THE EFFECT OF SOIL RESIDUE COVER ON MEDICAGO PASTURE ESTABLISHENT AND PRODUCTION UNDER CONSERVATION AGRICULTURAL PRACTICES

By

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DECLARATION

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ABSTRACT

Annual medic pastures play an important role in conservation agriculture (CA) practices in the Western Cape, because of the beneficial role it plays in rotation systems and the fact that it can re-establish on its own. In the Overberg medic pastures are the main pasture short rotation crop, but farmers in recent years shifted away from including medics. This was due to unsuccessful re-establishment and a visible decrease in dry matter production. This trend started after CA practices were implemented for a few years.

A field study conducted during 2013 investigated medic re-establishment and production following a wheat, barley, oat and medic pasture production year (WM, BM, OM and MM) of which residues were left on the soil surface at different cover percentage levels (100%, 75%, 50%, 25% and 0%). The objective of this study was to determine what the effect of different amounts of residues was on annual medic re-establishment and production. Data from this study suggest that management of annual medic pastures should aim to re-sow the medic pasture if plant count drops below 78 pants per square meter. Weed management is of cardinal importance as it competes for resources, light and space and decrease medic pasture re-establishment and production. The data also indicates that the wheat/medic sequence is the best option when applying a short cash crop/annual pasture cropping system. Producers should manage their animals to ensure that a 50% to 75% cover is left on top of the soil following the grazing of residues during the summer months.

The study in 2013 should have been replicated, but due to the low levels of re-establishment and production a decision was made to re-plant the trial sites. The field study conducted during 2014 investigated the medic/clover establishment and production following a re-plant. Medics were replanted following a W, B, O and M season, respectively. Residues again were manipulated to different cover percentages (100%, 75%, 50%, 25% and 0%). The objective was again to look at the amount and type of residues on medic/clover establishment and production following re-plant. Data from this study indicated that it might be advisable for annual medic/clovers to be re-sown after a cereal production year rather than a medic pasture year. With the production of medic/clover pastures not being affected by the residue cover percentage, a 100% residue cover following re-plant is best in rotations, if the optimal effect of CA wants to be observed. If animals are included in the production cycle, grazing of residues during summer months can occur until 50% cover is left. Soils will take longer to reach its potential, but by including animals the gross margin is more stable year on year.

Two supplementary studies were conducted to investigate the germination of annual medics under controlled conditions. The objectives of the first supplementary study was to investigate the physical barrier effect of residues at different percentage cover (100%, 75%, 50%, 25% and 0%) and a possible allelopathic action from different types of residues (wheat, barley, oat and medic) on the annual medic

cultivar Cavalier (one of the cultivars used during 2014 field re-plant). The different amounts of residue had no significant effect on percentage emergence of Cavalier. The 0% residue cover having the slightly higher germination could be because there are no physical obstructions preventing seedlings to establish. The different types of residue cover had no significant effect on the germination of annual medics, as the germination under wheat, barley, oats and medic residues did not differ from the control. The control had a slightly higher germination percentage (85%), while germination under residues was just below the recommended germination rate of 80-85%. This could be an indication of allelopathy from residues.

The objective of the second supplementary study was to investigate the allelopathic effects of different residue leachates (wheat, barley, oat and medic) at different levels of concentrations (100% leachate, 75%, 50%, 25% and distilled water being the control) on Cavalier germination. The interaction between leachate type and concentration were significant. Low levels of leachate concentration did not have a significant impact on medic germination when compared between each other and the control. When the concentration percentage was increased differences were detected. Cavalier germination decreased drastically when medic leachate concentration increased, indicating allelopathic effects. Cavalier germination followed the same trend, just not as drastic, when wheat leachate concentration increased. This indicates that wheat could also have a negative allelopathic effect. With oat leachate Cavalier germination did not decrease except when 100% concentrate was used, which could indicate a small allelopathic effect. Cavalier germination following barley leachate showed no effect as concentration increased, even showing the odd increase.

Depending on repeatability or follow-up studies of these experiments, data suggest that re-plant of medic pastures is beneficial if plant count drops below sustainable levels. Management of weeds during the medic pasture year improves production. Annual medic pastures should be re-planted following a cereal production year rather than a previous pasture year. Thus single medic rotations are preferred, for example WMWM rotation. Greater amounts of residues are beneficial for CA effects, but allelopathic effects of wheat and oat residues should be taken in consideration during re-establishment and residue levels should be lowered.

OPSOMMING

Eenjarige medic weidings speel ŉ belangrike rol in bewaring landbou (CA) praktyke in die Wes Kaap, vanweë sy vermoë om jaarliks op sy eie te hervestig en sy voordelige rol in rotasie stelsels. Eenjarige medic weidings is tans die hoof kort rotasie gewas in die Overberg, maar boere is tans besig om dit uit die rotasie uit te sluit. Dit is as gevolg van lae hervestiging sowel as die opvallende afname in produksie. Hierdie waarnemings het na ŉ paar jaar na die toepassing van CA praktyke begin.

Gedurende 2013 is daar ŉ veldstudie voltooi rakende medic weiding hervestiging en produksie wat na ŉ koring, gars, hawer en medic weiding produksie jaar volg (WM, BM, OM en MM). Gedurende die studie is stoppels by verskillende persentasie vlakke van bedekking op die grond gelaat (100%, 75%, 50%, 25% en 0% bedekking). Die doel van die studie was om die invloed van verskillende tipes en hoeveelhede stoppels op die hervestiging en produksie van eenjarige medic weidings vas te stel. Data van hierdie studie dui aan dat jaarlikse medic weidings so bestuur moet word dat medics in die Overberg area se plant telling nie laer as 78 plante per vierkante meter daal nie. Onkruid bestuur is van kardinale belang, omdat dit kompeteer met medics en veroorsaak ŉ verlaging in hervestiging en opbrengs. Data dui ook aan dat ŉ koring/medic stelsel die beste opsie is wanneer ŉ kort kontant gewas/eenjarige weiding gewas stelsel toegepas word. Produsente moet hul vee so bestuur dat ŉ 50 tot 75% stoppel bedekking gedurende die somer maande oorgelaat word na beweiding.

Die herhaling van die 2013 veld studie was van plan, maar ag gevolg van lae hervestiging en produksie was die proef kampe oor geplant. Die veldstudie in 2014 was medic/klawer vestiging en produksie na herplanting ondersoek. Die medic/klawer saad is geplant na ŉ koring, gars, hawer en medic weiding seisoen onderskeidelik. Stoppels is weereens na verskillende bedekking persentasies verander (100%, 75%, 50%, 25% en 0% bedekking). Die doel was om te kyk wat die effek van verskillende tipes en hoeveelhede stoppels op eenjarige medic/klawer weiding is na herplant. Data wys dat medic/klawer weidings verkieslik herplant moet word na ŉ graan produksie jaar as ŉ medic weiding produksie jaar. Die medic/klawer weiding is nie geaffekteer deur die hoeveelheid stoppels op die grond oppervlakte nie, dus is ŉ 100% stoppel bedekking verkieslik vir optimale CA effekte. As diere in die sisteem teenwoordig is, kan stoppels bewei word gedurende die somer maande tot ŉ 50% bedekking bereik word. Grond sal langer vat om sy potensiaal te bereik, maar die jaarlikse bruto marge sal meer stabiel wees.

