysed samples for mineral content and samples, collected from material utilised by livestock, were also analysed for nutritional value. The determination of the mineral content was based on the methods described by AgriLASA (2007). The nutritional value analysis included *in vitro* organic matter digestibility (IVOMD), proximal analysis, neutral detergent fibre (NDF), acid detergent fibre (ADF) and crude fibre. The IVOMD was done according to the methods of a two-stage rumen fluid-pepsin technique developed by Tilley & Terry (1963). The other nutritional analyses were based on methods described by AOAC (2012) for proximal analysis, Van Soest *et al.* (1991) for NDF and ADF and Goering & Van Soest (1970) for crude fibre.

3.2.6.1 Grazing samples

In order to establish the amount of material removed by grazing, biomass samples were taken prior to the start of grazing and again after grazing on the grazed and un-grazed (mulch) plots. This was done in order to measure the growth of plants during grazing and the amount of plant material removed during grazing. Biomass samples were dried and mass determined according to the process described in Section 3.2.6. Samples taken prior to grazing went through the whole process described in Section 3.2.6 (except for the wheat stubble which is unpalatable) in order to evaluate the nutritional value of the different cover crop mixtures at the start of grazing. The nutritional value was analysed according to the nutritional value analysis described in Section 3.2.6. The samples collected after grazing were fractionated into the botanical components mentioned, dried and mass determined as described in Section 3.2.6. Apart from determining the dry matter content and yield of the different fractions, these samples were not analysed further.

3.2.6.2 Hay samples

During mowing of hay, the material was spread unevenly on the specific subplots which complicated collection samples from a specific area on the subplots. Rather than cutting three quadrants, the entire subplots fresh mass was recorded and a representative grab-sample was collected from each subplot and dried, to determine the dry matter content. The collected samples were fractionated according methods described in Section 3.2.6. In order to evaluate the nutritional value of hay for the different cover crop mixtures, each sample was dried, mass determined, milled and analysed for quality parameters as described in Section 3.2.6.

3.2.6.3 Residue samples on all subplots

At the end of the growing season when all cover crops had been terminated, a biomass sample was collected from all 72 subplots. The samples were collected in order to calculate the amount of material covering the soil and the proportion of leguminous cover crops, cereal cover crops, weeds and wheat stubble in the residue was determined. These samples were collected, fractioned into botanical components, dried, mass determined and milled according to methods described in Section 3.2.6. The samples were sent to Elsenburg for a quality analyses as described in Section 3.2.6, in order to establish the amount of minerals in the above-ground residue.

3.2.6.4 Percentage soil cover

The amount of residue is not necessarily an indication of the percentage soil cover. The percentage soil cover was therefore determined at the end of the growing season (the same date when the amount of soil cover was measured). Percentage soil cover was measured using an experimental pin meter as described by Swanepoel *et al.* (2017). The pin meter is a frame with 42 pins 20 mm apart in a straight line which can slide up and down (Figure 6). The pin meter was randomly placed on three different spots on each subplot and the pins released to slide down. Each time the pins were released the number of pins in contact with soil and the number of pins in contact with plant material was counted in order to calculate the percentage of soil cover.

Figure 6: Experimental pin meter being used to determine the percentage of soil cover

3.2.7 Soil sampling and analyses

Soil cores (45 mm in diameter) were collected using a steel pipe and a hammer. Three different soil analyses were used: 1) The Complete Soil Health Tool (Haney Analyses) analysed by Soil Health Solutions, 2) standard chemical analysis analysed by Elsenburg Laboratories, Western Cape Department of Agriculture and 3) gravimetric soil moisture content determined on Langgewens Research Farm. The time and depth of each sample was dependant on the specific analysis. Soil samples were taken and stored in a cool dark place during sampling. During the first year of this trial (2016) the results of all these soil analyses where used in order to get an indication of how treatments affected soil biological, chemical and physical properties. In order to get an indication of the effect of the treatments on soil health, soil samples were sent to Soil Health Solutions for The Complete Soil Health Tool (Haney Analyses). Soil samples collected for Soil Health Solutions were delivered to Soil Health Solutions as is, within a day after sampling. The terminology of the different analysis performed by Soil Health Solutions are defined in Section 5.1.

The soil samples that were sent to Elsenburg Laboratories, were dried after sampling in order to determine the gravimetric soil moisture content. In order to determine soil moisture, soil samples were dried for a week directly following sampling in an oven at 60°C. The mass of each soil sample was determined before and after drying in order to calculate the percentage moisture loss. It was established that a week at 60°C was sufficient to dry samples as no additional loss in mass were noted after one week. This standard chemical analyses were based on the procedures described by the Handbook of Standard Soil Testing Methods for Advisory Purpose (Non-Affiliated Soil Analysis Work Committee and Soil Science Society of South Africa, 1990).

3.2.7.1 Samples collected prior to planting in 2016

Soil cores were taken at depth increments of 0-150 mm and 150-300 mm. At the start of the trial, subplots had a similar management regime before being subjected to the three utilisation methods and no difference was expected between different subplots of one whole plot. All samples collected prior to the utilisation of the cover crops were therefore taken as one composite sample consisting out of a minimum of six cores from each whole plot. The six cores were mixed in order to compile one representative sample for each whole plot. After the treatments had been applied to each subplot, five cores were collected from each subplot. The five cores from each subplot were combined in order to compile a representative sample for each subplot.

The first soil cores in 2016 were collected 21 days before seeding in order to establish baseline values. Six soil cores from the same whole plot and depth were mixed to make a composite sample. The soil samples collected at a depth of 0-150 mm were divided into two samples. One of the two samples from each plot was sent to Soil Health Solutions for analysis. Baseline results from The Complete Soil Health Tool can be viewed in Table 21. The rest of the soil collected, at a depth of 0-150 mm and 150-300 mm from each whole plot, was sent to Elsenburg Laboratories for a standard chemical analysis (Table 22 and Table 23).

The first soil samples were collected 21 days prior to planting, thus a second sample was collected one day prior to planting, to establish the soil moisture content at planting. Six cores were taken at a depth of 150 mm from each whole plot and mixed to form a composite sample for each whole plot. A representative soil sample from each whole plot were dried and the soil moisture content determined (Table 24). Soil moisture was not determined beyond 150 mm because the Piket double disc seed-drill were set to place seeds no deeper than 25 mm.

3.2.7.2 Samples collected after the growing season

The third set of samples were collected at the end of the growing season when cover crops across all the subplots had been terminated. Composite soil samples for each subplot, at depths of 0-150 mm and 150-300 mm, comprised five cores. For each subplot, samples collected at 0-150 mm were split into two samples. One of these two samples were sent to Soil Health Solutions for The Complete Soil Health Tool. The other samples, collected at a depth of 0-150 mm and samples 150-300 mm deep, were dried to determine the soil moisture. After the soil moisture had been established, all dried samples were sent to Elsenburg Laboratories for standard chemical analyses.

3.2.8 Statistical analyses

For 2016 data, mixed regression models were used to analyse the effects of two different cover crop mixtures and three different cover crop utilisations on nutritional value, quality and quantity of the mulch, as well as soil parameters. Residuals followed a normal distribution and variances were homogenous. The fixed effects were cover crop mixtures and cover crop utilisations, and interactions amongst the mixtures and utilisations. Random effects in the model were specified as the blocks as well as the interaction between block and mixture. To determine the effects of growth over grazing period, and the change of nutritional value from flag leaf stage to soft dough stage, time had to be taken into account. To test for these effects, the fixed effects were specified as above, but the random effects were specified as the utilisation nested within the effects of mixture and time. The Bonferroni test was used as a post hoc test to determine the significant differences between group means. The Bonferroni test is very conservative when a large number of group means are being compared. Because the Fisher's Least Significant Difference (LSD) test is less strict, it was only used to indicate significant differences when the Bonferroni test indicated significant differences at $p<0.05$. The Variance Estimation, Precision and Comparison (VEPAC) package of Statistica Version 13 TIBCO Software, 2017) was used.

3.3 Results and discussion

3.3.1 Fodder production

The growth results of both mixtures during the grazing period can be observed in Table 2 where cover crop biomass increased ($p < 0.05$) during the grazing period. The results showed how the quantity of cover crop biomass changed and which component of each mixture had the highest growth rate during the grazing period. In the mainly leguminous mixture, legume biomass increased ($p < 0.05$), but not the cereal biomass ($p > 0.05$). On the other hand, the cereal biomass in the cereal mixture increased ($p < 0.05$) and not the legume biomass ($p > 0.05$).

The total above-ground biomass of both mixtures did not follow the same trend as the cover crop biomass. Total above-ground biomass did not change ($p > 0.05$) over the grazing period. It has to be taken into consideration that the total above-ground biomass included wheat stubble from the previous year (2015), which was still decomposing, as well as weeds. A possible assumption is that the slow decomposition rate of the wheat stubble compensated for growth of cover crops, leading to no significant change in total above-ground biomass during grazing.

Table 2: Biomass production and the proportions of legume and cereal biomass in the leguminous- and cereal cover crop mixtures on 26 August and 9 September 2016. Different letters indicate significant differences ($p < 0.05$) between the measurements taken on 26 Aug 2016 and the measurements taken on 9 Sep 2016. CV = Coefficient of variation

	26 Aug 2016	**9 Sept 2016**	**Standard error**	**CV**
Leguminous cover crop mixture biomass production (kg ha^{-1})				
Total above-ground	2603^{a}	2633^{a}	134	16.96
Legume	794^{b}	1039^{a}	81.1	48.50
Cereal	1016^{a}	1251^{a}	156	44.66
Cover crop	1810^{b}	2291^{a}	157	28.44
Cereal cover crop mixture biomass production (kg ha^{-1})				
Total above-ground	2670^{a}	2791^{a}	134	16.96
Legume	484^{a}	562^{a}	81.1	48.50
Cereal	1367^{b}	1922^{a}	156	44.66
Cover crop	1851^{b}	2484^{a}	157	28.44

Due to the growth of cover crops during grazing and the decomposition of wheat stubble, it is difficult to establish the amount of fodder grazed by the sheep. One year old wheat stubble has a low palatability compared to cover crops and sheep would prefer cover crops rather than wheat stubble. Wheat stubble was therefore not taken into account when calculating the amount of biomass removed as grazing, because it was assumed that sheep would not eat the wheat stubble.

Although cover crop growth was monitored on un-grazed subplots, it is not clear how sheep grazing the cover crops would influence the cover crop growth. The herbage biomass (i.e. biomass utilised as grazing) can be calculated with three methodologies. In the first method, the amount of biomass left after grazing is subtracted from the biomass on offer at the start of grazing, which gives the biomass utilised as grazing. The second method calculates herbage biomass by subtracting the amount of biomass left after grazing from the biomass on offer of the adjacent subplot from the grazed subplots, at the end of the grazing period. The third method use the average of biomass on offer at the start of grazing, and biomass on offer on the adjacent subplot at the end of the grazing period, from which the amount of material left after grazing is subtracted. The first of these three methods take no growth during the grazing period into account. The second method takes growth during the grazing period into account, but not the negative effect which grazing has on growth through removal of leaf area. The third method takes some growth into account but not all of the growth during grazing, as the grazing can have a negative effect on growth. In this study, the third method was used to calculate the herbage biomass (Figure 7). The two mixtures produced similar ($p > 0.05$) amounts of biomass. The mainly leguminous mixture contained more ($p < 0.05$) leguminous biomass and less ($p < 0.05$) cereal biomass compared to the mainly cereal mixture, which was to be expected with the compilation of the two cover crop mixtures.

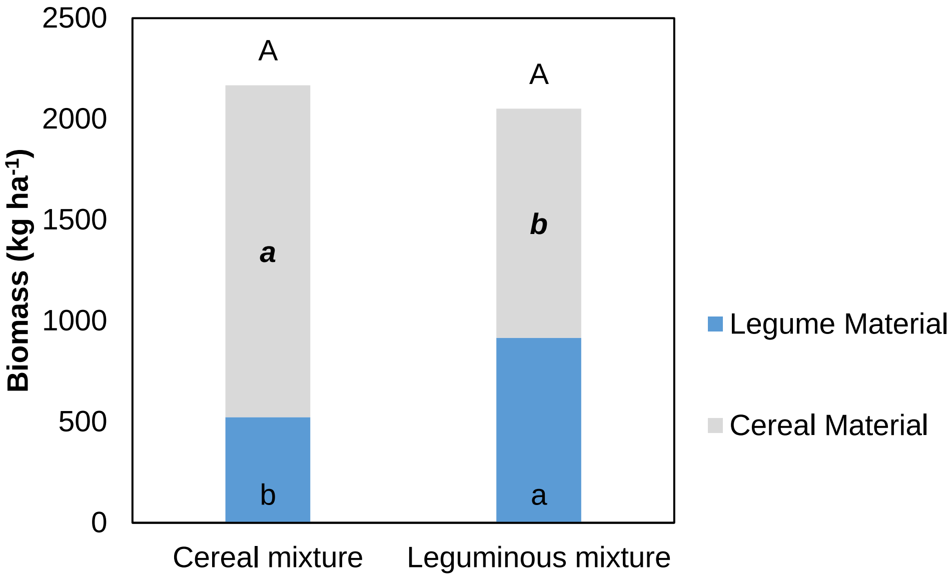

Figure 7: Cover crop biomass (dry matter) on offer for grazing when cereals in the cover crop mixture was at flag leaf stage. Different uppercase letters indicate a significant difference ($p < 0.05$) in the total quantity of cover crop biomass with a standard error = 111 kg ha^{-1} and a coefficient of variation = 39.35. Different lowercase letters in bold italics indicate a significant difference ($p < 0.05$) in the quantity of cereal biomass with a standard error = 110 kg ha^{-1} and a coefficient of variation = 44.66. Normal lowercase letters indicate a significant difference in the quantity of legume biomass with a standard error = 57 kg ha^{-1} and a coefficient of variation = 48.50.

The amount of biomass utilised as grazing and the amount of biomass removed as hay, are compared in Figure 8. The amount of biomass removed as hay was similar ($p > 0.05$) in both mixtures. The sheep also utilised similar ($p > 0.05$) amounts of biomass in the two different mixtures.

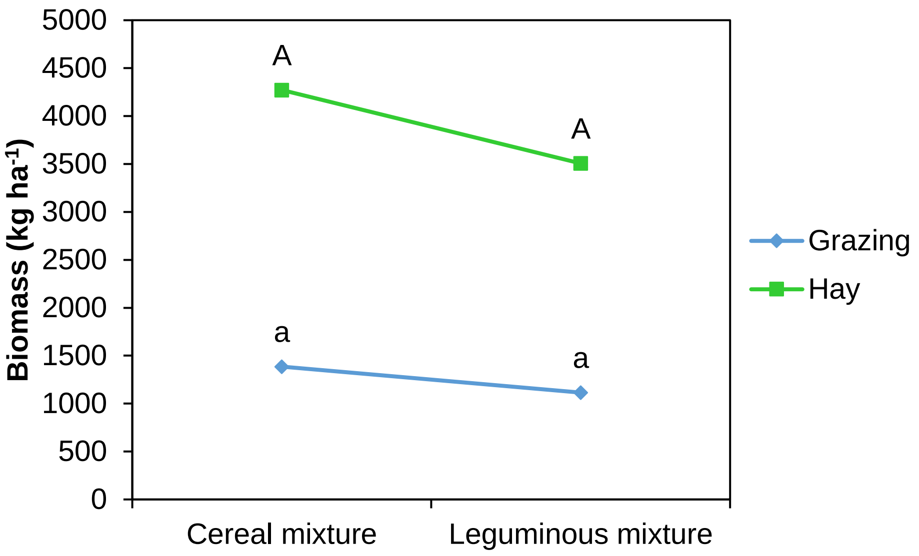

Figure 8: The amount of cover crop biomass (dry matter) utilised as grazing or removed as hay. Different uppercase letters indicate a significant difference ($p < 0.05$) in the amount of hay removed with a standard error = 319 kg ha^{-1} and a coefficient of variation = 29.58. Different lowercase letters indicate a significant difference ($p < 0.05$) in the amount of material grazed with a standard error = 107 kg ha^{-1} and a coefficient of variation = 27.85.

3.3.2 Nutritional value of cover crops

3.3.2.1 Effect of cover crop mixture

The nutritional value of the leguminous- and cereal mixtures at the time of grazing (when cereals in the mixtures reached flag leaf stage), are presented in Table 3. The mainly leguminous mixture had higher ($p < 0.05$) crude fat, crude protein (CP), gross energy (GE), Ca, Fe and Mg contents. Higher CP content of the mainly leguminous mixture can be a result of a bigger proportion of legume material in this mixture, and the ability of legumes to fix N. Crude fibre (CF), neutral-detergent fibre (NDF) and N-free extractives (NFE) were higher ($p < 0.05$) in the mainly cereal mixture compared to the mainly leguminous mixture. A higher ($p < 0.05$) proportion of cereal biomass (which is normally more fibrous than legumes) in the mainly cereal mixture may have led to higher CF and NDF.