Twee aanvullende studies is onderneem en ontkieming van eenjarige medics is ondersoek onder beheerde toestande. Die doelwit van die eerste aanvullende studie was om te kyk na die fisiese versperring effek van stoppels by verskillende persentasie bedekking (100%, 75%, 50%, 25% en 0%) en ŉ moontlike allelopatiese effek van verskillende tipe stoppels (koring, gars, hawer en medic) op die eenjarige medic kultivar Cavalier. Verskillende hoeveelhede stoppels het geen beduidende uitwerking

op die vestiging van Cavalier gehad nie. Die 0% stoppel bedekking het ŉ effens hoër vestiging gehad. Dit kon wees as gevolg van geen fisiese versperring wat die saailing verhoed om te vestig nie. Die verskillende tipes stoppels het geen beduidende uitwerking op die ontkieming van eenjarige medics nie, die vestiging onder koring, gars, hawer en medic stoppels het nie statisties verskil van die kontrole nie. Die kontrole het wel ŉ effense hoër persentasie vestiging gehad (85%), terwyl die vestiging onder die stoppels onder die aanbevole koers van 80-85% was. Dit kan dalk ŉ allelopatiese effek van die stoppels aandui.

Die doel van die tweede aanvullende studie was om die allelopatiese effek van die verskillende tipes stoppels (koring, gars, hawer en medic) by verskillende vlakke van konsentrasie (100%, 75%, 50%, 25% van die onverdunde loogsel en gedistilleerde water as kontrole) op Cavalier ontkieming. Daar was ŉ beduidende interaksie tussen tipe en konsentrasie loogsel. Met lae konsentrasie vlakke van loogsel was daar nie ŉ werklike impak op Cavalier ontkieming tussen die verkillende tipes en die kontrole nie. Slegs wanneer die konsentrasie persentasie verhoog is, is verskille waargeneem. Cavalier ontkieming het drasties af geneem soos die medic loogsel konsentrasie toegeneem het, wat ŉ negatiewe allelopatiese en verhoogde osmolaliteit effek wys. Cavalier ontkieming het dieselfde tendens gewys wanneer koring loogsel konsentrasie verhoog was, maar nie so drasties soos medic loogsel. Dit dui daarop dat koring ook ŉ negatiewe allelopatiese effek wys. Met hawer loogsel het Cavalier ontkieming slegs by die 100% konsentrasie pyl afgeneem, wat op ŉ lae allelopatiese effek dui. Cavalier ontkieming onder gars loogsel het geen verandering gewys as konsentrasies toegeneem het nie, en het selfs ŉ toename in ontkieming in party gevalle ondergaan.

Afhangend van herhaling of op-volg studies van hierdie eksperimente, wys die data dat dit voordelig is om medic weidings te herplant as plant telling onder 78 plante per vierkante meter daal. Die bestuur van onkruid tydens die medic weidings jaar verbeter opbrengs. Eenjarige medic weidings moet herplant word na ŉ graan produksie jaar liewer as ŉ vorige weidings jaar. Medics moet dus in ŉ eenjarige rotasie stelsel wees, byvoorbeeld WMWM rotasie. Meer stoppels is voordelig vir CA promosie, maar allelopatiese stowwe van koring en hawer stoppels moet in ag geneem word en stoppels moet verlaag word vir hervestiging.

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LIST OF ABREVIATIONS

B	Boron
BGA	Bluegreen aphid
BM	Medic production following barley residues or barley production year
C	Carbon
C: N	Carbon to nitrogen ratio
Ca	Calcium
CA	Conservation agriculture
CO_2	Carbon dioxide
CT	Conventional tillage
DM	Dry matter
MM	Medic production following medic residues or medic production year
N	Nitrogen
NT	No-till
OM	Medic production following oat residues or oat production year
P	Phosphorus
Ppm	Parts per million
Pn	*Pratylenchus neglectus* root lesion nematode
S	Sulphur
SAA	Spotted alfalfa aphid
SMB	Soil microbial biomass
SOC	Soil organic carbon
SOM	Soil organic matter
WM	Medic production following wheat residues or wheat production year

ZT	Zero-till

CHAPTER 1

GENERAL INTRODUCTION AND RESEARCH AIMS

Conservation agriculture (CA) is growing rapidly in the Western Cape of South Africa, with a high percentage of farmers already converted to CA practises. Research farms in different areas of the Western Cape helps to promote CA practices through providing statistical evidence as to why CA outperforms conventional practices to the local farmers. The Tygerhoek Research Farm near Riviersonderend, situated in the Overberg district of the Western Cape, is one such facility, which provides scientific data that shows CA increase crop yields (Strauss et al. 2012) and improves soil productivity (Smith 2014). The research area was in its 12th year of practicing CA during 2014, which is favourable as it usually takes 10 to 20 years before CA practices start to show the benefits (Personal communication, JA Strauss, 2014, Western Cape Department of Agriculture). Implementing CA on a full scale basis in the Western Cape can alleviate climate challenges by enhancing water preservation. One of the principles to be classified as a CA practice is to leave at least 30% residue cover on the soil directly after planting (FAO 2010). Residues on top of the soil reduce evaporation from the soil surface because of the physical obstruction that keeps water in the soil (Farooq et al. 2011). This is just one of the many benefits of a permanent residue cover. The second principle of CA is to use different crops in rotation, with the inclusion of legumes being beneficial (Kassam et al. 2012). The third principle of CA is continuous minimum or no disturbance through mechanical implements (FAO 2010).

The Overberg area is known for its dryland crop rotation production. Selection of crops is limited due to the unpredictable rainfall patterns, which cause variable yields year on year. Crops used in rotation in the Overberg are mostly wheat, barley, canola, oat and lupins, but crops such as annual medic and lucerne pastures are being utilised more in rotation systems. This is due to the benefits legume pastures bring to the rotation system. In the Overberg lucerne is the primary forage crop, but must be used in long term rotation systems with cash crops. Thus the trend in the Overberg was to introduce annual medics in the rotation systems because of the benefits of its annual growing habit. Benefits like re-establishment after being planted just once and high annual biomass production which increase the SOM (Smith 2014). This makes medics the primary short rotation pasture crop in the Overberg. Annual medic pastures has the ability to fix N into the soil for subsequent crops (El Msehli et al. 2011; Angus et al. 2012; Kassam et al. 2012), increase the production as well as gross margin of the following crop (Stevenson and Kessel 1996; Strauss et al. 2012), control grass weed population during the pasture year (van Heerden 2013), increase the organic fraction in the soil (Hobbs et al. 2008; Smith 2014) and breaking of disease and pest cycles (Stevenson and Kessel 1996; Thiombiano et al. 2009).

With the introduction of CA the annual medic pastures did not fully adapt to the Overberg area and CA conditions, with re-establishment and production varying year on year. Studies were done on medic pastures in the area, with few in detail as to why some of the CA principles could affect the germination, establishment, re-establishment and production. By observing the effects of the principles of CA on medic pastures, a reason for the varying degrees of re-establishment and production can be found. Principles such as the type of residue cover and amount of residue cover could influence the medic re-establishment and production.

The objectives of this study were to determine what the effect of different amounts of different crop residues is on annual medic re-establishment and production. Then to investigate the effect of the amount of residues and type of residues on medic establishment and production after re-plant. Other objectives were looking at the effect of residue cover on re-establishment and production in more controlled conditions with less variables and the effect of different concentrations of leachates from different crops on medic germination.

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CHAPTER 2

LITERATURE REVIEW

2.1 MEDICS IN GENERAL

2.1.1 Origin, distribution and environment

Annual *Medicago spp* (also referred to as medics) are from Mediterranean origin, characterised by hot, dry summers and wet winters. Since medics are adapted to this type of climate they are able to survive and adapt in other parts of the world that possess similar climate conditions. Therefore annual medics are distributed all around the world, from the Western Cape of South Africa, Western and South Australia, central Chile, certain parts in central Asia to California in the United States of America.

The Mediterranean climate is divided into four seasons namely winter, spring, summer and autumn. All Mediterranean climates have a predominant winter rainfall, which varies between 250 and 500 mm precipitation per annum (Quinlivan 1965). Winter rainfall is usually three times more than summer rainfall (Perry 2014). Winter is the season of extremes with heavy rains, snow, hail and gale storms a common occurrence (Perry 2014), while in the summer the conditions are hot and dry (Kottek et al. 2006). Plants in the Mediterranean environment, like annual medics, had adapted to these extreme differences in climate shift between seasons.

2.1.2 Medic growth and production

Adaptation to the harsh climate is crucial for survival and plants need a survival mechanism during the hot, dry summers. Annual medic survival mechanism may be related to its hard seed coat, which makes it capable to regenerate on its own year on year through seed reserve build up in the soil (Denney et al. 1979; Kotzé 1990). This hard seed coat is called hardseededness and is classified as a physical dormancy (Baskin and Baskin 2004). The level of annual medic hardseededness is dependent on the specie and cultivar. By breaking the seed coat through natural conditions or artificial techniques, water can infiltrate to stimulate germination. Dormancy of medics is naturally broken through sufficient day/night temperature fluctuations during the summer months (Puckridge and French 1983) or by the hooves of animals as well by passing through the animal digestive track. The artificial way to break dormancy is through scarification, for instance planting implements that break the hard seed coat of the medic seeds (Swart 1998).

Annual medics start to germinate during autumn after the first sufficient rains, but only if dormancy was broken and water infiltrates the seed coat (Crawford and Nankivell 1989). The seeds do not all germinate at the same time because of different levels of hardseededness, resulting in seedlings emerging at different times (van Heerden 1984). If seedlings emerge too early in the season there may be a chance of fatality and if they emerge too late in the season the plant might not set seed, making a variable germination pattern beneficial as conditions change between years.

The two main growing season phases of annual medics are the period from emergence to flowering and the period from flowering to ripening (van Heerden 1984). The growth from emergence to flowering is important for a successful medic production. If the seedling does not grow adequately before environmental conditions affect it, the plant can die, resulting in lower medic production (Swart 1998). The pre-flowering phase is greatly affected by the temperature (Craufurd and Wheeler 2009) and soil moisture levels (van Heerden 1984) as well as the photoperiod (van Heerden 1984; Craufurd and Wheeler 2009). This phase is typically about 72 - 77 days (Swart 1998), but differs between species, cultivars and areas.

Medic plants have a vernalisation period requirement, which is a period where plants are exposed to low temperature in order to induce flowering (van Heerden 1984). Vernalisation and photoperiod is strongly correlated in medics (van Heerden 1984). More days of vernalisation (cold winter temperatures) combined with longer photoperiods (mid-winter to summer day lengths) results in fewer days from germination to flowering. Low soil moisture levels has a similar effect, causing medics to flower earlier than normal (Swart 1998). The flowering date of the medic plant is important for pasture and seed production. By shortening the duration of growth till flowering, production is negatively influence (Craufurd and Wheeler 2009). In some instances earlier flowering annual medic cultivars are preferred to ensure seed production for the following year, to the detriment of high production rates. This is usually in areas where rainfall is low or not evenly distributed throughout the growing season. Swart (1998) found that earlier flowering annual medic cultivars are more adapted in the Western Cape's grain production areas. Annual medic plants that a flower too late in the season is susceptible to soil moisture stress, resulting in seed losses. The early flowering of medics as well as maintaining the flowering period for as long as possible is very important, as environmental conditions in spring are unpredictable (Swart 1998).

Seed formation starts in the seed pod from mid-spring to early summer. Seed pods differ between medic species and cultivars. Seed pods can differ in the direction of the whorl, have different shapes and sizes, can have spines or not and may differ in weight. The spines on the pods can be seen as an important seed distribution method (Swart 1998). A total of at least 700 kg seed per hectare must be produced for a successful pasture re-establishment the following year (Puckridge and French 1983). An exceptional annual medic establishment will exceed 600 plants per square meter, but between 200 and 300 is acceptable (van Heerden 2013). It is only when plant count per square meter fall below 78 that seed production would not be efficient for sustainability (Kotzé 1999). Annual medic pastures can produce 6 to 10 tons of dry matter per hectare in exceptional conditions (Kotzé 1999). During the early summer months, when moisture levels in the soil start to diminish, annual medics start to die off. Seeds are distributed on the land and are dormant till the next rains come.

2.1.3 Establishment and requirements

Annual legumes such as medics and clovers re-establish every year after being planted just once. It is beneficial to re-plant annual legume pastures every 5 to 7 years, depending on the sward density (Personal communication, JA Strauss, 2014, Western Cape Department of Agriculture). To establish annual legume pastures an average of 4 to 6 kg per hectare of medic seeds should be planted for a pure annual medic sward or 2 to 3 kg per hectare medic in combination with grass seeds for a grass/legume mix pasture (Puckridge and French 1983). It is optimal for medic seeds to be planted at a depth of 10 to 25 mm (Puckridge and French 1983). A depth deeper than 30 mm would cause a longer time for seedlings to emerge, which causes reduced rates of seedling survival (Kotzé 1999). A landroller or press wheel should be attached to the planter to ensure that there is good seed-soil contact, which improves germination and establishment (Nair et al. 2006).

When planting just medic pastures, a combination of annual medic cultivars should be sown together. With inconsistent rainfall year on year, early-, medium- and late-season flowering medics, as well as cultivars which differ in hardseededness, should be planted together for optimal survival. Seeds can be treated with inoculants (N fixating bacteria, phosphorus-solubilizing bacteria and mycorrhiza) before re-plant, which are live organisms that improve legume plant production (Shabani et al. 2011).

Annual legumes do not usually require fertiliser during re-establishment or re-plant, but it can be beneficial to supply fertiliser. Medics mostly depend on an adequate supply of phosphorus (P), sulphur (S) and calcium (Ca), while nitrogen (N) is generally not needed because of the N-fixation from the atmosphere. Phosphorus, being the most important macro-nutrient for legumes, can be top-dressed in the pasture phase or band placed during the cereal year beneath the soil in a cereal/medic ley farming system (Puckridge and French 1983). A ley farming system is a traditional rotation system with a self-regenerative pasture phase, which remains dormant during the cropping phase of one or two years (Nichols et al. 2006). The P requirement depends on the soil type, climate in the region, quantity given the previous year and the grazing pressure the previous year (Puckridge and French 1983), thus soil analyses should determine amount P needed. Micro-nutrients that are important to legumes are zinc, copper, molybdenum and cobalt, because these nutrients are important during the nitrogenase enzyme complex (Nair et al. 2006).

There are a variety of medic cultivars to choose from which all have different planting and environmental requirements. By way of breeding strategies various medic cultivars came into existence. The two main species which are best adapted to the Western Cape are *Medicago truncatula* and *Medicago polymorpha.* These two species is also the main species around the world (Nichols et al. 2006).

2.2 DIFFERENCES BETWEEN TWO MEDIC SPECIES

2.2.1 *Medicago truncatula* (Barrel medic)

Medicago truncatula, also known as barrel medic, is an enormously popular medic species. It can produce a reasonable dry matter production during low rainfall years and also plays an important role as a grazing cultivar (Viljoen et al. 1984). It is best adapted to a short rotation system where the cereal phase does not exceed three years (Nichols et al. 2006). If other crops are planted for longer than three years in a row it does not allow this annual medic to re-establish and the medic seed bank will be decimated, causing the medic to disappear in the rotation.