Table 3: Nutritional value of the mainly leguminous- and mainly cereal cover crop mixtures when cereals in the mixtures reached flag leaf stage. Different letters indicate significant differences ($p < 0.05$). CV = Coefficient of variation

	Cover crop mixture		Standard Error	CV
	Leguminous	Cereal		
Ash (%)	11.55[a]	11.07[a]	0.26	33.52
Crude protein (%)	20.66[a]	17.22[b]	0.39	27.94
Crude fibre (%)	24.15[b]	25.21[a]	0.35	7.33
Crude fat (%)	3.49[a]	3.07[b]	0.04	30.32
Neutral-detergent fibre (%)	40.60[b]	44.44[a]	0.93	11.54
Acid-detergent fibre (%)	28.25[a]	28.88[a]	0.42	6.32
Acid-detergent lignin (%)	3.25[a]	3.11[a]	0.13	19.48
Gross energy (MJ kg^{-1})	17.89[a]	17.67[b]	0.05	1.34
Metabolisable energy (MJ kg^{-1})	10.40[a]	10.37[a]	0.04	2.25
***In Vitro* digestibility (%)**	80.25[a]	79.34[a]	0.78	7.05
N-free extractives (%)	40.15[b]	43.43[a]	0.47	12.98
Total digestible nutrients (%)	69.39[a]	69.17[a]	0.28	2.25
Ca (%)	0.93[a]	0.67[b]	0.04	35.68
P (%)	0.51[a]	0.50[a]	0.01	28.75
Mg (%)	0.24[a]	0.20[b]	0.01	13.94
K (%)	3.86[a]	3.96[a]	0.11	29.07
Na (mg kg^{-1})	1609[a]	1091[a]	213	48.65
Mn (mg kg^{-1})	46.60[a]	44.87[a]	2.37	22.58
Cu (mg kg^{-1})	5.33[a]	4.98[a]	0.17	12.42
Fe (mg kg^{-1})	223[a]	162[b]	16.42	47.39
Zn (mg kg^{-1})	25.24[a]	24.89[a]	0.87	16.05

In order to establish the expected nutritional value when a mainly leguminous- or cereal cover crop mixture is used for hay production, the nutritional value of the two mixtures at the time when hay was mowed (when the cereals in the cover crop mixtures reached the soft dough stage) are shown in Table 4. The trend, observed between the two mixtures when hay was mowed in terms of nutritional value, were similar to the trends observed between these two mixtures at grazing. Although the nutritional value changed at the different growth stages it was expected that the trends observed between mixtures at different growth stages wold be similar due to the botanical composition. In the mainly leguminous mixture CP, Ca, Mg and Zn were higher ($p < 0.05$), but CF, NDF and NFE were lower ($p < 0.05$) in comparison with the mainly cereal mixture.

Table 4: Nutritional value of mainly leguminous- and mainly cereal cover crop mixtures when cereals in the mixtures reached the soft dough stage. Different letters indicate significant differences ($p < 0.05$). CV = Coefficient of variation

	Cover crop mixture		**Standard Error**	**CV**
	Leguminous	**Cereal**		
Ash (%)	6.12^{a}	5.66^{a}	0.26	33.52
Crude protein (%)	12.82^{a}	10.22^{b}	0.39	27.94
Crude fibre (%)	27.00^{b}	28.02^{a}	0.35	7.33
Crude fat (%)	1.82^{a}	1.80^{a}	0.04	30.32
Neutral-detergent fibre (%)	47.42^{b}	52.34^{a}	0.93	11.54
Acid-detergent fibre (%)	30.60^{a}	31.25^{a}	0.42	6.32
Acid-detergent lignin (%)	4.29^{a}	4.41^{a}	0.13	19.48
Gross energy (MJ kg^{-1})	18.10^{a}	18.08^{a}	0.05	1.34
Metabolisable energy (MJ kg^{-1})	10.76^{a}	10.78^{a}	0.04	2.25
***In Vitro* digestibility (%)**	71.35^{a}	70.10^{a}	0.78	7.05
N-free extractives (%)	52.24^{b}	54.29^{a}	0.47	12.98
Total digestible nutrients (%)	71.76^{a}	71.89^{a}	0.28	2.25
Ca (%)	0.62^{a}	0.40^{b}	0.04	35.68
P (%)	0.30^{a}	0.29^{a}	0.01	28.75
Mg (%)	0.22^{a}	0.18^{b}	0.01	13.94
K (%)	2.24^{a}	2.31^{a}	0.11	29.07
Na (mg kg^{-1})	2054^{a}	1830^{a}	213	48.65
Mn (mg kg^{-1})	38.36^{a}	34.83^{a}	2.37	22.58
Cu (mg kg^{-1})	4.69^{a}	4.81^{a}	0.17	12.42
Fe (mg kg^{-1})	119^{a}	105^{a}	16.42	47.39
Zn (mg kg^{-1})	22.38^{a}	19.65^{b}	0.87	16.05

3.3.2.2 Effect of growth stage

The nutritional value of plants change as the plants grow (McDonald *et al.*, 2011). Table 5 gives an indication of how the nutritional value of a mainly leguminous mixture can change over time. When cover crops were grazed, the majority of nutritional parameters in the mainly leguminous mixture were higher ($p < 0.05$) compared to the same mixture when hay was mowed. At grazing, the mainly leguminous mixture had a higher ($p < 0.05$) *in vitro* digestibility, ash, CP, crude fat, Ca, P, Mg, K, Mn, Cu, Fe and Zn in comparison with the same mixture when hay was mowed. When the mainly leguminous mixture reached the stage where hay was mowed, the plants had become more ($p < 0.05$) fibrous and CF, NDF, acid-detergent fibre

(ADF), acid-detergent lignin (ADL), metabolisable energy (ME), GE, NFE and total digestible nutrients (TDN) had increased ($p < 0.05$) since the previous samples were taken at grazing.

Table 5: Nutritional value of the mainly leguminous cover crop mixture at grazing (when cereals in the mixture reached flag leaf stage) and mowed for hay (when cereals in the mixture reached the soft dough stage). Different letters indicate significant differences ($p < 0.05$). CV = Coefficient of variation

	Utilisation		Standard Error	CV
	Grazing	**Hay**		
Ash (%)	11.55^{a}	6.12^{b}	0.26	33.52
Crude protein (%)	20.66^{a}	12.82^{b}	0.39	27.94
Crude fibre (%)	24.15^{b}	27.0^{a}	0.35	7.33
Crude fat (%)	3.49^{a}	1.82^{b}	0.04	30.32
Neutral-detergent fibre (%)	40.60^{b}	47.42^{a}	0.93	11.54
Acid-detergent fibre (%)	28.25^{b}	30.60^{a}	0.42	6.32
Acid-detergent lignin (%)	3.25^{b}	4.29^{a}	0.13	19.48
Gross energy (MJ kg^{-1})	17.89^{b}	18.10^{a}	0.05	1.34
Metabolisable energy (MJ kg^{-1})	10.40^{b}	10.76^{a}	0.04	2.25
***In Vitro* digestibility (%)**	80.25^{a}	71.35^{b}	0.78	7.05
N-free extractives (%)	40.15^{b}	52.24^{a}	0.47	12.98
Total digestible nutrients (%)	69.39^{b}	71.76^{a}	0.28	2.25
Ca (%)	0.93^{a}	0.62^{b}	0.04	35.68
P (%)	0.51^{a}	0.30^{b}	0.01	28.75
Mg (%)	0.24^{a}	0.22^{b}	0.01	13.94
K (%)	3.86^{a}	2.24^{b}	0.11	29.07
Na (mg kg^{-1})	1609^{a}	2054^{a}	213	48.65
Mn (mg kg^{-1})	46.60^{a}	38.36^{b}	2.37	22.58
Cu (mg kg^{-1})	5.33^{a}	4.69^{b}	0.17	12.42
Fe (mg kg^{-1})	223^{a}	119^{b}	16.42	47.39
Zn (mg kg^{-1})	25.24^{a}	22.38^{b}	0.87	16.05

The nutritional value of the mainly cereal cover crop mixture changed over time. Table 6 shows the change that took place in this mixture from grazing to the stage when hay was mowed. Except for Cu and Na, the mainly cereal cover crop mixture had the same changes ($p < 0.05$) in nutritional value from grazing to the stage when hay was mowed as the mainly leguminous mixture. In the mainly cereal mixture Cu did not change ($p > 0.05$) and Na increased ($p < 0.05$) from grazing to the stage when hay was mowed. Although the mainly cereal cover crop mixture had a different botanical composition than the mainly leguminous mixture, both cereal- and legume plants became more ($p < 0.05$) fibrous and less ($p < 0.05$) digestible as the plants matured.

Table 6: Nutritional value of the mainly cereal cover crop mixture at grazing (when cereals in the mixture reach flag leaf stage) and mowed for hay (when cereals in the mixture reached the soft dough stage). Different letters indicate significant differences ($p < 0.05$). CV = Coefficient of variation

	Utilisation		Standard	CV
	Grazing	Hay	Error	
Ash (%)	11.07^{a}	5.66^{b}	0.26	33.52
Crude protein (%)	17.22^{a}	10.22^{b}	0.39	27.94
Crude fibre (%)	25.21^{b}	28.02^{a}	0.35	7.33
Crude fat (%)	3.07^{a}	1.80^{b}	0.04	30.32
Neutral-detergent fibre (%)	44.44^{b}	52.34^{a}	0.93	11.54
Acid-detergent fibre (%)	28.88^{b}	31.25^{a}	0.42	6.32
Acid-detergent lignin (%)	3.11^{b}	4.41^{a}	0.13	19.48
Gross energy (MJ kg^{-1})	17.67^{b}	18.08^{a}	0.05	1.34
Metabolisable energy (MJ kg^{-1})	10.37^{b}	10.78^{a}	0.04	2.25
***In Vitro* digestibility (%)**	79.34^{a}	70.10^{b}	0.78	7.05
N-free extractives (%)	43.43^{b}	54.29^{a}	0.47	12.98
Total digestible nutrients (%)	69.17^{b}	71.89^{a}	0.28	2.25
Ca (%)	0.67^{a}	0.40^{b}	0.04	35.68
P (%)	0.50^{a}	0.29^{b}	0.01	28.75
Mg (%)	0.20^{a}	0.18^{b}	0.01	13.94
K (%)	3.96^{a}	2.31^{b}	0.11	29.07
Na (mg kg^{-1})	1091^{b}	1830^{a}	213	48.65
Mn (mg kg^{-1})	44.87^{a}	34.83^{b}	2.37	22.58
Cu (mg kg^{-1})	4.98^{a}	4.81^{a}	0.17	12.42
Fe (mg kg^{-1})	162^{a}	105^{b}	16.42	47.39
Zn (mg kg^{-1})	24.89^{a}	19.65^{b}	0.87	16.05

3.3.2.3 The implication of different mixtures and growth stages

The botanical composition did not affect the majority of the nutritional parameters, but some of the main contributing factors like CP and CF, was influenced ($p < 0.05$) by the different mixtures irrespective of the growth stage. This enables producers to adjust the nutritional value of cover crop mixture by changing the botanical composition of the mixture. Crude protein can be increased by increasing the proportion of legumes and CF can be increased by increasing the proportion of cereals.

In this study growth stage of the cover crop mixture influenced the nutritional parameters more than the botanical composition of the different mixtures. This proves that plants change over time and the timing of utilisation and mowing of hay can influence the nutritional value of a cover crop mixture. The timing of utilisation can be combined with the botanical composition of a mixture in order to satisfy the specific nutritional needs, which a production system might desire.

3.3.3 Effect of cover crop utilisation on mulch quantity and quality

No material was removed from the unutilised cover crop subplots, however, on the grazed subplots 1000 – 1500 kg ha^{-1} of biomass was utilised by sheep and on the hay subplots, 3500 – 4500 kg ha^{-1} biomass was removed as hay (Figure 8). Samples collected after the cover crop growing season, were used to determine what the effect of cover crop utilisation would be on the biomass left as soil cover (Figure 9).

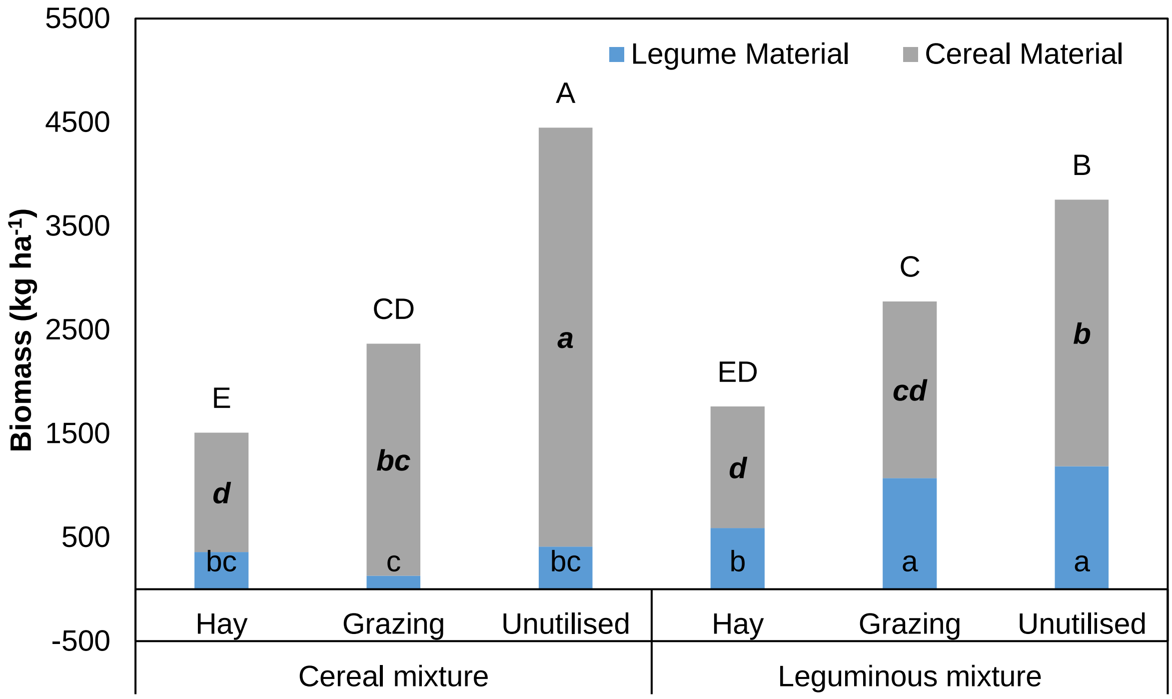

Figure 9: Total cover crop biomass (dry matter) and the proportions of legume and cereal biomass left on each subplot (hay, grazing and unutilised for the mainly leguminous- and mainly cereal mixture) after the cover crop growing season. Different uppercase letters indicate a significant difference ($p < 0.05$) in the total amount of cover crop material with a standard error = 252 kg ha^{-1} and a coefficient of variation = 48.67. Different lowercase letters in bold italics indicate a significant difference ($p < 0.05$) in the amount of cereal material with a standard error = 263 kg ha^{-1} and a coefficient of variation = 62.05. Different normal lowercase letters indicate a significant difference ($p < 0.05$) in the amount of legume material with a standard error = 130 kg ha^{-1} and a coefficient of variation = 93.26.

There was a visible difference between different utilisations in biomass and its response to utilisation (Figure 10).

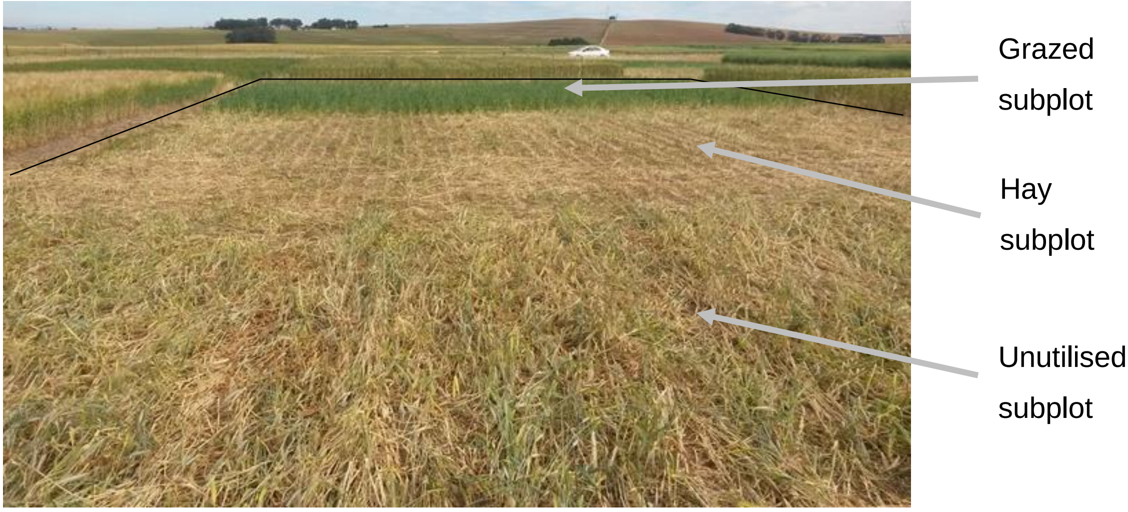

Figure 10: A mainly cereal cover crop plot after utilisation, where the grazing plot is re-growing and the utilised subplots have less material in comparison with the unutilised subplots.

Despite the reduction in total cover crop biomass, the legume and cereal components of each mixture were not influenced by utilisation in the same manner. The legume biomass in the mainly cereal mixture was similar ($p > 0.05$) in the hay and unutilised subplots. In this mixture, legumes where overshadowed by cereal plants and the legumes grew under the canopy created by the cereals. The mower could therefore not reach low enough to mow the legume biomass. In the mainly leguminous mixture the legumes were not overshadowed by cereals and the mower was able to cut the legume biomass. Leguminous biomass was reduced ($p < 0.05$) in the mainly leguminous mixture through the mowing of hay in comparison with the unutilised subplots. The sheep would have been able to reach the legume plants but did not reduce ($p > 0.05$) the amount of leguminous biomass in comparison with the unutilised subplots in both mixtures. This may be due to legume plants re-growing after grazing or selective grazing, despite high stocking rates.