Barrel medic cultivars have a higher pod mass (71-91 mg) than burr medics (23 mg), but seed to pod ratio is lower (18-28%) than burr medics (34%) (Kotzé et al. 1995). Only 4% of seeds are recovered after ingestion by sheep by sheep (Kotzé et al. 1995). Although the seed to pod ratio is low in this species, the amount of seeds per pod is still relatively high. More seeds per pod create a build-up of the annual medic seed bank in the soil, leading to greater re-establishment and production in the future. The low survival rate after ingestion by sheep should be taken into consideration during the summer grazing period of seed pods, and stocking rate should be kept to a minimum.

Barrel medic is suitable in rotations because of its early flowering and large pod size. It is an earlier flowering specie than burr medic (Swart 1998), which is beneficial during dry years, because soil moisture levels are still relatively high and causes less stress on the plant. If flowering is late on these occasions, the soil moisture will be low which negatively influence seed production. Barrel medic seeds have a high hard seed percentage, which allows it to geminate after a year or two of alternative cropping (Nair et al. 2006).

Barrel medic grows best in neutral to alkaline soils (pH > 6.5) of which a pH of 7 is best suited, and soils with texture from sandy loams to clay (Nair et al. 2006). Annual medics can fix N through symbioses with rhizobia. The rhizobia of medics are less tolerable to acid soils than that of other legumes, which may be why medics prefer neutral to alkaline soils.

There are several different cultivars of barrel medics of which Jester (in 2001), Caliph (in 1993), Mogul (in 1992), Parabinga (in 1986) and Sephi (in 1984) are commercially available (Nair et al. 2006).

Jester prefers sandy loam to clay loam soils to grow in. This cultivar is moderately sensitive to Boron (B) toxicity and soils with high levels should therefore be avoided. It requires an average annual rainfall of 350 mm and more for optimal production. With most of the rainfall required during the rainy season, which is applicable to all medic cultivars. From germination to flowering takes 110 days, this is moderately long compared to other cultivars. The seed pod turns in an anti-clockwise direction with 5-7 whorls and is 7 to 9.5 mm long. There are 8 to 12 seeds per pod of which 80-90 % will be hardseeded. Bluegreen aphid (BGA), spotted alfalfa aphid (SAA) and *Pratylenchus neglectus* root lesion nematode (Pn) are pests that caused excessive damage on medic production in the past, thus resistant cultivars where developed to overcome this problem. Jester is BGA and SAA resistant and moderately resistant to Pn (Nair et al. 2006).

Caliph prefers loam to clay soils with an annual rainfall greater than 275 mm. Soils with high B content does not affect the production of Caliph that much. Caliph takes 90 days from germination to flowering, which is the shortest time for barrel cultivars. Seed pods coil in a clockwise direction with 3.5 to 5.5 whorls and are between 5.4 to 7.9 mm long. In the pod there are 5 to 8 seeds of which 85 to 95% is hardseeded. Caliph is BGA and SAA resistant as well as Pn resistant (Nair et al. 2006). Caliph was developed through back-crossing Cyprus with aphid-resistant cultivars (Nichols et al. 2006).

As is the case with Caliph, Mogul favours loam to clay, but with an annual rainfall larger than 305 mm. Care should be taken in soils with high B levels, because Mogul is sensitive to B. It has an intermediated time from germination to flowering of 105 days. The seed pods have an anti-clockwise turn with 3.5 to 4.5 whorls. Seed pods are 5 to 7 mm long and contain 5 to 7 seeds per pod of which 70 to 80% is hardseeded. This lower percentage of hardseededness is good for first year medic production as 30 to 20 % of the seeds will germinate in the next season. Like Jester, Mogul is BGA resistant and moderately resistant to Pn, but is moderately susceptible to SAA (Nair et al. 2006). By back-crossing Borung with aphid-resistant cultivars Mogul was developed (Nichols et al. 2006).

Parabinga grows well in sandy loam to clay loam soils and is moderately tolerant to tolerant to B in the soil. It requires an annual rainfall greater than 275 mm. Parabinga, like Caliph, only takes 90 days from germination to flowering, which is the shortest for barrel cultivars. Seed pods turn in a clockwise direction with 4.5 to 6 whorls per pod which is 6 to 9 mm long. Parabinga seedpods are very spiny compared to the others. Each pod contains 6 to 9 seeds of which 80-90% are hardseeded. Parabinga is BGA resistant, moderately resistant to Pn and moderately susceptible to SAA (Nair et al. 2006).

Sephi favours sandy loam to clay loam soils with a relative high annual rainfall of 350 mm. It is well adapted to soils with high B levels. It requires 110 days from germination to flowering. The rotation of the seed pods is clockwise with 3 to 4 whorls. There are 7 to 9 seeds per pod of which 80 to 90% is hardseeded. Sephi, as most of the barrel cultivars, is BGA and SAA resistant (Nair et al. 2006).

2.2.2 *Medicago polymorpha* (Burr medic)

Medicago polymorpha, known as burr medic, grows in more acidic soils than the other medic species. Del Pozo et al. (2002) found this when looking at burr medic in the wild in central Chile, where the soils had a relatively low pH compared to places where other medic species grow. Burr medic grows in a pH range of 5.2 to 8.5 (Nichols et al. 2006), but prefers a pH between 6.0 and 6.5 (Del Pozo et al. 2002). This also makes burr medic more tolerant to salinity (Nichols et al. 2006). Cultivars used in the Western Cape, like Scimitar and Cavalier, are better adapted to waterlogged soils than barrel medics. These cultivars also naturalised in South Africa over time (Wassermann 1974). The flowering period of burr medic can begin at 75 to 77 days (Swart 1998) while Del Pozo et al. (2002) found that onset to flowering can be up to 124 days after emergence. In Chile there is a positive correlation between days to first flowering and mean annual rainfall (Del Pozo et al. 2002). Burr medic also has the highest cold requirement before onset of flowering (van Heerden 1984).

The average seed pod mass of burr medic is 23 mg with a high seed to pod ratio of 34% (Kotzé et al. 1995). This species can have up to 95% hard seeds per pod which is beneficial for the building of the medic seed bank for future germination (Kotzé et al. 1995). Burr medic can be utilised as a permanent pasture or in longer rotations of over three years because of the ability to proliferate in the seed bank (Nichols et al. 2006).With this species being naturalised to the Southern Africa climate and environment, it is a good option to use in rotations in the area.

Burr medic is the best suited for passing through the digestive track of sheep, as 23% goes through and is viable for germination (Kotzé et al. 1995). This species is also used to produce hay. The problem with some of the cultivars in the species is that the seeds have long spines (Swart 1998). This has a negative effect on wool quality and wool will be downgraded and sold at lower prices (Del Pozo et al. 2002). There are burr medic cultivars that are spineless like var. Cavalier and Scimitar that can be used as an alternative.

Cavalier is a cultivar that prefers sandy clay to red clay soils with an average annual rainfall between 325 to 450 mm (McClements et al. 2004). Soils with high levels of B must be avoided as Cavalier is sensitive to boron toxicity (McClements et al. 2004). Flowering begins at 90 days after germination which is particularly short compared to other cultivars. The seed are small with around 250 to 280 seeds per gram (McClements et al. 2004) of which 80-85% in the pod are hardseeded. Burr medic is not that resistant against pests as barrel medic because of selection for greater production. Cavalier was crossbred and released in 2003 as a more productive replacement for Circle Valley

(Nichols et al. 2006). Cavalier has some resistance to BGA but is susceptible to SAA and the Cowpea Aphid as well as black stem fungus (*Phoma* spp.) (McClements et al. 2004).

Scimitar is similar to Cavalier and favours sandy clay to red clay soils (McClements et al. 2004) but prefers a higher annual rainfall range of 350 to 500 mm. This specie shows salt tolerance during key growing periods for soils with a water table problem. Scimitar has an erect growing habit with above average herbage and seed production making it a worthy hay and pasture producing cultivar. Scimitar was crossbred and released in 2003 as a more productive replacement for Santiago (Nichols et al. 2006). In Scimitar 76% of seeds in the pods are hardseeded (McClements et al. 2004), which is relatively low compared to other cultivars. Like Cavalier, Scimitar has a low resistance to BGA and is susceptible to SAA and Cowpea Aphid (McClements et al. 2004). McClements et al. (2004) also found that Scimitar is affected by black stem fungus (*Phoma* spp.) and shows moderate resistance to Pn.

2.3 PASTURE MANAGEMENT

Animals will normally prefer legume pastures over grass pastures because of their palatability. Medics adapted as a pasture crop over the centuries and can withstand grazing over a period of time. During annual medic establishment, grazing should be postponed until plants are well established, approximately the 6 leave stage or a soil-cover around 1 000 kg ha^{-1} dry material or an average plant height between 2.5 to 3 cm (Nair et al. 2006). During the winter when grazing pressure is higher, upright grasses can be controlled and prostrate growth of medics is encouraged (Puckridge and French 1983; Nair et al. 2006). At early spring grazing pressure must also be high to prevent a very dense creeping pasture, which is more prone to moisture stress and foliar fungal diseases (Nair et al. 2006). Medics should be grazed or cut frequently during this time to a height of 7 to 13 cm, which help with additional weed control (Miller et al. 1989). Winter and early spring grazing of medic pastures is the best time for growing and finishing of livestock. During flowering the carrying capacity must be lowered and animals must be totally removed at seed set (Miller et al. 1989). It is important for medics to be grazed or cut correctly, because this stimulates flowering and maximises seed production (Miller et al. 1989; Nair et al. 2006). During the summer months the seed pods and medic dry material can be grazed by animals to maintain their condition. Summer grazing must also be monitored and managed carefully in the first year to prevent overgrazing that will reduce future re-establishment. Cereal residues can be grazed in the summer to relief high grazing pressure on medic pastures.

Higher seeding rates enhance medic pastures weed competition and higher DM production, resulting in higher animal carrying capacity in the first year (Nair et al. 2006). Annual medics are best grazed by sheep, but can be grazed by cattle as well (van Heerden 2013). Sheep are more nimble with their mouths, which results in more effective seedpod collection from the soil. During the collecting of seed pods on the pasture, some pods are trampled into the soil which helps with re-establishment (Puckridge and French 1983). Small seedpods are difficult to pick up with the mouth making them better adapted to heavy grazing. Pastures are usually sown in combination with grass seeds to prevent bloat in ruminants, which are a common phenomenon in legume pastures (McCartney and Fraser 2010). Sheep are less affected by bloat than cattle on annual medic pastures. Bloat from medics usually occurs when wet winters follow a dry summer and when grasses are limited in the pasture. The best way to overcome bloat is to provide access to dry hay or grasses. Annual medic pastures can also cause photosensitisation in horses. Most of the new medic cultivars have a much lower bloat risk than that of lucerne (McCartney and Fraser 2010). This was done through breeding cultivars with higher flavanol polymers (tannins) in its leaves which reduce bloat in ruminants through decreasing soluble protein levels to below the levels required to produce foam in the rumen (Marshall et al. 1981).

In general, animals can be expected to achieve better live weight gain and wool production on legumes than grasses, as a result of higher intake and more efficient utilisation of high protein, high energy feed. Medic pastures tested by Michalk and Beale (1976) could support up to 6.8 breeding ewes per ha^{-1} during a sufficient rainy year, but during a dry year the stocking rate need to be adjusted. In Table 2.1 from Michalk and Beale (1976) there is evidence that in 1971 there was uneven rainfall and in 1972 there was drought, causing the wool production of the animals to decline as the stocking rate increases.

Table 2.1: Clean wool production (kg) of ewes grazing Jemalong barrel medic

Stocking rate (sheep/ha)	**Wool production per head**		
	1970	1971	1972
3.1	3.63a*	3.48a	3.51a
4.3	3.61a	3.26ab	3.28ab
5.6	3.67a	3.09b	3.01bc
6.8	3.48a	2.73c	2.78c

*Values followed by the same letter in each parameter do not differ at p = 0.05

(Michalk and Beale 1976)

In the study from Michalk and Beale (1976) it can be deducted that environmental conditions may play a significant role in reducing the medic re-establishment and DM production, which leads to lower stocking rates. A stocking rate of five breeding ewes per hectare was calculated as the most economical and beneficial for medic pasture survival (Michalk and Beale 1976; Kotzé 1999).

It is important to maintain high seedling survival rates and densities, which determines the winter forage production (Swart 1998). If medic pasture sward density was below 78 plants per square meter, the medic seeds produced for regeneration were not sufficient to sustain a cereal/medic ley farming system (Kotzé 1999).To maintain a decent carrying capacity on medic pastures, great importance must be placed on the medic vegetative growth. The problem with high vegetative medic cultivars is that the seed production is low (Swart 1988). Importance should be placed on recovery of medic pastures after grazing for an adequate seed production. Annual medic cultivars with short internodes, lots of tributaries and growth points close to the base of the plant, allows the plant to recover the best after heavy grazing (Swart 1998).

The plants and seedpods of annual medic pastures have a high nutritional value, which makes it a popular pasture crop (Interrante et al. 2011). The forage has a high protein value in the winter and early spring and in the drier summer months the protein content of the pods increase (Swart 1998). Forage crude protein is between 17 and 23% and digestibility ranges from 55 to 75%, depending on the growth stage. The medic plant's metabolic energy equates to 8-10 MJ kg^{-1} dry material. Medic seed pods contains 23.8% crude protein, 5.2% long-chain fatty acids and 77.5% acid-detergent fibre of which 19.9% is lignin (Denney et al. 1979). The pod digestibility was just 24.3%, but this can be because of the high lignin content (Denney et al. 1979). Most of the nutrient value in the pod comes from the seeds, particularly the protein and lipid components (Denney et al. 1979). The amount of seed in the pod and the crude protein level of the pod have a significant relationship to each other (Kotzé 1999). The researchers Vercoe and Pearce (1960; as quoted by Swart 1998) reported that the crude protein of the seeds were 45% and that of the rest of the pod only 6%. There is a positive relationship with the increase in seed to pod ratio and higher nutritive value of the pod (Swart 1998). Both strand medic (*M. littoralis*) and burr medic has a higher seed to pod ratio than barrel medic and thus a higher crude protein value in the pods (Kotzé 1999). About 23% of the burr medic seeds where recovered after being grazed by sheep, followed by strand medic with 9% and barrel medic with 4% survival after ingestion by sheep (Kotzé 1999). Medic pastures can furthermore be used for hay production. The digestibility of medic hay is 65% of which 16.9% is crude protein, 3.1% long-chain fatty acids and 35.3% acid detergent fibre (Denney et al. 1979). It was found that medic hay has the same nutrient value than that of good quality lucerne hay (Denney et al. 1979).

2.4 CONSERVATION AGRICULTURE (CA)

2.4.1 History of CA

It is said that conservation of agricultural land started in forestry, because the forester may not see the results of his own work in his lifetime (Pinchot 1937). It was therefore important for a forester to look into the future and conserve the area for the successor. Conservation of agricultural land was done by many older civilisations, because they realised that when the land was not protected, the risk of starvation increased. An example of a civilisation which did not protect their resources, eventually leading to their extinction, was that of the Polynesians of Easter Island. Even the powerful Roman Empire used tillage-based agricultural practices, resulting in soil degradation and in turn lowered soil productivity in the long term (Kassam et al. 2012). Tillage dates back to 3000 BC according to artefacts found in Mesopotamia (Hobbs et al. 2008). Objectives of tillage were to loosen the soil and level it for seeding, resulting in a more uniform germination, mixing the fertiliser into the soil, releasing soil nutrients through mineralisation and oxidation, temporarily relieving compaction and controlling weeds and diseases (Hobbs et al. 2008; Farooq et al. 2011).