The utilisation of cover crops reduced ($p < 0.05$) the amount of cereal biomass in both of the mixtures. In the mainly cereal mixture the amount of cereal biomass was higher ($p < 0.05$) compared to the hay subplots of the same mixture. In the mainly leguminous mixture, hay and grazing subplots also had similar ($p > 0.05$) amounts of cereal biomass. Regrowth from the cereal plants on the hay plot, or legume plants competing with cereals on the grazed plots of the mainly cereal mixture, could have led to an insignificant difference ($p > 0.05$) between these two subplots in terms of cereal biomass.

Methods of utilisation of cover crop mixtures were compared in order to establish if the method of utilisation has different effects on the two different mixtures. The mainly cereal mixture produced more ($p < 0.05$) cereal- and total cover crop biomass on the unutilised subplots, compared to the same subplots in the mainly leguminous mixture. The larger portion of cereals in the mainly cereal mixture could have led to a higher total cover crop biomass production as cereals produce more material. Due to the botanical composition, the mainly leguminous mixture contained more ($p < 0.05$) leguminous material in the unutilised subplots compared to the same subplots in the other mixture.

It would seem that the mowing and removal of material eliminated differences ($p > 0.05$) between the two different mixtures. Similar ($p > 0.05$) amounts of total cover crop-, legume- and cereal biomass were measured between the two different mixtures on the hay subplots.

On the grazed subplots the total cover crop- and cereal biomass was comparable ($p > 0.05$) between the two mixtures. The mainly leguminous mixture contained more ($p < 0.05$) legume biomass than the same subplots in the other mixture. Sheep grazing the mainly legume mixture did not consume pea plants, which they did consume in the mainly cereal mixture. This could have led to a difference ($p < 0.05$) in terms of legume biomass for the two different cover crop mixtures.

The total cover crop biomass shown in Figure 9 does not include weeds and wheat stubble left on the field from the previous wheat crop. Figure 11 includes above-ground biomass on the different subplots at the end of the cover crop growing season.

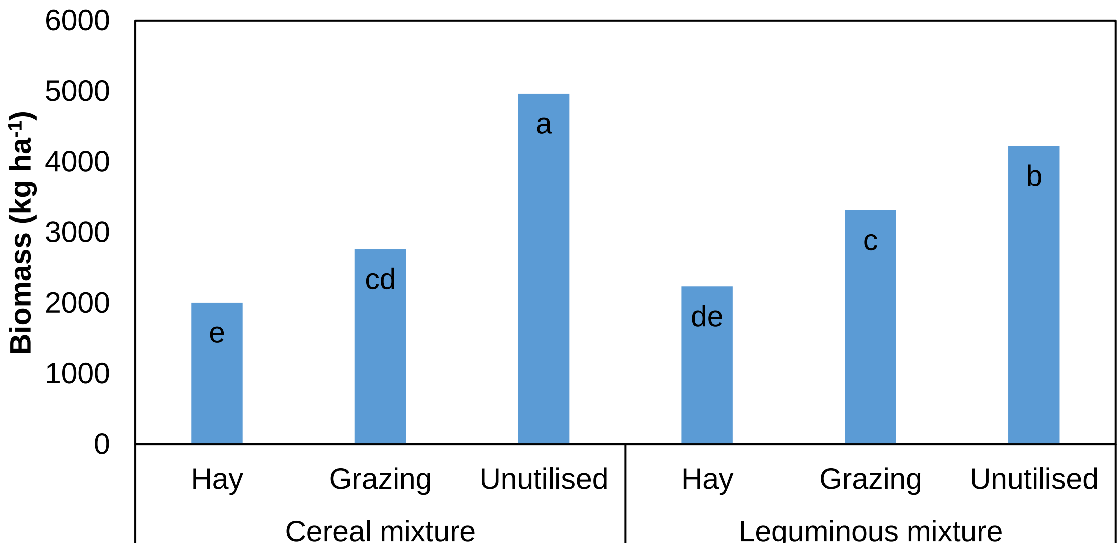

Figure 11: The total above-ground biomass (dry matter) left on each subplot (hay, grazing and unutilised for the mainly leguminous- and mainly cereal mixture) following the cover crop growing season as soil cover. Different letters indicate significant differences ($p < 0.05$). Standard error = 260 kg ha^{-1}. Coefficient of variation = 42.30.

At the end of the cover crop growing season most of the wheat stubble from the previous year had been broken down and the quantity of weeds in the different subplots were insignificant. The significant differences in total above-ground biomass were therefore the same as the significant differences in the total cover crop biomass. The total amount of above-ground biomass on the hay-, grazed- and unutilised subplots ranged between 2006 – 2234 kg ha^{-1}, 2762 – 3314 kg ha^{-1}and 4966 – 4223 kg ha^{-1}, respectively.

Total above-ground biomass (kg ha^{-1}) did not necessarily correlated with the percentage of soil cover. Ward *et al.* (2012) found that treatments which included rolling had a higher percentage of soil cover compared to unrolled treatments, irrespective of biomass production. In this study grazing and hay treatments did not include rolling, but the unutilised treatment did. Figure 12 shows the percentage of soil cover after cover crops were utilised and died off. The unutilised subplots, which were rolled, had a higher ($p < 0.05$) percentage soil cover, compared to the grazed and hay subplots for both mixtures. According to Ward *et al.* (2012) the improved soil cover percentage, after rolling, is due to the horizontal arrangement of plant material. The same form of utilisation between the two different cover crop mixtures did not differ ($p > 0.05$) from one another.

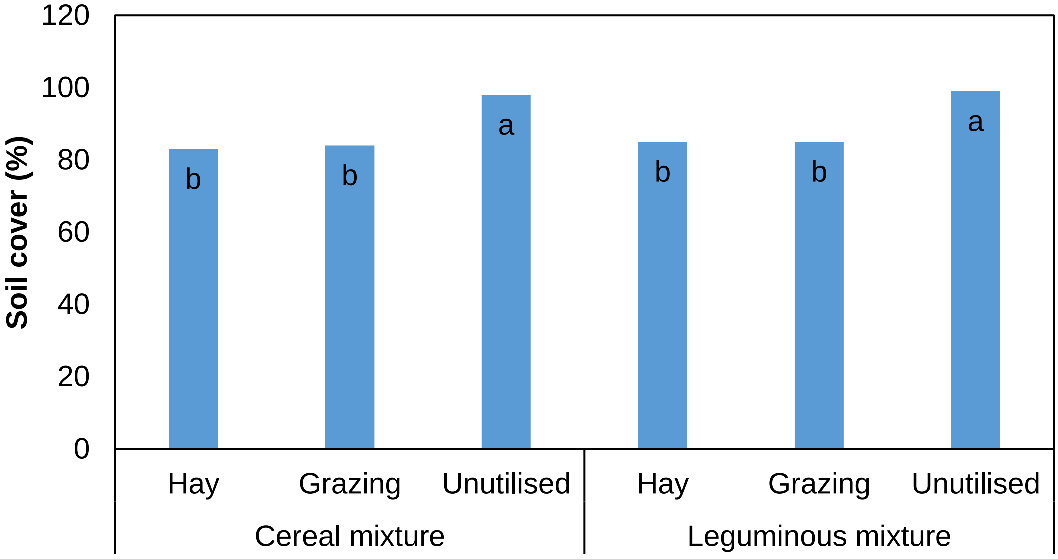

Figure 12: The percentage soil covered with plant material after the cover crop growing season on all subplots. Different letters indicate significant differences ($p < 0.05$). Standard error = 2.6%. Coefficient of variation = 12.57.

The percentage of soil cover was influenced by management and is not an accurate indication of the effect that utilisation had on soil cover. For instance, if the grazed subplots were rolled after the cover crop growing season, it may have improved the percentage of soil cover on the grazed subplots.

The percentage- and the amount of plant material can influence the benefits obtained from soil cover. According to Ranaivoson *et al.* (2017) the amount of soil cover is correlated to how effectively the soil cover can prevent soil water evaporation. Büchi *et al.* (2018) suggested that soil cover is the main predictor of a cover crop's ability to suppress weeds in subsequent cash crops, and not necessarily cover crop biomass. It would seem that increased amount- and percentage of soil cover will improve the benefits obtained from the soil cover.

The percentage- and amount of soil cover are not the only indications of the benefits which can be obtained from soil cover. The minerals in the cover crop material can be utilised by subsequent cash crops. In order to establish how cover crop mixtures and utilisations will influence minerals in the soil cover, the mineral composition and content of each subplot will be discussed below and the mineral content of each subplot in the mainly leguminous mixture and mainly cereal mixture can be seen in Table 7.

The hay subplots were compared to the grazed subplots in terms of mineral content for the leguminous mixture. It would seem that the mineral content followed the same trend as the total above-ground biomass between these two subplots. It was found that the hay subplots had a lower ($p < 0.05$) amount of Al, ash, N, Ca, P, Mg, K, Na, Fe, S, Mn, Cu, Zn and B compared to the grazed subplots. Iron was the only mineral of which the grazed and hay subplots contained similar ($p > 0.05$) amounts.

When the hay and unutilised subplots of the mainly leguminous mixture were compared, the hay subplots had less ($p < 0.05$) total above-ground biomass which thus resulted in less ($p < 0.05$) available minerals. The amount of ash, N, Ca, P, Mg, K, Na, S, Mn, Cu, Zn and B were lower ($p < 0.05$) than the unutilised subplots. These two subplots had comparable ($p > 0.05$) amounts of Fe and Al.

The grazed subplots in the mainly leguminous mixture was compared to the unutilised subplots of the same mixture. It is clear that the mineral content of this mixture does not follow the same trend as the amount of biomass on these subplots. Grazing does not reduce ($p > 0.05$) the amount of ash, N, Ca, Mg, K, Na, Fe, S, Al, Mn, Cu, Zn and B in the above-ground biomass. Phosphorus was the only mineral of which the grazed subplots contained less ($p < 0.05$) than the unutilised subplots, while the grazed subplots contained more ($p < 0.05$) Al compared the unutilised subplots. When the mineral content and biomass did not follow the same trend, the concentration of minerals had to increase in order to compensate for the removal of material.

Table 7: Mineral content of the total above-ground biomass following the cover crop growing season for each subplot (hay grazed and utilised) in the mainly leguminous- and mainly cereal cover crop mixtures. Different letters indicate significant differences ($p < 0.05$). CV = Coefficient of variation

	Hay	Grazing	Unutilised	Standard Error	CV
			Mainly leguminous mixture		
Ash (kg ha^{-1})	190^{b}	271^{a}	297^{a}	30.07	45.01
N (kg ha^{-1})	39.04^{b}	72.51^{a}	73.86^{a}	5.11	43.47
Ca (kg ha^{-1})	12.70^{b}	19.93^{a}	20.51^{a}	1.35	43.42
P (kg ha^{-1})	5.05^{c}	7.98^{b}	10.01^{a}	0.64	43.39
Mg (kg ha^{-1})	3.80^{b}	6.67^{a}	7.39^{a}	0.51	44.53
K (kg ha^{-1})	31.96^{b}	53.3^{a}	63.44^{a}	5.06	47.02
Na (kg ha^{-1})	3.13^{b}	10.60^{a}	8.08^{a}	1.92	116
Fe (kg ha^{-1})	1.96^{a}	2.86^{a}	2.11^{a}	0.37	59.35
S (kg ha^{-1})	3.01^{b}	5.05^{a}	5.50^{a}	0.46	46.51
Al (kg ha^{-1})	1.10^{b}	1.68^{a}	1.08^{b}	0.14	43.52
Mn (g ha^{-1})	100.6^{b}	156.0^{a}	162.2^{a}	13.63	42.92
Cu (g ha^{-1})	10.86^{b}	17.15^{a}	20.82^{a}	2.11	50.85
Zn (g ha^{-1})	41.09^{b}	67.88^{a}	70.82^{a}	5.20	41.59
B (g ha^{-1})	28.94^{b}	45.26^{a}	41.56^{a}	3.22	40.43
			Mainly cereal mixture		
Ash (kg ha^{-1})	176^{b}	258^{a}	310^{a}	30.07	45.01
N (kg ha^{-1})	29.65^{c}	51.95^{b}	72.16^{a}	5.11	43.47
Ca (kg ha^{-1})	9.09^{b}	10.11^{b}	15.52^{a}	1.35	43.42
P (kg ha^{-1})	4.39^{c}	6.75^{b}	11.22^{a}	0.64	43.39
Mg (kg ha^{-1})	2.85^{c}	4.88^{b}	7.15^{a}	0.51	44.53
K (kg ha^{-1})	27.04^{c}	51.80^{b}	73.59^{a}	5.06	47.02
Na (kg ha^{-1})	2.33^{b}	4.71^{ab}	7.61^{a}	1.92	116
Fe (kg ha^{-1})	2.08^{a}	2.22^{a}	1.74^{a}	0.37	59.35
S (kg ha^{-1})	2.38^{c}	4.05^{b}	5.72^{a}	0.46	46.51
Al (kg ha^{-1})	1.04^{a}	1.16^{a}	1.11^{a}	0.14	43.52
Mn (g ha^{-1})	88.02^{b}	112.1^{b}	179.2^{a}	13.63	42.92
Cu (g ha^{-1})	10.60^{c}	17.10^{b}	22.46^{a}	2.11	50.85
Zn (g ha^{-1})	33.49^{c}	54.31^{b}	80.27^{a}	5.20	41.59
B (g ha^{-1})	23.73^{b}	24.91^{b}	37.15^{a}	3.22	40.43

In the mainly cereal mixture the utilisation of cover crops had a similar effect on mineral content as in the total above-ground biomass. This was not the case in the mainly legume mixture where the majority of minerals in the grazing- and unutilised subplots was similar ($p < 0.05$) although total above-ground biomass differed.

In the mainly cereal mixture the unutilised subplots had higher ($p < 0.05$) N, Ca, P, Mg, K, S, Mn, Cu, Zn and B content compared to the grazed- and hay subplots. The grazing subplots had a higher ($p < 0.05$) N, P, Mg, K, S, Cu and Zn content compared to the hay subplots. Some of the minerals, however, did not follow the same trend as the total above-ground biomass between different utilisations. The utilisation of cover crops did not influence ($p > 0.05$) Fe and Al contents in the mainly cereal mixture. The ash and Na did not differ ($p > 0.05$) between the unutilised- and grazed subplots while there were no differences ($p > 0.05$) in the amount of Ca, Mn, Na and B between the grazed and hay subplots.

Utilisations did not have the same effect on the amount of minerals in the total above-ground biomass, between the two different mixtures. Table 8 compares the mineral content of the two different cover crop mixtures in terms of each utilisation.

In the hay subplots there was no difference ($p > 0.05$) between the two different mixtures in terms of mineral content. This may be because only a small amount of material was left after the cover crops were utilised as hay compared to the other subplots in both of the mixtures.

The amount of ash, P, K, Fe, S, Cu and Zn in the total above-ground biomass of the grazed subplots did not differ ($p > 0.05$) in the two different mixtures. The mainly leguminous mixture contained more ($p < 0.05$) N, Ca, Mg, Na, Al, Mn and B compared to the mainly cereal mixture. The total above-ground biomass between these two subplots did not differ ($p > 0.05$).

In the unutilised subplots, of the two different mixtures, the amount of Ca was higher ($p < 0.05$) in the mainly leguminous mixture. Except for Ca, there was no difference ($p > 0.05$) between the two different mixtures on the unutilised subplots in terms of mineral content. Although the mainly cereal mixture contained more ($p < 0.05$) total above-ground biomass, the majority of minerals did not differ ($p > 0.05$) between the two mixtures.

Table 8: Mineral content of the total above-ground biomass remaining after cover crops were utilised as hay, grazing and unutilised, for both the mainly leguminous mixture (MLM) and mainly cereal mixture (MCM). Different letters indicate significant differences ($p < 0.05$). CV = Coefficient of variation

	Hay		Grazing		Unutilised		Standard Error	CV
	MLM	MCM	MLM	MCM	MLM	MCM		
Ash (kg ha^{-1})	190^{bc}	176^{c}	271^{a}	258^{ab}	297^{a}	310^{a}	30.7	45.01
N (kg ha^{-1})	39.04^{bc}	29.65^{c}	72.51^{a}	51.95^{b}	73.86^{a}	72.16^{a}	5.11	43.47
Ca (kg ha^{-1})	12.70^{bc}	9.09^{c}	19.93^{a}	10.11^{c}	20.51^{a}	15.52^{b}	1.35	43.42
P (kg ha^{-1})	5.05^{cd}	4.39^{d}	7.98^{b}	6.75^{bc}	10.01^{a}	11.22^{a}	0.64	43.39
Mg (kg ha^{-1})	3.80^{bc}	2.85^{c}	6.67^{a}	4.88^{b}	7.39^{a}	7.15^{a}	0.51	44.53
K (kg ha^{-1})	31.96^{c}	27.04^{c}	53.3^{b}	51.80^{b}	63.44^{ab}	73.59^{a}	5.06	47.02
Na (kg ha^{-1})	3.13^{c}	2.33^{c}	10.60^{a}	4.71^{bc}	8.08^{ab}	7.61^{ab}	1.92	116
Fe (kg ha^{-1})	1.96^{ab}	2.08^{ab}	2.86^{a}	2.22^{ab}	2.11^{ab}	1.74^{b}	0.37	59.35
S (kg ha^{-1})	3.01^{cd}	2.38^{d}	5.05^{ab}	4.05^{bc}	5.50^{a}	5.72^{a}	0.46	46.51
Al (kg ha^{-1})	1.10^{b}	1.04^{b}	1.68^{a}	1.16^{b}	1.08^{b}	1.11^{b}	0.14	43.52
Mn (g ha^{-1})	100.6^{b}	88.02^{b}	156.0^{a}	112.1^{b}	162.2^{a}	179.2^{a}	13.63	42.92
Cu (g ha^{-1})	10.86^{c}	10.60^{c}	17.15^{ab}	17.10^{b}	20.82^{ab}	22.46^{a}	2.11	50.85
Zn (g ha^{-1})	41.09^{cd}	33.49^{d}	67.88^{ab}	54.31^{bc}	70.82^{a}	80.27^{a}	5.20	41.59
B (g ha^{-1})	28.94^{bc}	23.73^{c}	45.26^{a}	24.91^{c}	41.56^{a}	37.15^{ab}	3.22	40.43

The concentration of minerals changed as a result of utilisation and the amount of biomass and the mineral content did not follow the same trend. In order to establish the impact of cover crop utilisation on the concentration of minerals in the total above-ground biomass, these concentrations within in each mixture and utilisation are compared in Table 9.