Giller et al. (2009) found that by converting forest or grassland to agricultural soils, the soil organic matter (SOM) declined drastically, with up to 50% of organic matter being lost in the first 10 to 15 years. Most of the Mediterranean agricultural soils today have low organic matter because of these non-CA practices (Kassam et al. 2012). Over time this can lead to desertification, which has happened in many areas of the Mediterranean (FAO 2010; Kassam et al. 2012). By ploughing the soil, there is an increased chance of soil erosion during rainy days or dry days with high wind speeds. From the dust bowl in the United States of America to the heavy erodible soils in South Africa, wind erosion as well as water erosion had a big impact in the conversion to conservation of the soil. In the 1930's the United States of America was severely struck by dust storms, which came from the top soil of agricultural land. The dust storms happened, during years of low rainfall and high wind speeds, because of poor management and ploughing of soils. In Africa soils are deteriorating because of traditional farming methods, like nomadic grazing (Thiombiano and Meshack 2009), monoculture and shifting cultivation, and poor management practices such as overgrazing (Paterson et al. 2013). This caused a decline in the productivity of the land, soil salinization, loss of vegetation and soil erosion. In South Africa 12.5% or 15.25 million ha are classified as a high or very high risk to water erosion, high risk meaning a loss of 25 - 60 tons of topsoil per ha per year and very high 60-150 tons (Paterson et al. 2013). Conservation agriculture was specifically implemented to prevent soil degradation due to removing natural vegetation, cleaning the seedbed for planting and implementing monoculture cropping on the soils (Giller et al. 2009). CA is still opposed to the traditional method of farming and adoption by farmers started slowly.

New ways of ploughing or lack thereof needed to be tested and evaluated. The questioning of the necessity of ploughing or tillage was first raised, by an agronomist called Edward H. Faulker, in 1930 during the dust storms (Hobbs et al. 2008). He argued that the plough breaks the natural way of mixing organic matter in the soil through worms, other burrowing animals and different plant root types (Hobbs et al. 2008). Promotion of CA gained momentum in the 1970s in southern Africa through the promotion of minimum tillage methods as a way to lessen soil erosion (FAO 2010).

During the mid-1970s the first tillage studies was conducted in South Africa's 'Maize Triangle' by the Agricultural Research Council's Grain Crops Institute (Fowler and Rockstrom 2001). This was done because of the high wind erosion that degraded the sandy soils of the area (Fowler and Rockstrom 2001). Less tillage action of the soil and a cover on the soil, from plant residues, lessened soil wind erosion.

Zero-tillage was developed by researchers from the need to prevent this degradation of soils (Giller et al. 2009). CA is now an expanding practice in many different areas of the world with a 7 million ha per year expansion from 45 million ha in 1999 to 125 million ha in 2011 (FAO 2010). In South Africa the CA culture had reasonable growth, from 300 000 ha in 2005 to approximately 368 000 ha in 2009 (Kassam et al. 2012). It was found to restore life in the soil, increase soil activity, conserve time and fuel and improve soil diversification (Giller et al. 2009).

2.4.2 Principles of CA

The FAO define CA in three basic principles which include 1) a permanent organic soil cover from cover crops or dead residues from previous crops; 2) continuous minimum or no soil disturbance through mechanical implements; and 3) a variety of crops in rotation with each other (Hobbs et al. 2008; Giller et al. 2009; Thiombiano and Meshack 2009; FAO 2010). These key principles was set to conserve natural resources, achieving acceptable profits while maintaining or increasing production levels and to conserve the natural environment.

These principles must be used together as the contributions of each are equally important. The benefits of the three principles together are lost when only one principle is practiced. Implementation of these principles will benefit the environment and has a neutral to positive effect on the crop yield (Giller et al. 2009). Long term studies done on CA showed an initial loss, neutral or small gain in yield in the short term, but in the long term (longer than 8 years) there is an increase in yield (Farooq et al. 2011). Sommer et al. (2012) also found this trend over a period of 6 years of comparing CA and conventional tillage (CT) methods in northern Syria. The only reason for lower yields in the long term may be because of inappropriate crop rotations, and increase in weed and disease incidence and soil compaction (Farooq et al. 2011). Two of these three problems can be managed, thus management must be optimal before implementing CA. Management practices must focus on using good quality well adapted seed, supplying the right crop nutrition for each crop keeping in mind the soil quality, well adapted management of weeds, pests and diseases and the efficient management of water use. Farmers need to be taught how to implement CA practices, starting with local farmers near the research centres.

2.4.2.1 Permanent soil cover

As Giller et al. (2009) quoted the Conservation Technology Information Centre (1999), for a practise to be classified as CA, at least 30% of the soil surface must be covered with crop residues following the planting action, the ideal being 100% cover. It was shown that this 30% cover decreased soil erosion by 80% and with an increase in cover there was a further decrease in erosion (Giller et al. 2009). Farooq et al. (2011) and Hobbs et al. (2008) also found that permanent cover reduced water and wind erosion and caused less surface crusting. Lower erosion of agricultural land results in the sustainability of the land and the potential to increase agricultural production. In the past the burning of crop residues was considered the norm, but this decreased the C and N in the soil by 6% while retaining the crop residues increased it by 1% every year (Hobbs et al. 2008).

Long term benefits of crop residue retention include the increase in SOM. The SOM is derived from a living component (undecomposed plant and animal material) and a non-living component (humus) (Smith 2014). The SOM of a soil is determined by the quantities of organic matter returned to the soil (Giller et al. 2009). A residue cover of 30% should be enough to provide sufficient SOC to improve and maintain SOM (Kassam et al. 2012). An increase in organic matter improves the soil porosity which results in improved soil structure and enhanced infiltration effect of rainwater in the soil (Thiombiano and Meshack 2009).

Residues on top of the soil reduce evaporation from the soil surface because of the physical obstruction that keeps water in the soil and because of the lowering of temperatures in the top soil (Farooq et al. 2011). It was found that upright and flat residues differ in their benefits for the soil. Flat residues reduce evaporation much better because of the higher area to mass ratio (Sommer et al. 2012). Upright stubbles makes it easier to plant in and may lower wind speeds at the soil surface while also maintaining a beneficial micro environment for the seedlings (Sommer et al. 2012). A combination of the two is preferred before planting. Retained residues also decrease soil temperature fluctuations and light penetration which also suppresses weed germination (Ferreira and Reinhardt 2010). Residues on the top soil have a positive effect on the transpiration rate of plants. Sommer et al. (2012) found that by retaining residues under CA practices transpiration was 14 mm higher, which indicates that the plant takes up more water from the soil. This leads to faster germination and stronger plant growth, which suppresses weeds.

Other long term benefits are that residue cover increases the soil N mineralisation and improves soil aggregation (Giller et al. 2009). The impact of raindrops on bare soil can cause destruction of the soil aggregate, blocking the soil pores causing runoff of water and increasing the risk of erosion (Hobbs et al. 2008). A soil cover intercepts these raindrops leading to an increase in aggregate stability and an improvement in soil distribution and stability (Farooq et al. 2011). Improved soil porosity is an indication of an improved soil aggregate, which leads to an enhanced infiltration effect of rainwater in the soil and less rainwater runoff (Sommer et al. 2012). Higher levels of SOC in the soil, from crop residues, increases the water holding capacity in the soil (Smith 2014). The improved soil aggregate, higher water holding capacity and lower soil water evaporation improves water and nutrient availability for the plant (Kassam et al. 2012). Soils where the water and nutrients are available freely increase agronomic production such as yield and quality, which in turn improves the profit margin for the farmer.