In the mainly leguminous mixture, the concentration of each mineral in the unutilised subplots were compared to the same mineral in the hay- and grazed subplots. The concentration of the following minerals increased ($p < 0.05$): ash, Ca, Fe, Al and B in the hay subplots, and ash, N, Ca, Mg, S, Na, Fe, Al, Mn, Zn and B in the grazed subplots. Not one of the minerals had a lower ($p < 0.05$) concentration in the total above-ground biomass of the hay- or grazed subplots in comparison with the unutilised subplots. This indicates that the utilisation of cover crops in the form of grazing- and hay production can increase the concentration of minerals in the above-ground biomass. Nitrogen, which is the most expensive fertiliser for producers in the area, was 1.75% in the unutilised subplots and 2.18% in the grazed subplots ($p < 0.05$). This significant increase in N can have great economic value for producers.

There were some differences ($p < 0.05$) in the concentration of minerals of the total above-ground biomass between the grazing- and hay subplots of the mainly leguminous mixture. The grazing subplots contained a higher ($p < 0.05$) concentration of N, Mg, K, S, Na and Zn compared to the hay subplots. None of the minerals had a higher ($p < 0.05$) concentration on the hay subplots compared to the grazed subplots.

The grazing subplots had the highest ($p < 0.05$) concentration of minerals in the total above-ground biomass, compared to the hay- and unutilised subplots of the mainly leguminous mixture.

In the mainly cereal mixture and the mainly leguminous mixture the same trend was observed in terms of mineral concentrations of the above-ground biomass. In the mainly cereal mixture the concentration of ash, Ca, Fe, Al, Mn and B in the hay subplots and ash, N, Ca, P, Mg, K, S, Fe, Al, Cu and Zn in the grazed subplots were higher ($p < 0.05$) than in the unutilised subplots. None of the minerals had a lower ($p < 0.05$) concentration in the hay- and grazed subplots compared to the unutilised subplots. In the mainly cereal mixture it is not exactly the same minerals which increased ($p < 0.05$) compared to the mainly leguminous mixture as a result of utilisation, but the same trend was observed.

The hay- and grazed subplots of the mainly cereal mixture did not contain similar ($p < 0.05$) concentrations of minerals in the total above-ground biomass. The hay subplots contained more ($p < 0.05$) Ca and B but the grazing subplots contained more ($p < 0.05$) N, P, Mg, K, S and Zn.

Table 9: Mineral concentration of the total above-ground biomass following the cover crop growing season for each subplot (hay grazed and utilised) in the mainly leguminous- and mainly cereal cover crop mixtures. Different letters indicate significant differences ($p < 0.05$). CV = Coefficient of variation

	Hay	**Grazing**	**Unutilised**	**Standard Error**	**CV**
Mainly leguminous mixture					
Ash (%)	8.21^{a}	8.39^{a}	6.84^{b}	0.64	30.49
N (%)	1.72^{b}	2.18^{a}	1.75^{b}	0.06	19.12
Ca (%)	0.58^{a}	0.62^{a}	0.49^{b}	0.02	28.17
P (%)	0.23^{a}	0.24^{a}	0.24^{a}	0.01	12.89
Mg (%)	0.17^{b}	0.20^{a}	0.17^{b}	0.004	14.83
K (%)	1.42^{b}	1.59^{a}	1.49^{ab}	0.07	18.76
S (%)	0.13^{b}	0.15^{a}	0.13^{b}	0.01	18.02
Na (%)	0.14^{b}	0.28^{a}	0.18^{b}	0.04	88.68
Fe (mg kg^{-1})	965^{a}	974^{a}	512^{b}	144	70.36
Al (mg kg^{-1})	518^{a}	543^{a}	268^{b}	43.08	45.80
Mn (mg kg^{-1})	44.88^{ab}	50.19^{a}	39.68^{b}	3.97	32.34
Cu (mg kg^{-1})	4.80^{a}	5.34^{a}	4.96^{a}	0.74	49.27
Zn (mg kg^{-1})	18.09^{b}	20.79^{a}	16.91^{b}	0.99	20.69
B (mg kg^{-1})	13.02^{a}	13.47^{a}	9.96^{b}	0.68	28.14
Mainly cereal mixture					
Ash (%)	8.54^{a}	9.33^{a}	6.14^{b}	0.64	30.49
N (%)	1.47^{b}	1.97^{a}	1.46^{b}	0.06	19.12
Ca (%)	0.45^{a}	0.37^{b}	0.32^{c}	0.02	28.17
P (%)	0.22^{b}	0.25^{a}	0.23^{b}	0.1	12.89
Mg (%)	0.14^{b}	0.18^{a}	0.14^{b}	0.004	14.83
K (%)	1.33^{b}	1.89^{a}	1.47^{b}	0.07	18.76
S (%)	0.12^{b}	0.15^{a}	0.12^{b}	0.01	18.02
Na (%)	0.11^{a}	0.19^{a}	0.15^{a}	0.04	88.68
Fe (mg/kg)	1009^{a}	823^{a}	354^{b}	144	70.36
Al (mg kg^{-1})	507^{a}	436^{a}	227^{b}	43.08	45.80
Mn (mg kg^{-1})	45.76^{a}	43.03^{ab}	36.13^{b}	3.97	32.34
Cu (mg kg^{-1})	5.19^{ab}	6.64^{a}	4.46^{b}	0.74	49.27
Zn (mg kg^{-1})	16.80^{b}	20.66^{a}	16.28^{b}	0.99	20.69
B (mg kg^{-1})	11.79^{a}	9.47^{b}	7.64^{b}	0.68	28.14

When the utilisation of cover crops was compared within each mixture the two different mixtures did not follow the same trend in terms of mineral content. This was not the case in terms of the concentration of minerals where the two mixtures followed the same trend.

There were only a few differences ($p < 0.05$) observed between the two mixtures in terms of mineral concentration in the total above-ground biomass for the hay-, grazing- and unutilised subplots. The mainly leguminous mixture contained a higher ($p < 0.05$) concentration of N, Ca and Mg compared to the mainly cereal mixture of the hay-, grazed- and unutilised subplots. The mainly legume mixture contained a higher ($p < 0.05$) concentration of B on the grazed- and unutilised subplots. The mainly cereal mixture contained a higher ($p < 0.05$) concentration of K on the grazed subplots.

Grazing and the mowing of hay were done when the cover crops were at different growth stages. This is why it is difficult to establish if the differences between grazing and hay are a result of the different utilisations or just the timing of these utilisations.

Concentration of some minerals in the hay subplots, and to a greater extend, in the grazed subplots, increased ($p < 0.05$) in comparison with the unutilised subplots. Mineral concentrations may have increased due to the fact that cover crops could regrow after utilisation, in the form of hay and grazing. Grazed subplots had more time to regrow as the grazing was done before the hay plots were mowed for hay. The plants on the grazed- and hay subplots were at an earlier growth stage, compared to the unutilised subplots, at the end of the growing season as a result of the regrowth. Section 3.3.2 indicates that plants had a higher concentration of nutrients at an earlier growth stage, which might explain why the concentration of some minerals in the cover crops increased after grazing and hay production.

Although both mixtures compensated in terms of mineral concentration in the above-ground biomass after grazing or hay production, the two mixtures did not compensate to the same extent. The grazed subplots of the mainly leguminous mixture were the only utilised subplots where the majority of minerals in the above-ground biomass were present in the same quantity ($p > 0.05$) as in the unutilised subplots of the same mixture. The grazing did not have a significant effect on the majority of minerals, but still reduced ($p < 0.05$) the amount of soil cover in terms of total above-ground biomass compared to the unutilised subplots of the same mixture.

Table 10: Mineral concentration of the total above-ground biomass remaining after cover crops were utilised as hay, grazing and unutilised, for both the mainly leguminous mixture (MLM) and mainly cereal mixture (MCM). Different letters indicate significant differences ($p < 0.05$). CV = Coefficient of variation

	Hay		Grazing		Unutilised		Standard Error	CV
	MLM	**MCM**	**MLM**	**MCM**	**MLM**	**MCM**		
Ash (%)	8.21^{a}	8.54^{ab}	8.39^{a}	9.33^{a}	6.84^{bc}	6.14^{c}	0.64	30.49
N (%)	1.72^{c}	1.47^{d}	2.18^{a}	1.97^{b}	1.75^{c}	1.46^{d}	0.06	19.12
Ca (%)	0.58^{a}	0.45^{b}	0.62^{a}	0.37^{c}	0.49^{b}	0.32^{d}	0.02	28.17
P (%)	0.23^{b}	0.22^{b}	0.24^{a}	0.25^{ab}	0.24^{ab}	0.23^{b}	0.01	12.89
Mg (%)	0.17^{b}	0.14^{c}	0.20^{a}	0.18^{b}	0.17^{b}	0.14^{c}	0.004	14.83
K (%)	1.42^{c}	1.33^{c}	1.59^{b}	1.89^{a}	1.49^{bc}	1.47^{bc}	0.07	18.76
S (%)	0.13^{b}	0.12^{bc}	0.15^{a}	0.15^{a}	0.13^{bc}	0.12^{c}	0.01	18.02
Na (%)	0.14^{b}	0.11^{b}	0.28^{a}	0.19^{ab}	0.18^{b}	0.15^{b}	0.04	88.68
Fe (mg kg^{-1})	965^{a}	1009^{a}	974^{a}	823^{ab}	512^{bc}	354^{c}	144	70.36
Al (mg kg^{-1})	518^{a}	507^{a}	543^{a}	436^{a}	268^{b}	227^{b}	43.08	45.80
Mn (mg kg^{-1})	44.88^{ab}	45.76^{ab}	50.19^{a}	43.03^{abc}	39.68^{bc}	36.13^{c}	3.97	32.34
Cu (mg kg^{-1})	4.80^{ab}	5.19^{ab}	5.34^{ab}	6.64^{a}	4.96^{ab}	4.46^{b}	0.74	49.27
Zn (mg kg^{-1})	18.09^{bc}	16.80^{c}	20.79^{a}	20.66^{ab}	16.91^{c}	16.28^{c}	0.99	20.69
B (mg kg^{-1})	13.02^{a}	11.79^{ab}	13.47^{a}	9.47^{cd}	9.96^{bc}	7.64^{d}	0.68	28.14

3.3.4 Effect of cover crop utilisation on soil properties

The results obtained from The Complete Soil Health Tool are presented in Table 11. The three different utilisations within the mainly leguminous mixture, influenced only some of the N parameters. The hay subplots contained more ($p < 0.05$) total N compared to the unutilised subplots. The grazed subplots had a higher ($p < 0.05$) concentration of total N, nitrate (NO_3^-) and inorganic N compared to the unutilised subplots. The grazed subplots furthermore had a higher ($p < 0.05$) concentration organic N in reserve compared to the hay subplots. Hay production had a positive effect on one of the soil N parameters, but grazing had a positive effect on four of the soil N parameters in the mainly leguminous mixture.

In the grazed subplots of the mainly cereal mixture, the concentration of ammonium (NH_4^+) increased ($p < 0.05$) compared to the hay- and unutilised subplots. Grazing also increased ($p < 0.05$) the concentration of inorganic N in comparison with the unutilised subplots. The unutilised subplots, on the other hand, had a higher ($p < 0.05$) volumetric aggregate stability compared to the grazed subplots. In both the mainly leguminous- and cereal mixture the utilisation of cover crops increased ($p < 0.05$) some of the soil N parameters. Grazing showed a larger increase ($p < 0.05$) in soil N parameters compared to hay production, in both the cover crop mixtures.

On the hay subplots there were no differences ($p > 0.05$) between the two mixtures in terms of The Complete Soil Health Tool. In terms of grazed subplots, the mainly leguminous mixture contained a higher ($p < 0.05$) concentration of NO_3^-, while the mainly cereal mixture contained a higher ($p < 0.05$) concentration of organic P.

Results from the standard chemical soil analyses presented in Table 12 (depth 0 – 150 mm) and Table 13 (depth 150 – 300 mm) were used to compare the two different mixtures within the different utilisation methods. In the unutilised subplots the concentration of Mn was higher ($p < 0.05$) at both depths (0 – 150 mm and 150 – 300 mm) in the mainly leguminous mixture compared to the mainly cereal mixture. This was the only difference between the two different mixtures.

Only two difference in the results of the mainly leguminous mixture were noted between the hay, grazed- and unutilised subplots. The hay subplots contained a higher ($p < 0.05$) concentration of Ca compared to the unutilised subplots in the top 150 mm of soil, while at a depth of 150 – 300 mm, the unutilised subplots had a higher ($p < 0.05$) resistance compared to the grazed subplots.

Except for Zn, all other soil parameters obtained from the two different depths in the hay-, grazed- and unutilised subplots in the mainly cereal mixture were similar ($p > 0.05$). The concentration of Zn was higher in the unutilised subplots compared to the hay subplots.

Table 11: Soil Health Solutions soil analysis of soil collected after the cover crop growing season at a depth of 0 – 150 mm from hay-, grazing- and unutilised subplots in mainly leguminous- and mainly cereal cover crop mixtures (see Section 5.1.1 and 5.1.2). Different letters indicate significant differences ($p < 0.05$). CV = Coefficient of variation

	Cereal mixture			Leguminous mixture			Standard error	CV
	Hay	Grazing	Unutilised	Hay	Grazing	Unutilised		
Soil pH	6.62	6.58	6.63	6.58	6.52	6.49	0.07	3.72
Soluble Salts (mmho cm^{-1})	0.27	0.27	0.25	0.26	0.28	0.24	0.02	25.35
Soil organic matter (%)	2.43	2.48	2.47	2.36	2.33	2.28	0.11	15.06
CO_2-C (ppm)	51.87	53.57	57.77	56.48	50.53	55.75	3.69	23.19
Total N (ppm)	18.63^{bc}	18.95^{abc}	16.38^{c}	21.05^{ab}	22.91^{a}	18.9b^{c}	1.48	27.46
Organic N (ppm)	11.74	11.63	11.29	13.03	13.28	12.92	0.90	25.33
Total Organic C (ppm)	185	190	190	189	188	190	5.95	10.57
NO_3^- (ppm)	4.92^{bc}	3.95^{bc}	2.62^{c}	6.13^{ab}	7.63^{a}	3.9^{bc}	0.85	67.81
NH_4^- (ppm)	2.43^{b}	4.73^{a}	2.60^{b}	2.79^{b}	3.43^{ab}	3.13^{b}	0.54	62.04
Inorganic N (ppm)	7.33^{bc}	8.69^{ab}	5.22^{c}	8.95^{ab}	11.09^{a}	7.04^{bc}	1.03	48.33
Inorganic P (ppm)	23.49	22.04	20.68	27.47	27.63	26.15	3.56	49.66
Total P (ppm)	30^{ab}	28.5^{ab}	27^{b}	34.58^{ab}	35.08^{a}	33^{ab}	4.05	44.25
Organic P (ppm)	6.46^{bc}	6.48^{bc}	6.21^{c}	7.11^{ab}	7.34^{a}	6.93^{abc}	0.54	27.27
K (ppm)	94.67	110	101	107	114	101	9.58	31.16
Ca (ppm)	107	107	109	123	122	114	8.63	26.00
Al (ppm)	261^{ab}	302^{ab}	240^{b}	354^{ab}	376^{a}	343^{ab}	50.26	56.01
Fe (ppm)	160	166	152	193	203	191	21.25	41.45
C:N ratio	16.19^{ab}	16.81^{ab}	17.27^{a}	14.91^{b}	15.08^{ab}	15.64^{ab}	0.82	18.02
N mineralisation (ppm)	3.58^{ab}	2.78^{b}	2.55^{b}	5.27^{a}	4.28^{ab}	4.32^{ab}	0.84	78.26
Organic N Release (ppm)	7.18^{ab}	6.22^{b}	6.19^{b}	9.64^{a}	8.33^{ab}	8.71^{ab}	1.29	58.48
Organic N Reserve (ppm)	4.56^{ab}	5.42^{a}	5.08^{a}	3.40^{b}	4.93^{a}	4.21^{ab}	0.59	45.05
P mineralisation (ppm)	2.12^{ab}	1.39^{b}	1.23^{b}	3.50^{a}	2.78^{ab}	2.66^{ab}	0.68	106
Organic P reserve (ppm)	4.36^{ab}	5.09^{a}	5.00^{ab}	3.61^{b}	4.56^{ab}	4.25^{ab}	0.73	55.44
Soil Health Index	6.34	6.31	6.44	7.14	6.69	6.93	0.44	22.82
Volumetric aggregate stability (%)	19.83^{ab}	16.75^{b}	21.83^{a}	21.42^{ab}	21.83^{ab}	22.67^{ab}	2.68	44.25
Solvita Labile Amino-N total releasable N (ppm)	132^{ab}	139^{ab}	149^{a}	127^{ab}	123^{b}	126^{ab}	7.9	20.96

Table 12: Chemical soil analysis of soil collected at the end of the cover crop growing season at a depth of 0 – 150 mm from the hay-, grazing- and unutilised subplots in the mainly leguminous- and mainly cereal cover crop mixtures. Different letters indicate significant differences ($p < 0.05$). Coefficient of variation (CV).

	Cereal mixture			**Leguminous mixture**			**Standard error**	**CV**
	Hay	**Grazing**	**Unutilised**	**Hay**	**Grazing**	**Unutilised**		
Soil moisture (%)	1.73	1.46	1.47	1.95	1.96	1.66	0.27	54.39
pH (KCl)	5.61	5.56	5.59	5.61	5.48	5.48	0.08	4.68
Resistance (ohm)	1577	1543	1643	1482	1842	1580	184	38.79
Ca (mg kg^{-1})	744^{ab}	742^{ab}	744^{ab}	816^{a}	751^{ab}	728^{b}	45.94	20.70
Mg (mg kg^{-1})	84.99	89.77	89.26	108	94.65	102	9.84	35.67
Na (mg kg^{-1})	21.75	21.08	19.58	20.17	22.42	19.17	1.91	31.40
K (mg kg^{-1})	117	128	123	120	119	117	9.94	27.70
Cation exchange capacity (cmol kg^{-1})	4.96	5.04	5.08	5.49	5.19	5.25	0.29	19.15
P (mg kg^{-1})	67.58	60.67	60.92	72.17	68.17	69.5	6.93	35.40
Cu (mg kg^{-1})	1.09	1.21	1.14	1.39	1.44	1.44	0.15	40.84
Zn (mg kg^{-1})	1.46^{b}	1.53^{ab}	2.08^{a}	1.85^{ab}	1.60^{ab}	1.70^{ab}	0.23	46.10
Mn (mg kg^{-1})	48.65^{b}	55.98^{ab}	52.83^{b}	79.11^{ab}	86.38^{ab}	93.42^{a}	13.8	71.12
S (mg kg^{-1})	6.35	7.98	5.98	8.48	6.65	6	1.18	58.93
Organic C (%)	1.31	1.25	1.28	1.25	1.13	1.14	0.07	19.70

Table 13: Chemical soil analysis of soil collected at the end of the cover crop growing season at a depth of 150 – 300 mm from the hay-, grazing- and unutilised subplots in the mainly leguminous- and mainly cereal cover crop mixtures. Different letters indicate significant differences ($p < 0.05$). Coefficient of variation (CV)

	Cereal mixture			**Leguminous mixture**			**Standard error**	**CV**
	Hay	**Grazing**	**Unutilised**	**Hay**	**Grazing**	**Unutilised**		
Soil moisture (%)	2.83	3.22	2.78	2.95	2.98	2.73	0.25	55.50
pH (KCl)	5.17	5.1	5.11	5.38	5.24	5.19	0.13	8.59
Resistance (ohm)	1948^{ab}	1985^{ab}	2085^{ab}	1809^{ab}	1783^{b}	2114^{a}	150	26.46
Ca (mg kg^{-1})	459	466	461	684	686	514	108	68.75
Mg (mg kg^{-1})	67.41	71.07	63.44	86.32	92.62	77.47	15.47	69.00
Na (mg kg^{-1})	27.17	26.58	24.08	22.58	25.25	21.33	4.84	66.52
K (mg kg^{-1})	97.17	103	99.83	93.83	98.33	89.25	7.86	27.48
Cation exchange capacity (cmol kg^{-1})	3.77	3.91	3.76	5.02	5.13	4.08	0.63	50.76
P (mg kg^{-1})	46.67	39.08	41.83	48	49.25	45.83	6.36	47.78
Cu (mg kg^{-1})	0.96	1.15	0.96	1.23	1.34	1.25	0.17	51.52
Zn (mg kg^{-1})	0.83	0.83	1.07	1.10	1.00	0.94	0.11	40.87
Mn (mg kg^{-1})	37.39^{c}	46.61^{abc}	39.02^{bc}	65.95^{abc}	74.77^{ab}	76.73^{a}	12.96	81.60
S (mg kg^{-1})	6.66	7.17	6.44	7.33	6.98	5.98	0.57	28.83
Organic C (%)	0.72	0.78	0.76	0.74	0.78	0.73	0.03	13.71

3.3.5 Discussion

The following factors can influence the nutritional value of cover crops. According to McDonald *et al.* (2011) growth stage of a pasture is the main factor influencing the nutritional value of pastures. The same results were obtained from this study where the growth stage of cover crops influenced the nutritional parameters more than the composition did. The mixtures did not influence the nutritional value to the same extent as the growth stage of the cover crops, but the mainly leguminous mixture contained more ($p < 0.05$) CP and less ($P < 0.05$) CF. This was expected since legumes contain more protein and less fibre compared to cereals (McDonald *et al*., 2011). Cover crop mixtures can enable producers to change the nutritional value of fodder through the timing of utilisation and the composition of the mixture. In addition to this Elgersma and Søegaard (2016) showed that mixtures will outperform either pure legume or cereal swards in terms of plant growth- and nutritional value.

The quantity of mulch was reduced ($p < 0.05$) by the utilisation by hay production and grazing of cover crops in comparison with the unutilised subplots. According to Fisher *et al.* (2012), who did a study in similar climatic conditions, 1000 kg ha^{-1} of cereal- or 750 kg ha^{-1} of legume material is required to prevent wind and water erosion. In this study, after the utilisation of cover crops by grazing and hay production, there were more material left on the field than the minimum values given by Fisher *et al.* (2012). Despite the reduction of material as a result of utilisation, grazing had a smaller ($p < 0.05$) negative effect on the mulch quantity in comparison with hay production. The varying quantities of mulch between the different subplots may influence evaporation of soil moisture. The amount of evaporation is decreased as soil cover is increased (Ranaivoson *et al*., 2017).

Although the quantity of the mulch was reduced, the concentration of minerals in the mulch was increased ($p < 0.05$) by utilisation. Mineral content of the soil cover may have been influenced by the regrowth after utilisation. The mainly leguminous mixture subplots which was grazed, is the only subplots where the concentration of minerals in the mulch increased ($p < 0.05$) to the extent that this subplots contained similar ($p > 0.05$) amounts of minerals in the mulch compared to the unutilised subplots. Ngatia *et al.* (2015) obtained similar results, but in their study foliar P was the only mineral which increased after grazing. Gardner and Faulkner (1991) described hay production as a harvest and the removal of nutrients, but grazing as a form of nutrient cycling.

Utilisation of cover crops in the form of grazing and hay production did not have a negative effect on soil properties and the same trend was observed by Blanco-Canqui *et al.* (2015). In the no-tillage systems of Southern Brazil, grazing cover crops improved soil quality if the cover crops were not overgrazed (de Faccio Carvalho *et al.*, 2010). In the Swartland, grazing of cover crops improved ($p < 0.05$) soil N parameters compared to unutilised cover crops. In a system with limited N, an increase in soil N can lead to a reduction in input cost or an increase in yield. According to Mbuthia *et al*.(2015) cover crop derived N has a smaller effect on soil pH compared to N fertilisers. This can lead to a decrease in lime application of low pH soils.

3.3.6 Conclusion

Cover crops are cultivated globally under different climatic conditions and in various soil types, but cover crops are site specific and a specific cover crop must be selected for each system. If cover crops differ between different systems, the management and utilisation of the cover crop must be adapted accordingly to fit each cover crop in a specific system.

If cover crops are planted in order to improve the quantity of soil cover in a system, it will be ideal to leave the cover crop unutilised. This is due to the fact that the utilisation of cover crops reduced ($p < 0.05$) the quantity of soil cover irrespective of the mixture and -utilisation. Grazing subplots had a higher ($p < 0.05$) quantity of soil cover compared to the hay subplots. This indicates, if a producer wants to retain the maximum amount of soil cover, but is dependent on the utilisation of cover crops, grazing will be a better form of utilisation compared to hay production.

When the focus of cover crop production is on the minerals obtained from cover crop biomass the utilisation of the mainly leguminous mixture in the form of grazing will be the ideal cover crop and utilisation thereof for the Swartland. Grazing can improve the productivity of the system with no negative ($p > 0.05$) effect on the quantity of minerals left in the soil cover. This highlights the potential to integrate livestock into the cropping systems of the Swartland. Livestock can furthermore improve diversity and give producers an alternative way to manage herbicide resistant weeds.

Grazing of the mainly leguminous mixture improved the amount of nitrogen in the system, indicating that this practice can reduce fertiliser costs in the Swartland. In addition to this, producers can increase the productivity of their system due to the additional livestock which can utilise the cover crops. In this trial high stocking rates were used and producers should follow the same grazing management practices if they desire to obtain the same effect.

CHAPTER 4: The Effect of Cover Crop Mixture and Utilisation on the Subsequent Wheat Crop

4.1 Introduction

In Mediterranean climate areas, like the Swartland of South Africa, hot- and dry summers restrict dryland crop production to the winter rainy season. These climatic conditions limit the diversity of crops used in crop rotation systems. Cover crops have the potential to improve crop diversity. Producers in Mediterranean climatic conditions with crop- and crop-pasture systems have to replace pastures or cash crops with cover crops in an attempt to improve crop diversity (Allan *et al.*, 2016). The main crop in crop rotation systems in the Swartland is wheat (*Triticum aestivum)* (Swanepoel *et al.*, 2016). Currently most producers have adopted at least some conservation agriculture principles, and aim to adopt more management principles to support sustainable production. Varying rainfall restricts diversity and herbicide resistant weeds in the system can limit wheat production. Cover crops can potentially or partially overcome some of the challenges in the Swartland. Utilisation of cover crops can improve the profitability of cover crop production and therefore the adoption rate by farmers in this region (Gardner and Faulkner, 1991). Due to limited research, it is not clear how cover crops and the utilisation thereof will influence conservation agriculture systems in a Mediterranean climate (Blanco-Canqui *et al.*, 2015).

Conservation agriculture can improve profits through reduced input costs (Kassam *et al*., 2012; Pittelkow *et al*., 2014), but cover crop production may increase the input costs. The benefits obtained from cover crop production however may increase profits. It is not clear how the implementation- and utilisation of cover crops will influence nutrient content and soil moisture, which in turn have an influence on wheat produced in the year following the cover crop. When cover crops improve yields and reduce fertiliser costs (i.e. N fixation by legumes) it may increase the profitability and sustainability of the system. Blanco-Canqui *et al.* (2015) found that cover crop utilisation did not affect subsequent cash crop production, but it is not clear to what extend the implementation- and utilisation of cover crops will affect wheat production in the Swartland. The aim is to determine the effect of cover crops and cover crop utilisation on wheat production and quality.

4.2 Material and methods

4.2.1 Trial site and layout for 2017

The trial was conducted at the same site described in *Chapter 3, Section 3.2.1*.

Wheat was subjected to six treatments and a control. Treatments were based on the crop that was planted on the specific plot during the previous year (2016) and how these crops were managed in terms of its utilisation. The six treatments consisted of wheat planted in 2017 on plots previously planted to:

1) mainly leguminous mixture utilised as hay (LH);
2) mainly leguminous mixture utilised as grazing (LG);
3) mainly leguminous mixture unutilised and rolled (LU);
4) mainly cereal cover crop mixture utilised as hay (CH);
5) mainly cereal mixture utilised as grazing (CG);
6) mainly cereal mixture unutilised and rolled (CU).
7) The control was wheat planted (2017) on plots which were under wheat cultivation for the previous two years (2015 and 2016).

All treatments and the control were replicated four times which resulted in a total of 28 experimental units (plots) each with a size of 150 m^2 (10 x 15 m).

4.2.2 Rainfall

Western Cape Department of Agriculture has a weather station on Langgewens Research Farm, where the trials have been conducted. The long-term rainfall data measured on Langgewens from 1964 up to the end of 2017 were obtained from the Western Cape Department of Agriculture.

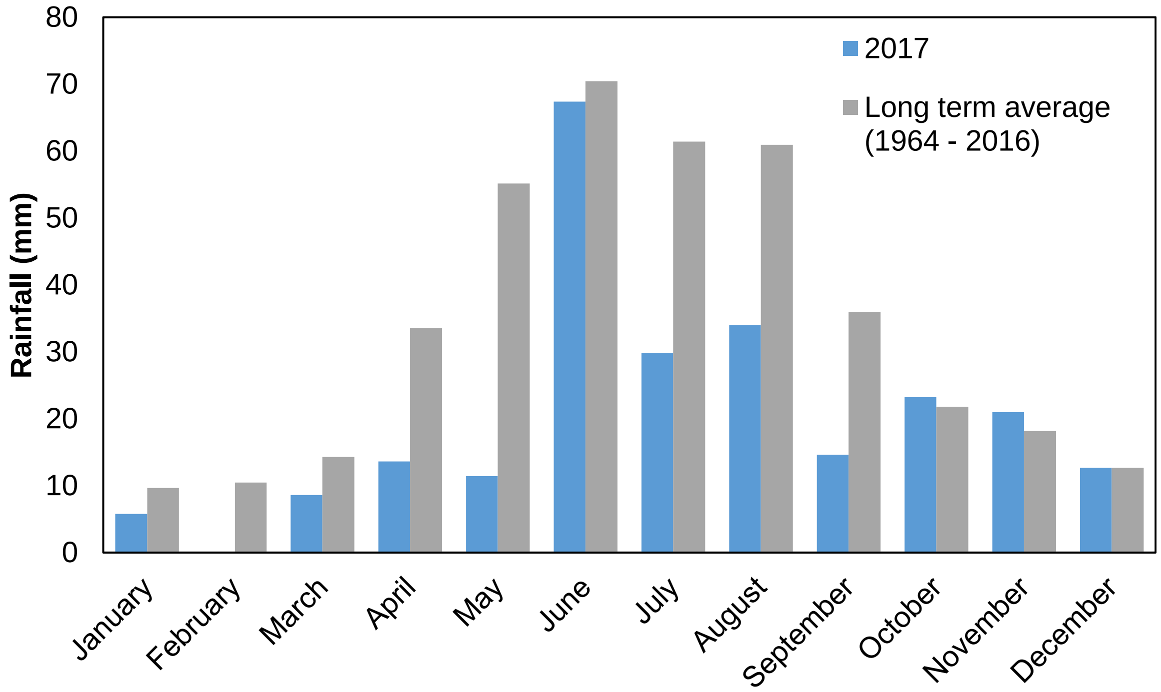

Figure 13: Long term (1964 – 2016) monthly rainfall and 2017 monthly rainfall for Langgewens Research Farm.

4.2.3 Wheat establishment and management

Wheat (cultivar SST 056) was planted with a Piket double disc seed-drill (described in Section 3.2.3.1) at a seeding rate of 75 kg ha^{-1} on 9 May 2017. A liquid fertiliser was applied at planting, consisting of 10.44 kg ha^{-1} N, 6.96 kg ha^{-1} P, 3.48 kg ha^{-1} K and 1.62 kg ha^{-1} S. A foliar application of 150 g ha^{-1} B (1 L Bortrac) was applied when wheat reached flag leaf stage. A single fertiliser topdressing was applied at the four-leaf stage of wheat development and consisted of 40.56 kg ha^{-1} N, 5.04 kg ha^{-1} P and 6.36 kg ha^{-1} S. Disease and weed control was done by spraying the wheat plots with the products summarised in Table 14. All products were sprayed with 200 L water ha^{-1}. A Crop Tiger 30 combine harvester manufactured by Claas was used to harvest the wheat (Figure 14).

Table 14: Weed and disease control applications on wheat plots during 2017

Date Applied	Purpose of application	Product		Active ingredient	
		Name	Application*	Name	(g ha^{-1})
03-05-2017	Pre-emergent herbicide	Sakura	125 g	Pyroxasulfone	106.25
03-07-2017	Selective herbicide	Resolve	0.75 L	Pyrasulfotole	28.13
				Bromoxynil	157.5
				Mefenpyr-diethyl	7.04
03-07-2017	Selective herbicide	Aurora 40 WG	20 g	Carfentrazone-ethyl	8.0
03-07-2017	Fungicide	Abacus	1 L	Pyraclostrobin	62.5
				Epoxiconazole	62.5
21-08-2017	Fungicide	Prosper Trio	0.5 L	Spiroxamine	125.0
				Tebuconazole	83.5
				Triadimenol	21.5

*Application rate of product per hectare

4.2.4 Soil samples

Prior to planting, five soil cores were collected from each plot at 0-150 mm and 150-300 mm and mixed to form two composite samples, one for each depth. The mass of the samples were determined and dried according to methods described in Section 3.2.7 to determine the soil moisture content. After the samples were dried the samples were sent to Elsenburg for standard chemical analyses as described in Section 3.2.7.

Figure 14: Claas Crop Tiger 30 harvesting wheat

4.2.5 Wheat samples and measurements

In order to determine treatment effects on wheat germination, plants were counted 44 days after wheat germinated in a 0.25 m^2 quadrant placed perpendicular to the wheat rows.

Wheat grain yields were recorded at harvest and a representative grain sample was taken from each plot. Some of the wheat plots were contaminated with barley due to ineffective termination of cover crops the previous year. The proportion barley in each grain sample, taken at harvest, was determined by physically separating the barley seeds from the wheat seeds. The grain yield of each wheat plot was adjusted with the proportion barley in each specific wheat plot. Wheat grain samples were analysed for hectolitre mass, protein content, screenings, thousand seed mass and the grading which was determined according to South African standards.