Some plant residues display an effect called allelopathy, which can suppress weed germination (Bhadoria 2011) and possibly annual medic pastures. Allelopathy is the process of chemicals (allelopathic chemicals) produced by plants to inhibit (Ferreira and Reinhardt 2010) growth of other plants. Allelopathic chemicals can derive from the plant seeds, pollen, roots, leaves and/or residues (Benyas et al. 2010). By leaving crop residues on the soil allelochemicals can be introduced through compounds directly from the residues or produced by microorganisms that feed on the plant residues (Ferreira and Reinhardt 2010). Great concentrations of stubble can be detrimental to crop yields (Kouyaté 2000). Some solutions to overcome the disadvantages of the allelopathic effects of residues are to use a rotation crop that is tolerant to the allelopathic effect or extra supplementation of N fertilizer because some allelopathic agents bind to N (Wu et al. 2001). It is important to remember that allelopathy does not kill plants, but mainly suppress it. Additional mechanisms of residues to control weeds can be because of the physical properties of the residues, such as prevention of light to the soil surface and obstruction of weed seedlings (Ferreira and Reinhardt 2010).

2.4.2.2 Minimal soil disturbance

Continuous ploughing over years destroys the soil structure and causes a decline in soil fertility and organic matter (Thiombiano and Meshack 2009). It also increases the risk of soil erosion and soil compaction (Peachey 1993). Disturbance by CA implements of the soil may not be more than 25% of the soil surface with bands not wider than 15 cm (Kassam et al. 2012). Disturbances must be kept to a minimum, with low disturbance no-till (NT) or zero-till (ZT) and direct low disturbance seeding (Kassam et al. 2012). No-till is seeding with a narrow knife-pointer (FAO 2010), while ZT is seeding with a disc opener (Farooq et al. 2011), both being a conservation tillage method if the disturbance is less than 25% and if soil is left without interruption from harvest to planting (Botha 2013). These tillage methods in combination with a permanent soil cover increases the SOM, SOC, soil N content and microbial and micro-organism activity in the soil (Hobbs et al. 2008). A study done in Brazil showed that by keeping residues and implementing conservation tillage the carbon in the soil increased by 45% with an increase of soil microbial biomass (SMB) of 83% in comparison to CVT and the burning of soil residues (Hobbs et al. 2008). Soil microbial biomass is an indication of below-ground microbial activity which is synonymous with the nutrient cycle for the plant (Hobbs et al. 2008). With continuous tilled soil the SOC levels dropped by 8.2 ton ha^{-1}, but by using conservation tillage and retaining residues the SOC level increased with 3.8 ton ha^{-1} (Hobbs et al. 2008). This was found by Smith (2014) to be relevant even between different no-tillage systems, as the medic-wheat rotation system had a higher SOC than a continuous cropping system because of limited disturbances by the planter in the top 10cm.

One of the benefits of using different crops in rotation is that some deep rooted crops acts as a natural plough (Hobbs et al. 2008). Under CA there is also an increase in micro-organisms, earthworms and arthropods which helps with tillage as well (Hobbs et al. 2008). CT damages these natural methods of tillage. It decreases the germination of some annual plants like medics as well, because of the deep burial of the seeds (Kotzé 1999). By continuously implementing conventional methods of tillage there is an increase in soil erosion. A study done in Paraguay showed that erosion caused by CT was 46.5 ton ha^{-1} while with conservational tillage it was merely 0.1ton ha^{-1} (Hobbs et al. 2008).The same trend was found by Fowler and Rockstrom (2001) where erosion from NT was 0.5 ton ha^{-1} compared to the 9.5 ton ha^{-1} of mouldboard ploughs . By implementing conservation tillage the loss of soil was 84-90 % less than that of CT (Fowler and Rockstrom 2001).

Machinery repair and fuel cost are lower in CA because of the decreased usage of machinery and conservation tillage practices (Kassam et al. 2012). With the burning of fossil fuels, large quantities of carbon dioxide (CO_2) are discharge into the atmosphere (Farooq et al. 2011). The CO_2 is one of the greatest contributors to climate change which can cause unpredicted changes in environments. The lower amount of fuel used in conservation tillage makes it more environmental friendly than conventional methods (Fowler and Rockstrom 2001). In CA systems less fertiliser and pesticides are used, which saves fuel consumption and in addition, causing less runoff of fertiliser into rivers and dams, helping the natural ecosystem to recover. The reduced use of tillage implements and seed bed preparations improves time management of operations. CT delays the time of planting which can cause a penalty in yield, while conservation tillage does not have this penalty (Hobbs et al. 2008).

2.4.2.3 Rotations

For the successful implementation of CA, different annual crops need to be used in rotation with each other, with inclusion of a legume being beneficial (Kassam et al. 2012). Legumes are especially important to rotations because of its N fixation ability. N fixation is when atmospheric N is converted into a form of N which is available to the plant to use, which is usually ammonia (El Msehli et al. 2011). This can be done through lightning or legumes. Legume plants in the presence of *Rhizobiaceae* are able to fix N. The Rhizobium bacteria can be found in the roots of medics and forms nodules (Long 1996). It is in these nodules that the transition from atmospheric N to available nitrogen for the plant takes place. A healthy nodule when cut open will show a pink fluid substance. Great temperature fluctuations and drought has a negative influence on the N fixation effect of the Rhizobium bacteria, but the tolerance to these effects differs between rhizobium strains (Kotzé 1990; Gil-Quintana et al. 2013). Thus with the appropriate strain of rhizobium for a specific legume plant in a particular environment, the optimum result will be concluded. For a thriving symbiosis between rhizobium and legumes, the plant must be healthy, meaning the plant must produce enough nutrients for itself and the bacteria (Long 1996). The environment plays an enormous role for optimum growth of both organisms. Legumes typically bind around 25 kg N per ton dry material produced of which 25% is available for non-legume plants and the rest is captured in the soil (McDonald et al. 2003). Interrante et al. (2011) found that annual medic pastures can fix between 100 and 200 tons of N per hectare per year. This is a low-cost and more sustainable way of N introduction (De Ron et al. 2013). A study done by Strauss et al. (2012) found that by incorporating a legume in a rotation, the average wheat yield following the legume improved from 1800 kg ha^{-1} in monoculture to 3200 kg ha^{-1}. Similar increases were also found by Stevenson and Kessel (1996) where the barley and wheat yield increases by 20% following a legume year. Legumes can also be incorporated as a pasture in rotation systems because of its high protein value which can be utilised by animals. This helps with the spread of capital on the farm, lowering the risk. Legumes can be used as a green manure cover crop as well, which improves the organic matter, increases soil N, smothers weeds and improves water holding capacity of the soil.

Weeds can be controlled in rotation systems in the legume year through using different herbicides and/or animals (van Heerden 2013). It is crucial to control the grass weeds during the legume year, because it competes with the cereal crop the following year and can be a vector for diseases (van Heerden 2013). By alternating plants that are not from the same species, diseases and pests can be controlled through breaking the disease cycle (Thiombiano and Meshack 2009). Stevenson and Kessel (1996) found that in a pea-wheat rotation system, the root rot in the wheat year decreased by 3.2 times compared to wheat monoculture. By incorporating crops with allelochemicals in rotations pest, weeds and pathogens can occasionally be controlled, resulting in less use of herbicides and pesticides, improving the profit margin (Ferreira and Reinhardt 2010; Kassam et al. 2012).