4.2.6 Biomass samples

Prior to planting of wheat, the first set of biomass samples were collected from each plot by gathering the above-ground biomass from three 0.25 m^2 quadrants per plot. A second set of biomass samples were taken prior to harvesting the wheat. For the second set of biomass samples, each sample was fractionated into three groups: 1) mulch (all the material left from the previous year and material added in the current production year); 2) volunteer cover crops and weeds (also barley); 3) wheat. Biomass samples were dried, in mass determined and milled, according to methods described in Section 3.2.6, and sent to Elsenburg for a mineral composition analysis.

The quantity of soil cover that decomposed and minerals released from the soil cover, during the wheat growing season, were calculated by using the following formula: (quantity of soil cover and each mineral measured at the start of the wheat growing season) – (quantity of soil cover and each mineral measured at the end of the wheat growing season).

4.2.7 Statistical analyses

An Analysis of Variance (ANOVA), based on a least squares linear regression (restricted maximum likelihood; REML) was used to analyse the effects of the previous season's treatments on wheat productivity and quality. Block was included as a random factor, while the treatments, date and the interaction between treatments and date were included as fixed effects. In cases where measurements were not taken over time, a one-way ANOVA was performed. The Bonferonni *post-hoc* test was used to separate treatment means at a 5% level of significance, and only if significant, the Fisher's least significant difference (LSD) test was used to conduct pairwise comparisons between different treatments. Where residuals did not follow a normal distribution the Games-Howel *post-hoc* test was used as a non-parametric test to confirm the results of the Bonferroni test. The Variance Estimation, Precision and Comparison (VEPAC) package of Statistica Version 13 TIBCO Software, 2017) was used to conduct statistical analyses.

4.3 Results and discussion

4.3.1 Soil properties prior to wheat establishment

Results from the standard chemical soil analysis on soil collected prior to the planting of wheat are presented in Table 15 (0 – 150 mm) andTable 16 (150 – 300 mm). Nearly all of the soil parameters of each treatment, at both depths, were similar ($p < 0.05$) to that of the control. The only differences ($p < 0.05$) were observed in the 0 – 150 mm depth. The CU treatment had a higher ($p < 0.05$) cation exchange capacity compared to the LH treatment. Zinc concentration in the soil of the LH treatment was higher ($p < 0.05$) compared to the CH treatment. The treatment effects observed in the wheat year (2017) did not correspond to treatment effects in the preceding year (2016) when cover crop mixtures were planted and utilised. Zinc was the only soil parameter which differed ($p < 0.05$) between treatments in both years (2016 and 2017). In the cover crop year (2016) the different treatments had a similar ($p > 0.05$) cation exchange capacity but different ($p < 0.05$) concentrations Mn and Ca and resistance.

Table 15: Chemical soil analysis of soil collected, prior to the planting of wheat, at a depth of 0 – 150 mm. The treatments consisted of wheat planted on plots previously planted to: 1) mainly leguminous mixture utilised as hay (LH); 2) mainly leguminous mixture utilised as grazing (LG); 3) mainly leguminous mixture unutilised and rolled (LU); 4) mainly cereal cover crop mixture utilised as hay (CH); 5) mainly cereal mixture utilised as grazing (CG); 6) mainly cereal mixture unutilised and rolled (CU) and wheat which acted as the control. Different letters indicate significant differences ($p < 0.05$). CV = Coefficient of variation

	LH	LG	LU	CH	CG	CU	Control	Standard error	CV
Soil moisture (%)	2.35	2.58	2.30	2.20	2.19	2.05	2.19	0.35	28.12
pH (KCl)	5.55	5.43	5.73	5.78	5.65	5.70	5.68	0.14	4.69
Resistance (ohm)	583	530	543	575	665	588	603	85.20	26.72
Ca (mg kg^{-1})	896	815	1011	1056	1018	1079	1071	80.61	17.19
Mg (mg kg^{-1})	143	109	182	177	160	178	161	27.74	35.48
Na (mg kg^{-1})	26.75	25.25	26.25	28.50	28.00	31.00	24.75	5.02	33.40
K (mg kg^{-1})	144	181	153	136	150	145	164	20.15	24.91
Cation exchange capacity (cmol kg^{-1})	6.31^{b}	5.88^{ab}	7.06^{ab}	7.21^{ab}	6.92^{ab}	7.37^{a}	7.54^{ab}	0.54	16.08
P (mg kg^{-1})	75.75	77.75	74.75	81.25	76.00	81.00	67.75	17.03	39.75
Cu (mg kg^{-1})	1.14	1.48	1.35	1.16	1.24	1.05	1.37	0.19	28.75
Zn (mg kg^{-1})	3.27^{a}	1.93^{ab}	2.07^{ab}	1.86^{b}	1.91^{ab}	1.89^{ab}	1.96^{ab}	0.47	45.15
Mn (mg kg^{-1})	41.26	83.12	65.90	45.86	54.72	36.16	68.46	19.57	67.25
B (mg kg^{-1})	0.42	0.46	0.45	0.50	0.50	0.45	0.51	0.06	22.38
S (mg kg^{-1})	10.83	10.13	9.88	14.05	9.55	11.93	12.38	2.45	40.80
Organic C (%)	1.39	1.29	1.49	1.39	1.41	1.42	1.35	0.11	14.23

Table 16: Chemical soil analysis of soil collected, prior to the planting of wheat, at a depth of 150 – 300 mm. The treatments consisted of wheat planted on plots previously planted to: 1) mainly leguminous mixture utilised as hay (LH); 2) mainly leguminous mixture utilised as grazing (LG); 3) mainly leguminous mixture unutilised and rolled (LU); 4) mainly cereal cover crop mixture utilised as hay (CH); 5) mainly cereal mixture utilised as grazing (CG); 6) mainly cereal mixture unutilised and rolled (CU) and wheat which acted as the control. Different letters indicate significant differences ($p < 0.05$). CV = Coefficient of variation

	LH	LG	LU	CH	CG	CU	Control	Standard error	CV
Soil moisture (%)	2.77	3.17	2.63	2.39	2.78	2.64	2.48	0.65	43.23
pH (KCl)	5.08	5.10	5.25	5.23	5.10	5.25	5.20	0.17	6.02
Resistance (ohm)	1053	1075	1103	983	1100	988	1203	93	16.69
Ca (mg kg^{-1})	543	572	600	590	578	665	586	66	20.69
Mg (mg kg^{-1})	89.37	84.79	105.84	88.15	98.21	107.06	87.84	17.39	33.75
Na (mg kg^{-1})	20.25	21.75	19.25	21.75	22.75	27.50	18.00	5.83	49.45
K (mg kg^{-1})	106	115	103	102	102	98.00	122	15.35	26.45
Cation exchange capacity (cmol kg^{-1})	4.41	4.45	4.69	4.54	4.57	5.02	4.42	0.38	15.12
P (mg kg^{-1})	59.00	55.50	54.00	62.25	51.50	58.00	45.25	13.97	45.76
Cu (mg kg^{-1})	0.87	1.32	1.10	0.98	1.09	0.90	1.24	0.22	39.58
Zn (mg kg^{-1})	1.53	1.08	1.15	1.06	0.98	1.10	1.14	0.21	35.78
Mn (mg kg^{-1})	31.03	76.19	61.29	39.09	44.21	27.37	66.84	21.41	84.41
B (mg kg^{-1})	0.33	0.37	0.31	0.37	0.41	0.38	0.37	0.07	33.45
S (mg kg^{-1})	8.13	7.48	7.55	9.18	7.35	10.88	8.48	1.34	31.39
Organic C (%)	0.90	0.88	0.83	1.00	0.94	0.97	0.90	0.07	15.18

4.3.2 Soil cover and the decomposition thereof

The mineral content of soil cover and total aboveground biomass that was present before the wheat growing season started, within each treatment and the control, are presented in Table 17. Compared to the control, the LH treatment had a lower ($p < 0.05$) quantity of soil cover, but LH soil cover contained similar ($p > 0.05$) quantities of all minerals measured. The LG plot also had a lower ($p < 0.05$) amount of soil cover, and similar ($p > 0.05$) quantities of all minerals in the soil cover compared to the control plot, except for Na of which the LG plot had a higher ($p < 0.05$) content. The two treatments, where the mainly leguminous mixture (LH, LG and LU) was utilised as hay or grazing in the previous year, the amount of soil cover was lower ($p < 0.05$) than in the control. The quantity of minerals left in the soil cover did not however differ from the control. The control plot and the LU plots contained similar ($p > 0.05$) quantities of minerals and soil cover.

When the control plots were compared to the plots planted to a mainly cereal mixture (CH, CG and CU) the previous year, similar trends to those found with the mainly legume mixture were observed in terms of mineral content- and total above-ground biomass. The only exception was the CU treatment which had a similar ($p > 0.05$) amount of soil cover, but the soil cover contained more ($p < 0.05$) N, P, K, Mg, Zn and Na compared to that of the control plot. Compared to the control, CH and CG treatments had both a lower ($p < 0.05$) amount of soil cover, but similar ($p > 0.05$) quantities of minerals in the soil cover. Irrespective of the cover crop mixture planted the previous year, utilisation of these mixtures in the form of grazing and hay production reduced ($p < 0.05$) the quantity of soil cover, but not the mineral content of the soil cover compared to the control.

The mineral content- and total above-ground biomass presented in Table 18 relates to the portion of biomass, left from the previous year (2016) at the end of the wheat growing season (2017). At this stage there were no differences ($p > 0.05$) between any of the treatments and the control in terms of the amount of soil cover and the mineral content of the soil cover, except for Al and Cu. The CH treatment contained less ($p < 0.05$) Al and Cu compared to the control plot. The small amount of difference ($p < 0.05$) may be due to the fact that the majority of the material was decomposed and the minerals released from the soil cover into the soil.

The quantity of soil cover which decomposed and the quantity of minerals released from the soil cover during the wheat growing season are presented in Table 19. These values are only presented if there were a significant reduction ($p < 0.05$) during the wheat growing season.

Table 17: Mineral content- and total above-ground biomass before the wheat growing season. The treatments consisted of wheat planted on plots previously planted to: 1) mainly leguminous mixture utilised as hay (LH); 2) mainly leguminous mixture utilised as grazing (LG); 3) mainly leguminous mixture unutilised and rolled (LU); 4) mainly cereal cover crop mixture utilised as hay (CH); 5) mainly cereal mixture utilised as grazing (CG); 6) mainly cereal mixture unutilised and rolled (CU) and wheat which acted as the control. Different letters indicate significant differences ($p < 0.05$). CV = Coefficient of variation

	LH	LG	LU	CH	CG	CU	Control	Standard error	CV
Soil cover (kg ha^{-1})	2072^{c}	2306^{c}	3217^{ab}	2188^{c}	2333^{bc}	3759^{a}	3265^{a}	347	78.22
N (kg ha^{-1})	29.28^{c}	36.53^{bc}	48.47^{ab}	32.28^{c}	37.09^{bc}	54.77^{a}	36.44^{bc}	5.83	83.72
P (kg ha^{-1})	3.15^{c}	4.19^{bc}	6.08^{ab}	4.07^{bc}	4.39^{bc}	7.56^{a}	3.81^{c}	0.78	95.88
K (kg ha^{-1})	5.37^{c}	8.88^{c}	18.41^{ab}	12.40^{bc}	10.10^{bc}	23.67^{a}	12.79^{bc}	3.05	124
Ca (kg ha^{-1})	11.61^{b}	14.35^{ab}	17.36^{a}	10.07^{b}	11.44^{b}	13.90^{ab}	10.56^{b}	1.87	78.13
Mg (kg ha^{-1})	2.25^{c}	3.48^{abc}	4.24^{ab}	2.69^{c}	3.14^{bc}	4.56^{a}	2.86^{c}	0.50	85.87
Al (kg ha^{-1})	3.35^{a}	3.72^{a}	4.00^{a}	2.88^{a}	4.16^{a}	3.50^{a}	3.88^{a}	0.70	47.12
S (kg ha^{-1})	1.90^{c}	2.52^{bc}	3.51^{ab}	2.29^{c}	2.57^{bc}	3.95^{a}	2.80^{abc}	0.45	91.96
Cu (g ha^{-1})	6.84	7.28	8.48	6.15	8.55	9.31	7.06	1.36	64.34
Zn (g ha^{-1})	36.04^{c}	47.72^{bc}	58.97^{ab}	38.68^{c}	50.75^{abc}	64.15^{a}	41.56^{c}	5.44	80.64
Mn (g ha^{-1})	111^{b}	148^{ab}	194^{a}	106^{b}	162^{ab}	161^{ab}	177^{ab}	29.03	70.94
B (g ha^{-1})	16.63^{b}	23.12^{ab}	25.68^{a}	16.18^{b}	21.75^{ab}	22.44^{ab}	17.25^{b}	3.08	69.96
Na (g ha^{-1})	609^{d}	1506^{abc}	1936^{a}	1098^{abc}	931^{bcd}	1685^{ab}	740^{cd}	304	123

Table 18: Mineral content- and total above-ground biomass (from the previous year) collected at the end of the wheat growing season. The treatments consisted of wheat planted on plots previously planted to: 1) mainly leguminous mixture utilised as hay (LH); 2) mainly leguminous mixture utilised as grazing (LG); 3) mainly leguminous mixture unutilised and rolled (LU); 4) mainly cereal cover crop mixture utilised as hay (CH); 5) mainly cereal mixture utilised as grazing (CG); 6) mainly cereal mixture unutilised and rolled (CU) and wheat which acted as the control. Different letters indicate significant differences ($p < 0.05$). CV = Coefficient of variation

	LH	LG	LU	CH	CG	CU	Control	Standard error	CV
Soil cover (kg ha^{-1})	531	511	539	244	441	787	1011	347	78.22
N (kg ha^{-1})	8.07	7.35	7.57	2.89	6.18	10.35	9.94	5.83	83.72
P (kg ha^{-1})	0.78	0.72	0.71	0.28	0.53	1.04	0.88	0.78	95.88
K (kg ha^{-1})	1.26	1.14	1.22	0.48	0.85	1.82	1.71	3.05	124
Ca (kg ha^{-1})	3.07	2.76	2.62	1.25	2.21	3.73	3.69	1.87	78.13
Mg (kg ha^{-1})	0.64	0.62	0.61	0.23	0.44	0.85	0.87	0.50	85.87
Al (kg ha^{-1})	2.62^{ab}	2.45^{ab}	2.65^{ab}	1.03^{b}	2.08^{ab}	2.88^{ab}	3.33^{a}	0.70	47.12
S (kg ha^{-1})	0.43	0.41	0.39	0.17	0.33	0.59	0.60	0.45	91.96
Cu (g ha^{-1})	2.65	2.87	2.85	1.27	2.21	3.34	3.70	1.36	64.34
Zn (g ha^{-1})	9.85	8.91	9.06	3.34	5.84	11.75	12.29	5.44	80.64
Mn (g ha^{-1})	46.04	63.19	50.57	20.46	39.65	54.19	76.93	29.03	70.94
B (g ha^{-1})	5.59	6.02	5.58	2.32	5.06	7.86	8.01	3.08	69.96
Na (g ha^{-1})	120.30	98.40	119.11	49.51	77.32	172.55	168.64	304	123

Table 19: The significant decrease ($p < 0.05$) in mineral content- and total above-ground biomass from before- to after the wheat growing season. The treatments consisted of wheat planted on plots previously planted to: 1) mainly leguminous mixture utilised as hay (LH); 2) mainly leguminous mixture utilised as grazing (LG); 3) mainly leguminous mixture unutilised and rolled (LU); 4) mainly cereal cover crop mixture utilised as hay (CH); 5) mainly cereal mixture utilised as grazing (CG); 6) mainly cereal mixture unutilised and rolled (CU) and wheat which acted as the control. CV = Coefficient of variation

	LH	LG	LU	CH	CG	CU	Control	Standard error	CV
Soil cover (kg ha^{-1})	1540	1795	2679	1943	1892	2971	2255	347	78.22
N (kg ha^{-1})	21.20	29.18	40.90	29.39	30.91	44.42	26.50	5.83	83.72
P (kg ha^{-1})	2.36	3.46	5.36	3.79	3.86	6.52	2.92	0.78	95.88
K (kg ha^{-1})			17.19	11.92	9.25	21.84	11.08	3.05	124
Ca (kg ha^{-1})	8.54	11.60	14.74	8.82	9.23	10.17	6.87	1.87	78.13
Mg (kg ha^{-1})	1.61	2.86	3.63	2.47	2.71	3.71	1.99	0.50	85.87
Al (kg ha^{-1})					2.08			0.70	47.12
S (kg ha^{-1})	1.47	2.11	3.12	2.13	2.23	3.36	2.19	0.45	91.96
Cu (g ha^{-1})	4.19	4.41	5.63	4.88	6.34	5.97	3.36	1.36	64.34
Zn (g ha^{-1})	26.19	38.80	49.91	35.33	44.91	52.40	29.27	5.44	80.64
Mn (g ha^{-1})	64.74	85.08	143.06	85.34	122.71	107.09	99.66	29.03	70.94
B (g ha^{-1})	11.04	17.10	20.10	13.87	16.69	14.58	9.24	3.08	69.96
Na (g ha^{-1})		1408	1817	1049	854	1513		304	123

4.3.3 Wheat establishment and production

The wheat plant population 44 days post-emergence are presented in Figure 15. The only difference ($p < 0.05$) in plant population was the LG which had a higher ($p < 0.05$) wheat plant population compared to the CU plot.

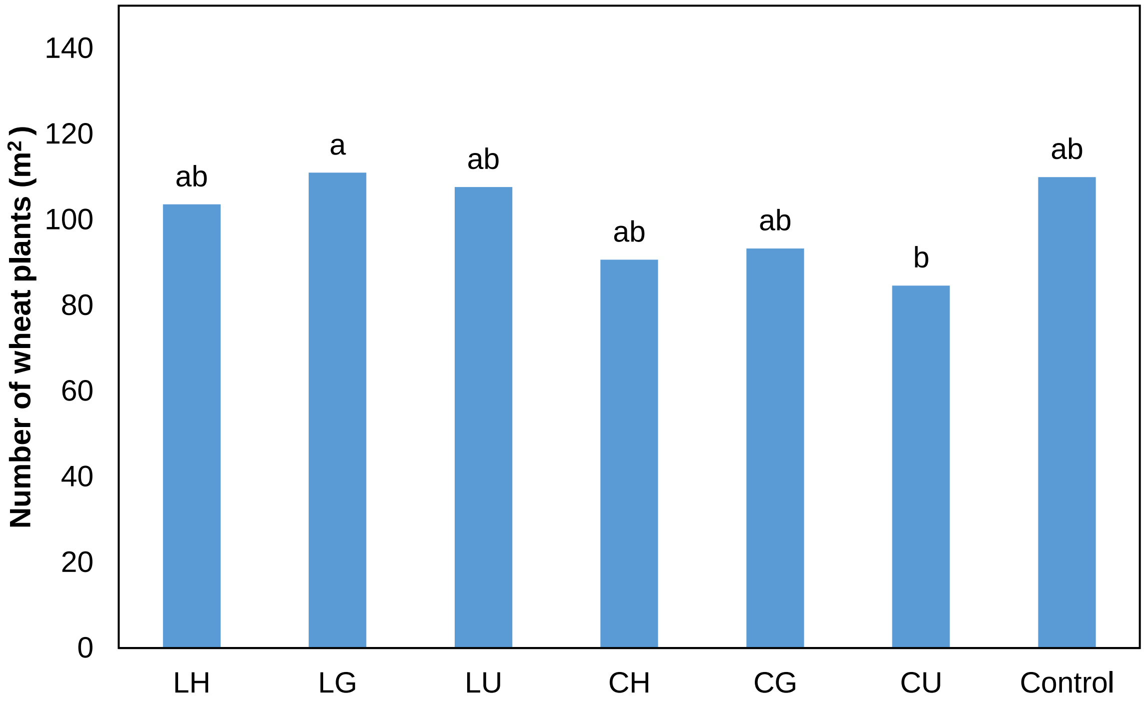

Figure 15: Wheat plant population forty-four days post emergence. The treatments consisted of wheat planted on plots previously planted to: 1) mainly leguminous mixture utilised as hay (LH); 2) mainly leguminous mixture utilised as grazing (LG); 3) mainly leguminous mixture unutilised and rolled (LU); 4) mainly cereal cover crop mixture utilised as hay (CH); 5) mainly cereal mixture utilised as grazing (CG); 6) mainly cereal mixture unutilised and rolled (CU) and wheat which acted as the control. Different letters indicate significant differences ($p < 0.05$). Standard error = 9 plants. Coefficient of variation = 18.51.

Results of all measurements and analyses done on wheat at the end of the growing season are presented in Table 20. The quantities of barley, which competed with the wheat, are also presented, as competition with barley might have influenced wheat productivity. The weed biomass was recorded, but the quantity of plots containing weeds was not significant ($p > 0.05$). Treatments had a similar ($p > 0.05$) amount of barley biomass, total grain yield, barley grain yield, wheat thousand seed mass and screenings compared to the control plot.

Compared to the control plot, the CU treatment contained a lower ($p < 0.05$) amount of wheat biomass. In the CU plot, 513 kg ha^{-1} barley biomass was recorded, which could have competed with the wheat and thus influence the subsequent yield of the specific plot. The control had the highest ($p < 0.05$) wheat hectolitre mass and the lowest ($p < 0.05$) percentage of screenings compared to all the other treatments. The only direct positive effect which cover crops had on wheat in this study, can be seen in the wheat protein concentration of wheat planted on plots following the mainly leguminous mixture (LH, LG and LU). All the wheat planted after the mainly leguminous mixture (LH, LG and LU) had a higher ($p < 0.05$) protein concentration irrespective of the utilisation.

In the 2017 growing season, the Swartland received well below average rainfall (Figure 13). The low rainfall may have influenced the wheat yield and is one of the possible reasons why the cover crops did not improve wheat yields. Despite the drought the mainly leguminous mixture (LH, LG and LU) improved ($p < 0.05$) one of the wheat quality parameters.

4.3.4 Discussion

Compared to the control cover crops did not influence ($p > 0.05$) soil parameters, but according to Mbuthia *et al.* (2015) cover crops can improve soil organic C and N storage. It has to be taken into account that soil N was not measured and Mbuthia *et al.* (2015) used bare soil as a control and not soil covered with wheat stubble. In the trial conducted by Büchi *et al.* (2018) similar results to the results of this trial were obtained and these authors also found that cover crops did not improve soil organic C.

In this study, cover crops, irrespective of mixture and utilisation, did not improve ($p > 0.05$) soil moisture retention when wheat was planted after the cover crops. Cover crops can improve the infiltration and storage of water in the soil (Dabney *et al.*, 2001; Ruis and Blanco-Canqui, 2017) and evapotranspiration can be reduced with sufficient soil cover (Lal, 2009; Ward *et al.*, 2012; Ranaivoson *et al.*, 2017). A possible explanation for this controversy are described by Ward *et al.* (2012). They found that in a Mediterranean climate, during hot and dry summers, cover crops only have an impact on soil moisture for a few days after a summer rainfall event. The fact that the control plot was a wheat plot, with no residue removed from the plot, could also have influenced these results.

According to Ward *et al.* (2012) cover crops do not increase the quantity of soil cover compared to cash crop residue. This was observed in the LU plot which had similar ($p > 0.05$) amounts of soil cover compared to the control plot. In contrast to what Ward *et al.* (2012) found, the CU plot increased ($p < 0.05$) the quantity soil cover compared to the control. These results indicate that cover crops, which are left unutilised, can improve the quantity of soil cover compared to wheat, but it is dependent on the cover crop mixture. All the plots where cover crops were utilised (LH, LG, CH and CG) the quantity of soil cover was lower ($p < 0.05$) compared to the control.

Table 20: All measurements and analyses done on wheat after the growing season and the quantity of barley (weeds originating from the previous year's cover crops) competing with the wheat. The treatments consisted of wheat planted on plots previously planted to: 1) mainly leguminous mixture utilised as hay (LH); 2) mainly leguminous mixture utilised as grazing (LG); 3) mainly leguminous mixture unutilised and rolled (LU); 4) mainly cereal cover crop mixture utilised as hay (CH); 5) mainly cereal mixture utilised as grazing (CG); 6) mainly cereal mixture unutilised and rolled (CU) and wheat which acted as the control. Different letters indicate significant differences ($p < 0.05$). Coefficient of variation (CV)

	LH	**LG**	**LU**	**CH**	**CG**	**CU**	**Control**	**Standard error**	**CV**
Wheat biomass (kg ha^{-1})	6011^{a}	5412^{ab}	5366^{ab}	4853^{ab}	5475^{ab}	4389^{b}	5766^{a}	423	17.03
Barley biomass (kg ha^{-1})	157	0.00	374	592	250	513	0.00	261	190
Total grain yield (kg ha^{-1})	2372	2264	2185	2495	2470	2260	2580	212	16.74
Wheat grain yield (kg ha^{-1})	2335^{a}	2224^{ab}	2112^{ab}	2453^{ab}	2387^{ab}	2108^{b}	2580^{a}	203	17.05
Barley grain yield (kg ha^{-1})	37.69	39.41	73.25	42.15	82.74	152	0.00	32.32	120
Wheat hectolitre mass (kg hL^{-1})	80.45^{b}	79.85^{b}	79.80^{b}	80.70^{b}	80.05^{b}	80.68^{b}	82.23^{a}	0.50	1.47
Wheat protein concentration (%)	15.85^{a}	15.85^{a}	15.95^{a}	13.98^{b}	14.33^{b}	13.38^{b}	13.80^{b}	0.40	8.56
Screenings (%)	0.80^{ab}	0.85^{ab}	0.95^{a}	0.83^{ab}	0.78^{ab}	0.75^{ab}	0.65^{b}	0.07	19.25
Wheat thousand seed mass (g)	36.18	36.58	36.23	37.03	36.40	37.75	35.65	1.01	5.18

The fibrous roots of cereals can scavenge for nutrients (Reeves, 1994; Fageria *et al.*, 2005; Clark, 2013). This was observed when the UC plot was the only plot where the soil cover contained more ($p < 0.05$) N, P, K, Mg, Zn and Na. The mainly cereal cover crop plots which was utilised (CH and CG) and all the leguminous cover crop plots (LH, LG and LU) contained similar ($p > 0.05$) amounts of minerals compared to the control plot.

Despite the fact that Blanco-Canqui *et al.* (2015) described cover crops as an multi-functional tool, the ideal function of cover cops is to improve the production of subsequent cash crops (Fageria *et al.*, 2005). In this case wheat grain yield was not influenced ($p > 0.05$) by cover crops or the utilisation of cover crops compared to the control. The dry year with limited soil water available for the wheat plants could have influenced the results, but if this is the case cover crops did not improve the amount of soil moisture available to wheat plants.

The wheat grain protein concentration was improved ($p < 0.05$) by the mainly leguminous mixture irrespective of utilisation (LH, LG and LU). This is an indication that the legume mixture could have increased the soil N as Mbuthia *et al.* (2015) indicated.

Production of cash crops following cover crops are not influenced by the utilisation of cover crops as grazing or for hay production (Blanco-Canqui *et al.*, 2015). Despite the fact that cover crops did not increase wheat yield in this study the utilisation of cover crops had no negative effect on wheat yield or wheat quality.

One of the main factors preventing farmers from converting to conservation agriculture, is the financial loss (or opportunity cost) when crop residue is left as soil cover and not utilised (Giller *et al.*, 2009; Lal, 2009). In this study the utilisation of cover crops reduced ($p < 0.05$) the amount of material left as soil cover but did not influence the wheat yield in this conservation agriculture system. This indicates that there is a possibility that cover crops can enable producers to profitably utilise cover crop material in a conservation agriculture system.

4.3.5 Conclusion

After one season, the implementation- and utilisation of cover crops, irrespective of mixture, did not have an effect ($p >0.05$) on the succeeding wheat grain yield. In this case the implementation- and utilisation of cover crops did not have any financial benefit in terms of wheat production compared to wheat following wheat. If cover crops were implemented with the sole purpose of improving succeeding cash crop yields, it would have led to a financial loss.

The 2017 cropping season received below average rainfall which may be the reason why wheat grain yield did not differ ($p > 0.05$) between treatments. If the fairly dry year resulted in no differences ($p > 0.05$) between treatments in terms of wheat grain yield it means that the treatments did not have an effect on soil moisture, despite different ($p < 0.05$) quantities of soil cover and different cover crop mixtures.

The mainly leguminous cover crop treatments (LH, LG and LU) increased ($p < 0.05$) the wheat grain protein concentration during an average rain fall season this increase in wheat grain quality may lead to an increase in the wheat grain price. Due to the fact that LH, LG and LU did not differ ($p > 0.05$) from one another in terms of wheat grain quality, an increase in price will give the LH (the treatment with the highest amount of fodder utilised) treatment the highest profit margin. This is not based on an economical evaluation and thus a detailed economic evaluation is required to compare all treatments over the two years

CHAPTER 5: Conclusion and Recommendations

5.1 Synopsis

Minimum soil disturbance, soil cover and crop diversity are the three principals of conservation agriculture, which is replacing conventional crop production systems in many cropping areas all over the world (Hobbs *et al.*, 2008; Derpsch *et al.*, 2010; Pittelkow *et al.*, 2014). Conservation agriculture is implemented to varying degrees and success. Despite differences in the effect of conservation agriculture on crop production, it is generally agreed that conservation agriculture improves profitability through reduced input costs (Kassam *et al.*, 2012; Pittelkow *et al.*, 2014).

Conservation agriculture has the potential to improve cropping systems in the Swartland region of South Africa, a region with a Mediterranean-type climate (Strauss *et al.*, 2010). Previous practices including tillage, monoculture and the misuse of herbicides, have degraded soil and have led to herbicide resistance of weeds. In this predominantly wheat production area, many producers converted to conservation agriculture, which subsequently led to sustainability of the production system and increased profitability (Crookes *et al.*, 2017).

Conservation agriculture systems in the Swartland have limited diversity and soil cover. Plant material is utilised as fodder in integrated crop- and livestock systems or sold as hay (Lal, 2009). This utilisation of soil cover prevents producers from fully implementing all the principals of conservation agriculture. Partial adoption of conservation agriculture (removal of soil cover combined with minimum-tillage) may lead to a reduction in crop yields (Fuentes *et al.*, 2009).

The incorporation of cover crops into cropping systems has the potential to improve diversity and soil cover in these systems. Cover crops are normally cultivated in the fallow season between cash crops and then left unutilised (Dabney *et al.*, 2001; Poeplau and Don, 2015; Wendling *et al.*, 2017). In Mediterranean regions, cover crop production is restricted to the cropping season because the fallow season is hot and dry and therefore not conducive to producing a crop or cover crop. Although indirect effects of cover crops on various processes are expected, no direct income are made from cover crops. In order to overcome the financial burden of cover crop establishment, maintenance and the loss of one season's crop harvest, it is suggested that cover crops can be utilised partially. Following utilisation, there should be enough material to still cover soil to be considered a cover crop, rather than a forage crop.

It is not clear how the implementation and utilisation of cover crops will influence conservation agriculture systems in a Mediterranean climate. A trial was therefore conducted in South Africa's Western Cape Province with a Mediterranean climate during 2016 and 2017 with the aim to investigate how cover crops and the utilisation of cover crops affect the productivity of a system.

In the first year (2016) two different cover crop mixtures were planted and utilised as: i) grazing, ii) hay or iii) rolled and left unutilised. The objective of the first year's trials was to evaluate the effect of cover crop utilisation on soil and the quality- and quantity of the mulch. During the growing season of (2016) the nutritional value of cover crops was monitored.

During the second year of the trial (2017), wheat was planted on the cover crop plots of the previous year (2016), i.e. a leguminous mixture utilised as hay (LH), grazing (LG) or rolled (LU) and a cereal cover crop mixture utilised as hay (CH), grazing (CG) or rolled (CU). A control was included in 2017 which was a wheat monoculture (three consecutive years of wheat). The objective of the second year was to determine the effect of cover crops and cover crop utilisation on wheat production and quality.

Objective 1: To evaluate the effect of cover crop utilisation on soil and the quality- and quantity of the mulch

The nutritional value of cover crops changed ($p < 0.05$) as the plants matured and plant material became more fibrous. Apart from the maturity of the plants, the different cover crop mixtures also influenced ($p < 0.05$) the nutritional value of the plant material.

In terms of biomass left on the field after the cover crop growing season on the unutilised subplots, the mainly cereal mixture had a higher ($p < 0.05$) quantity of biomass that covered soil compared to the mainly leguminous mixture. The utilisation of cover crops reduced ($p < 0.05$) the quantity of soil cover of both mixtures compared to the unutilised subplots. After utilisation, the two mixtures contained similar ($p > 0.05$) amounts of soil cover for the hay- and grazing subplots. In both mixtures the grazing subplots had a higher ($p > 0.05$) amount of soil cover compared to the hay subplots. Despite the reduction in soil cover all these utilised plots contained more than the minimum of soil cover described by Fisher *et al.* (2012). A minimum of 750 kg ha^{-1} leguminous material or 1000 kg ha^{-1} of cereal material is required to prevent soil erosion.

Despite the reduction ($p < 0.05$) in biomass that covered the soil due to utilisation, grazing- and hay production led to an increase ($p < 0.05$) in the concentration of minerals in the soil cover, produced by both mixtures. In the mainly leguminous mixture the amount of minerals in the soil cover, after grazing, was similar ($p > 0.05$) to the unutilised subplots. This indicates that a reduced amount of soil cover after grazing of cover crops does not necessarily mean a reduced amount of minerals in the soil cover. Grazing of the mainly leguminous mixture furthermore increased ($p < 0.05$) some of the soil N parameters, indicating that grazing enhances the N cycle. Hay production can improve the productivity of a cropping system, but led to a reduction ($p < 0.05$) in soil cover and minerals in the soil cover. Grazing, on the other hand, improved ($p < 0.05$) some of the soil N parameters. The grazed subplots of the mainly leguminous mixture contained similar ($p > 0.05$) quantities of N in the soil cover compared to the unutilised subplots, but the grazed subplots contained more ($p < 0.05$) soil N. This indicates that the total amount of N in the grazed subplots was higher compared to the unutilised subplots.

Cover crops are multi-functional, but site specific, and are influenced *inter alia* by climate, tillage, soil properties, cropping system, cover crop termination and different mixtures (Ruis and Blanco-Canqui, 2017). Due to the fact that cover crops are site specific, the utilisation of cover crops are also site specific. Depending on the system, the ideal method of utilisation will vary.

The utilisation of cover crops reduced ($p < 0.05$) the quantity of soil cover, but sufficient soil cover was retained. A reduction ($p < 0.05$) in the quantity of soil cover, however leads to a reduction in the soil organic C input (Blanco-Canqui *et al.*, 2013). In a cropping system where the main purpose of a cover crop is to improve soil organic C, cover crops should be left unutilised in order to improve the soil organic C input.

When the focus of cover crop production is on the nutrients, obtained through the decomposition of cover crop biomass, the mainly leguminous mixture utilised as grazing will be the ideal cover crop mixture and utilisation thereof for the Swartland. Grazing can increase the production of the system without decreasing ($p > 0.05$) the quantity of minerals in the soil cover. This further supports the motivation to integrate livestock in the Swartland's cropping systems to reduce reliance on herbicides and mitigate problems with herbicide resistant weeds (MacLaren *et al.*, 2018).

In the Swartland the grazing of the mainly leguminous mixture has the potential to reduce N fertiliser costs in subsequent wheat crops. The grazing obtained, can improve profits due to the additional livestock in the system. A high stocking rate was used and the sheep only grazed the cover crops for a short period. This is similar management practice as intensive rotational grazing systems, except for the fact that intensive rotational grazing systems have multiple gazing cycles, and in the current study there was only one grazing cycle (Badgery, 2017).

Objective 2: To determine the effect of cover crops and cover crop utilisation on wheat production and quality.

Compared to the control, the unutilised mainly cereal mixture (CU) treatment improved ($p < 0.05$) the quantity of soil cover and the mineral content of the soil cover. All of the treatments which included utilisation of cover crops irrespective of mixtures (LH, LG, CH and CG) reduced ($p < 0.05$) the quantity of soil cover compared to the control. The LH, LG, CH and CG treatments, however, contained similar ($p > 0.05$) content of minerals in the soil cover compared to the control. All the treatments (LH, LG, LU, CH, CG and CU) together with control were similar ($p < 0.05$) in terms of soil mineral content.

The majority of the soil cover was decomposed by the end of the 2017 rainy season and the minerals were released from the soil cover during the wheat growing season. Cover crops and utilisation of cover crops did not influence ($p > 0.05$) the following wheat grain yield. Wheat grain protein concentration however improved ($p < 0.05$) after cultivation of the mainly leguminous cover crop mixture, irrespective of utilisation (LH, LG and LU).

The utilisation of cover crops did not have a negative effect ($p > 0.05$) on wheat production or wheat grain quality, compared to the unutilised cover crop treatment for both mixtures. Cover crops and utilisation of cover crops therefore did not improve the financial income obtained from wheat following cover crops compared to wheat following wheat.

The dry season may have limited wheat production, but if this was the case, cover crops and utilisation of cover crops did not retain soil moisture. According to Ranaivoson *et al.* (2017) evaporation of soil moisture decreases as the amount of soil cover increase. However, in the current study, varying amounts ($p < 0.05$) of soil cover between treatments did not lead to differences ($p > 0.05$) in wheat grain yield during this fairly dry year.

In a production season with normal rainfall, improved wheat quality may improve the financial income. If the improved quality ($p < 0.05$) leads to a higher income, the LH treatment should have the highest profit margin of all the cover crop treatments. However, a detailed economic evaluation is necessary to evaluate the profit margins of incorporating and utilising cover crops. There was no difference between the LH, LG and LU treatments in terms of quality, but the LH treatment had the largest amount of fodder removed.

5.2 General conclusion

When cover crops were planted, one season's cash crop production was lost compared to the control treatment. Through this study, it became clear that cover crops in the Swartland have the potential to be utilised in terms of nutritional value. On the grazed and hay subplots 1000 – 1500 kg ha^{-1} and 3500 – 4500 kg ha^{-1} of fodder (on a dry matter basis), respectively, was utilised or removed from the subplots. Utilisation of cover crop can supply additional fodder, and has the potential to improve fodder flow in mixed crop-livestock systems. It must be taken into account that the utilisation of cover crop mixtures in the form of grazing and hay production decreased ($p < 0.05$) the quantity of soil cover compared to the unutilised subplots. When wheat was planted, a minimum of 2072 kg ha^{-1} of soil cover was still left on the field. This is in excess of the minimum quantity of soil cover required in a Mediterranean climate described by Fisher *et al.* (2012).

After the second objective was achieved, it was clear that the utilisation of cover crops does not have a negative effect ($p > 0.05$) on the subsequent wheat grain yield and quality. This indicates that producers can utilise cover crops without reducing future cash crop yields. It has to be taken into account that cover crops did not improve ($p < 0.05$) the following wheat grain production. The fact that this trial was conducted in a conservation agriculture system with sound management practices prior to the start of the trial, may have influenced the results. The control plot, however, was under wheat cultivation for a third consecutive year, but according to Howieson *et al.* (2000) the positive effects of legume pastures on cash crops can last for up to six years. This is why phase farming systems can consist out of 4-6 years of cash crops and 2-3 years of legume pastures (Howieson *et al.*, 2000). Cover crop production will not necessarily improve subsequent cash crop production in a conservation agriculture system with sound management practices. When the implementation of cover crops does not lead to an increase in subsequent wheat yields, the utilisation of cover crops must generate a similar profit as wheat in order to justify cover crop production.

Cover crops can be a multifunctional tool which can be used to address multiple concerns at once (Blanco-Canqui *et al.*, 2015). However, multiple concerns must exist before they can be addressed by cover crops. If a producer has concerns in a Mediterranean climatic region, which can be addressed by cover crop production, the utilisation of cover crops can improve the productivity of this system.

When cover crops enable producers to integrate livestock into a conservation agriculture system, it improves the economical sustainability of the production system (Bell *et al.*, 2014; Crookes *et al.*, 2017). The incorporation of livestock into a cropping system improves cash flow and spreads investments over different commodities. Utilisation of cover crops can replace single species pasture crops, rather than replacing cash crops with cover crops. This utilisation of cover crops must comply with the three main principals of conservation agriculture, i.e. soil should still be sufficiently covered with plant material following grazing.

5.3 Limitations of the study

During this study the mineral content of soil cover (above-ground biomass) and mineral content of the soil were measured. These measurements, however, excluded the mineral content of below-ground biomass. The below-ground biomass may contribute to the following cash crop production. The soil type and high rock content of the trial site would have complicated this measurement and therefore this measurement was not included.

Grazing and hay production were conducted at different growth stages. This gave the grazed subplots more time to regrow, which may have increased the variation between the two utilised subplots. The sheep would not have been able to graze the cover crops when hay was mowed. On the other hand, when the sheep grazed the cover crops, the moisture content of the cover crops was too high for hay production. Cattle can replace sheep as they would be able to graze the cover crops when hay was mowed (when cereals in the mixture reach the soft dough stage). In order to get a better indication of the financial benefit of cover crop grazing, the weight gained by calves during grazing, can be measured. In this study due to financial constraints only adult ewes (which are not growing) were available for use.

The percentage of soil cover was influenced by the fact that only the unutilised subplots was rolled (Ward *et al.*, 2012). This caused additional variation between treatments and as a result of the variation in percentage of soil cover, quantity of soil cover was used as an indication of soil cover. The variation can be eliminated by rolling all subplots after utilisation.

The first measurements on the control plot, used in the second year (2017), was collected prior to the establishment of wheat in 2017. The cover crop treatments were compared to the control during 2017. The breakdown of above-ground biomass could only be calculated for the wheat growing season in (2017), but not for the summer after the termination of cover crops due to the fact that there was no data for the control plot at the end of the cover crop growing season in 2016.

Soil moisture was only measured when soil samples were collected and not continuously throughout the trial. The continuous monitoring of soil moisture could have given an indication of how the implementation- and utilisation of cover crops affected soil moisture.

Soil health index was the only soil parameter which included soil biology. Cover crops have the potential to improve soil biology. However, this aspect was neglected during analyses. The inclusion of more soil biology parameters, for instance nematodes and the different functional groups of microorganisms, could have given an indication of how cover crops and utilisation of cover crops affect soil biological health.

Grazing of cover crops can increase soil compaction (Bell *et al.*, 2011), but on the other hand, cover crops can relieve compaction of the soil. The bulk density could have given an indication on how different treatments influenced soil compaction.

5.4 Recommendations for future research

This trial was conducted under specific climatic and soil conditions. Similar research is needed in other climates and soil types. This trial was only conducted over one year of cover crop production and one year of wheat production and should be continued in order to establish the sustainability and long-term effects. A specific management practice and only sheep were used in terms of grazing cover crop mixtures.

The utilisation of cover crops is not just the removal of material (Gardner and Faulkner, 1991) and do not always have a negative effect on the functional role of cover crops. It needs to be established as to which extent cover crops can be utilised without influencing the functional role of cover crops. Management guidelines need to be established for the grazing of cover crop mixtures and all livestock must be taken into account (Blanco-Canqui *et al.*, 2015). Franzluebbers and Stuedemann (2008) and Blanco-Canqui *et al.* (2015) indicated that cover crops can be utilised, but detailed information surrounding the utilisation of cover crops are limited.

Following studies should be done under different climatic and soil conditions globally. Cover crops can be utilised as fodder, but the utilisation of cover crop mixtures must be compared to pastures and crops planted for hay production (Blanco-Canqui *et al.*, 2015). This comparison should include nutritional value and amino acid profiles, soil properties and preceding cash crop production and quality. Not one study could be found where all these factors were compared, irrespective of climate. This information is required by producers in order to make informed decisions surrounding the utilisation of cover crops.

The economical implication of cover crops must take the ecological benefits obtained from cover crops into account (Blanco-Canqui *et al.*, 2015). The economical implication of cover crops and different utilisations of cover crops need to be established for different regions. The value of cover crop grazing can be measured in kg ha^{-1} meat gained. This can enable producers to determine how their specific production system can benefit financially from cover crop utilisation. Research surrounding cover crop utilisation, including this study and (Franzluebbers and Stuedemann, 2008)Franzluebbers and Stuedemann (2008), lacks an economic implication of cover crop utilisation. The economic implication of cover crop utilisation is one of the most important factors for producers when they need to make decisions surrounding the utilisation of cover crops.

Research in order to establish the minimum quantity of soil cover required to protect the soil. According Fisher *et al.* (2012) this quantity of soil cover is site specific and no research could be found for the Mediterranean climate of South Africa.

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Appendix

5.1 Definitions for Soil Health Solutions soil analysis

5.1.1 The definitions for terms used by Haney Analyses defined by Gunderson (2018).

Soil pH: "The pH of the soil using a 1:1 ratio of soil and water…"

Soluble Salts (mmho/cm): "Soluble Salts a measure of the electrical conductivity (EC) of the soil based on the amount of soluble salts at a 1:1 ratio of soil and water expressed as mmho/cm…"

Soil organic matter (%): "This is the total soil organic matter (SOM) expressed as percent loss on ignition (%LOI). SOM is made up mostly of organic carbon, but it also contains all other essential plant nutrients…"

CO_2-C (ppm): "This number is ppm CO_2-C released in 24 hours by soil microbes after a soil sample has been dried and rewetted…"

Total N (ppm): "The total water extractable N (WEN) from your soil expressed in ppm."

Organic N (ppm): "Organic N is the total water extractable N (WEN) minus inorganic N (NO_3^- and NH_4^+) in ppm…"

Total Organic C (ppm): "The total water extractable organic C (WEOC) from your soil expressed in ppm…"

NO_3^- (ppm): "The amount of NO_3-N extracted from your soil using H3A extractant expressed in ppm N…"

NH_4^+ (ppm): "The amount of NH_4-N extracted from your soil using H3A extractant expressed in ppm N."

Inorganic N (ppm): "This is a sum of the NO_3-N and NH_4-N expressed in ppm N…"

Inorganic P (ppm): "The amount of P in your soil extracted with H3A and measured as orthophosphate (PO_4-P) expressed in ppm P…"

Total P (ppm): "Total P is the amount of elemental P in your soil extracted with H3A and analysed on ICAP in ppm P."

Organic P (ppm): "Organic P is the total P minus inorganic P expressed in ppm P…"

K (ppm): "Is the total elemental K extracted with H3A from your soil expressed as ppm K…"

Ca (ppm): "Is the total elemental Ca extracted with H3A from your soil expressed as ppm Ca…"

Al (ppm): "Is the total elemental Al extracted with H3A from your soil expressed as ppm Al…"

Fe (ppm): "Is the total elemental Fe extracted with H3A from your soil expressed as ppm Fe…"

C:N ratio: "This is the ratio of organic C to organic N in your soil based on the water extraction…"

N mineralisation (ppm): "The amount of N being released through mineralization expressed in ppm N…"

Organic N Release (ppm): "The total amount of nitrogen being released through microbial activity from the organic N pool expressed as ppm N. The amount of N being released is dependent on how much water extractable organic N we can measure, how high the soil respiration or microbial biomass value is and how balanced the organic C:organic N ratio…"

P mineralisation (ppm): "The amount of P that will be released through mineralization of organic P by soil microbes depending on their activity and the organic C:organic N ratio expressed in ppm P…"

Soil Health Index: "The Soil Health Calculation number is calculated as soil respiration divided by 10 plus a weighted organic carbon and organic N addition. It summarizes the overall health of your system based on the indicators measured in the test…"

5.1.2 The flowing to definitions for terms used by Soil Health Solutions and defined by Soil Health Solutions

Volumetric Aggregate stability (%): "Volumetric Aggregate stability (%) provides a very good indication of how well aggregated a soil is after the initial soil is repeatedly placed into water (slaked). The retained aggregates are then forcibly destroyed retaining the mineral components around which the aggregates were formed. A percentage of gross aggregates are calculated with acceptable standards for comparative analyses."

Solvita Labile Amino-N Total releasable N (ppm): "SOLVITA LABILE AMINO-NITROGEN Total releasable N (PPM) measures the pool of organic nitrogen, called alkali-labile soil amino-N, that's available in your soil. This is a good indication of your reserve nitrogen status not yet in the potentially mineralisable (PMN) form but bound in larger organic molecules not yet water soluble in the process of being microbial degraded."

Tables containing baseline information concerning cover crops

Table 21: Soil Health Solutions (The Complete Soil Health Tool) soil analysis of soil collected at a depth of 0 – 150 mm prior to planting cover crop, from each whole plot of the mainly leguminous- and mainly cereal cover crop mixture (defined in Section 5.1.1 and 5.1.2).

	Cereal mixture		Leguminous mixture	
	Average	Standard error	Average	Standard error
Soil pH	6.0	0.06	6.0	0.08
Soluble Salts (mmho cm^{-1})	0.51	0.04	0.55	0.10
Soil organic matter (%)	2.4	0.14	2.4	0.13
CO_2-C (ppm)	61	5.1	54	3.2
Total N (ppm)	77	7.6	91	12
Organic N (ppm)	17	0.6	21	2.2
Total Organic C (ppm)	149	3.7	153	7.7
NO_3^- (ppm)	54	8.1	64	11
NH_4^+ (ppm)	3.3	0.33	3.5	0.60
Inorganic N (ppm)	58	7.9	67	11
Inorganic P (ppm)	22	2.6	26	3.1
Total P (ppm)	28	3.0	32	3.5
Organic P (ppm)	5.8	0.46	6.2	0.45
K (ppm)	109	4.4	106	5.9
Ca (ppm)	152	4.5	164	13
Al (ppm)	262	13	319	30
Fe (ppm)	156	7.7	180	13
C:N ratio	9.3	0.54	7.9	0.42
N mineralisation (ppm)	13	1.0	14	1.2
Organic N Release (ppm)	16	0.73	20	2.3
P mineralisation (ppm P)	5.8	0.46	6.1	0.4
Soil Health Index	10	0.63	11	1.0
Volumetric aggregate stability (%)	34	4.1	42	5.1
SOLVITA LABILE AMINO-N total releasable N (ppm)	80	7.6	98	9.2

Table 22: Chemical soil analysis of soil collected at a depth of 0 – 150 mm prior to planting cover crop, from each whole plot of the mainly leguminous- and mainly cereal cover crop mixture.

	Cereal mixture		**Leguminous mixture**	
	Average	**Standard error**	**Average**	**Standard error**
pH (KCl)	5.6	0.06	5.5	0.08
Resistance (ohm)	393	43	429	47
Ca (mg kg^{-1})	860	22	827	64
Mg (mg kg^{-1})	120	4.3	135	15
Na (mg kg^{-1})	49	5.1	43	5.0
K ((mg kg^{-1})	165	10	158	10
Cation exchange capacity (cmol kg^{-1})	6.1	0.20	6.1	0.43
P (mg kg^{-1})	70	7.4	75	6.2
Cu (mg kg^{-1})	1.2	0.09	1.4	0.16
Zn (mg kg^{-1})	1.7	0.16	1.9	0.14
Mn (mg kg^{-1})	49	7.2	82	13
B (mg kg^{-1})	0.5	0.03	0.50	0.05
S (mg kg^{-1})	23	2.4	19	2.0
Organic C (%)	1.4	0.07	1.4	0.11

Table 23: Chemical soil analysis of soil collected at a depth of 150 – 300 mm, prior to planting cover crop, from each whole plot of the mainly leguminous- and mainly cereal cover crop mixture.

	Cereal mixture		**Leguminous mixture**	
	Average	**Standard error**	**Average**	**Standard error**
pH (KCl)	5.0	0.10	5.0	0.16
Resistance (ohm)	737	47	943	128
Ca (mg kg^{-1})	471	21	524	77
Mg (mg kg^{-1})	75	12	81	15
Na (mg kg^{-1})	42	13	29	3.5
K (mg kg^{-1})	97	7.0	84	4.4
Cation exchange capacity (cmol kg^{-1})	4.0	0.15	4.2	0.47
P (mg kg^{-1})	39	5.9	44	4.8
Cu (mg kg^{-1})	1.2	0.10	1.3	0.19
Zn (mg kg^{-1})	0.99	0.09	0.93	0.08
Mn (mg kg^{-1})	36	5.8	64	13
B (mg kg^{-1})	0.36	0.09	0.29	0.03
S (mg kg^{-1})	10	1.8	8.7	0.56
Organic C (%)	0.83	0.10	0.65	0.04

Table 24: Soil moisture at a depth of 0-150 mm at planting of cover crops

	Cereal mixture		**Leguminous mixture**	
	Average	**Standard error**	**Average**	**Standard error**
Soil moisture (%)	3.6	0.23	3.8	0.36