Rotation improves the microbial activity in the soil, which helps keep pathogenic organism and pests under control (Hobbs et al. 2008). By using crops with different rooting systems the soil quality can be improved, there's a better distribution of nutrients in the soil levels because of deep roots bringing up the nutrients from below and an increase in the soil biological activity and diversity. Different rooting systems also improve root exploration in the soil and increase macro-pores in the soil (Hobbs et al. 2008). This enhances water infiltration to deeper depths. For example canola can act as a natural plough while wild mustard acts as a pest repellent.

In Table 2.2 the effect of the three principles, with addition of legumes in rotation, can be seen. We can see that CA can only be as close to a complete agro-ecosystem when all the principles are implemented.

Table 2.2: The interaction between the principles needed for CA. (adapted from Kassam et al. 2012)

Relevant features of agro-ecosystem	**CA principles**			
	Permanent soil cover	Conservation tillage	Crop rotations	Legumes in rotation
Reduce evaporation of water from soil surface	✓	✓		
Reduce evaporation of water from upper soil levels	✓	✓		
Minimise oxidation of SOM		✓		
Minimise temperature fluctuations at soil surface	✓	✓		
Maintain regular supply of organic matter as substrate for soil organisms' activity	✓	✓	✓	✓
Increase, maintain nitrogen levels in root-zone	✓	✓	✓	✓
Maximise water infiltration, minimise runoff	✓	✓		
Minimise erosion of wind and water	✓	✓		✓
Minimise weeds	✓	✓	✓	✓
Increase rate of biomass production	✓	✓	✓	✓
Reduce labour input	✓	✓		
Reduce fuel-energy input		✓	✓	✓
Recycle nutrients	✓	✓	✓	✓
Reduce pest-pressure of pathogens			✓	
Re-build damaged soil conditions and dynamics	✓	✓	✓	✓

2.4.3 CA in the Western Cape province

Farmers in the Western Cape started implementing CA only recently in terms of international CA history. The Western Cape is a region with a short growing season in the rainy winter months of May to September and usually continuous drought from November to March. This is the main trend as there are differences between areas within the Western Cape. In the past when the first rains fell in April/May and the soil was wet enough to plant, the farmers used to till the soil before planting, which lead to a delay in the time of planting which occasionally negatively affected the yield (Giller et al. 2009). Tillage with monoculture cropping and baling of residues resulted in degradation of the soils in the area and some farmers went in search of new ways to preserve their soils. They found that CA was an appropriate practice in this semi-arid region of the Western Cape. Climate is changing in the Western Cape and the need to preserve water is crucial. Crop yields vary substantially from year to year with soil temperature and rainfall being some of the influential factors (Farooq et al. 2011). Implementing CA on a full scale basis in the Western Cape region can alleviate these climate challenges by enhancing water preservation. Conservation agriculture is particularly beneficial in lower rainfall years due to its water preservation properties.

Earthworms and different rooting systems cause an increase in biopores when CA is practised, improving water infiltration (Kassam et al. 2012). This water is better held in the soil because of the crop residues (Giller et al. 2009) which acts as a buffer for water evaporation and extreme temperature fluctuations (Kassam et al. 2012).This improves crop yields in drier years when water is the limiting factor. Although crop residue retention increases the risk of diseases and pest outbreaks, the improved water filtration and availability overshadow the negative factors (Farooq et al. 2011). In some parts there are still farmers practising the burning of crop residues to control weeds and pests. By doing this the organic matter, water holding benefits, erosion reduction and all the other benefits of cover residues are discarded. When comparing the burning of crop residues to retaining it, the latter exceeds in benefits. Also when CA is practised correctly weeds can be controlled without burning. Van Heerden (2013) (citing Le Roux et al. 1995) found that by controlling weeds during the pasture year through herbicides and/or animals, there was an 89% decrease in grass weeds during the cereal year, leading to a 34% increase in wheat yield. But still not all CA principles is adopted by the farmers, which is not ‘‘ideal’’ for the benefits that CA has for the farm. This adoption of only certain principles may be due to some labour obligations, limited access to inputs such as cover crop seed or herbicide availability, or inadequate funds for new cash crop varieties or CA implements (Giller et al. 2009). In wetter years CA doesn’t differ in yield from CVT, but preservation of the soil is needed for future generations (Farooq et al. 2011).

2.4.4 Medics in the Western Cape

Medics play an important role in CA agriculture in the Western Cape because of its self-re-establishment and utilisation as a pasture crop (Kotzé et al. 1995). Medics are mostly used as a rotational crop with cereals and canola in the Swartland and Overberg districts. Rotations in the Swartland are mainly short rotation systems with one year medics followed by one year of wheat (Beyers 2001). In the Overberg lucerne (*Medicago sativa)* is the primary forage crop, but must be used in long term rotation systems with cash crops (Swart 1998). Thus the trend in the Overberg was to introduce annual medics in the rotation systems because of the benefits of its annual growing method. This makes medics the primary pasture crop in the Swartland and primary short rotation pasture crop in the Overberg. Van Heerden (2013) found that Santiago, Caliph, Serena and Parabinga were the best adapted cultivars for the Swartland area in the Western Cape. This must be revised because new cultivars were developed since then and needs to be tested in these areas, for example Scimitar can replace Santiago because of its greater production. This mixture of cultivars with different levels of hardseededness results in satisfactory medic production year after year, making it beneficial in rotation systems. The study done by van Heerden (2013) showed that a one year pasture, one year cereal rotation was best suited for medic production in the Western Cape.

Soil preparation for cereals also has an effect on the amount of permeable medic seed in the soil. A deep cultivation result in the burial of seeds leading to lower germination rates (Crawford and Nankivell 1989), but with CA this is not a problem. By using conventional cultivation practices instead of direct seeding, medic re-establishment was poorer due to the germination of grass weeds (van Heerden 2013). Direct seeding of cereals has an effect on the seed coat breakdown of medics because of the scarifying effect. This leads to germination of medic seedlings during the cereal year in rotations. These seedlings usually die before seed production because of the competiveness of the cereals, which can cause a decline in the medic seed bank. Annual medics were found to have a positive influence on the succeeding cereal crop (van Heerden 2013). This is due to the benefits of legumes in rotations such as previously mentioned.

Annual legume pastures can fix from 30 to 160 kg of N per hectare each year (Peoples et al. 2001), while Swart (1998) and Interrante et al. (2011) found that annual medics in the Western Cape can fix up to 200 kg N per ha per year. This N not only replaces the N used by the previous crop in the rotation, but there is extra N available for the next crop in the rotation. It is this extra N which increases the yields of cereals and improves the quality of the cereal (Swart 1998; Strauss et al. 2012). Smith (2014) found a 99% correlation between the soil C and soil N and a 94% correlation between soil C and wheat yields. This tells us that annual legumes such as medics which produce high levels of C and fixates N into the soil, will produce high wheat yields. This was found to be true, as the average wheat yield, at the Langgewens research farm, following medics in the rotation, was 3.2 ton ha^{-1}, while the average yield in a wheat monoculture was only 1.8 ton ha^{-1} (Strauss et al. 2012). There was a trend that showed that less wheat years in the rotation increased the average wheat yields (Strauss et al. 2012). Not only did medics increase the wheat yield, but it was more economical too. Where monoculture of wheat was implemented the gross margin fluctuated greatly between years, for example on Langgewens in 2003 the gross margin for wheat monoculture was -R2 000 (severe drought), while in 2007 it was R8 000 per hectare (Strauss et al. 2011). Not only does monoculture have bigger fluctuations of gross margins between years, but it results in more herbicide resistant weeds and nutrient exhaustion in the soil (Wessels 2001). If medics are included in the rotation a more stable gross margin can be expected. While the gross margin for sheep production remains low in most years, it never went below zero (Strauss et al. 2011). Input costs for pastures are lower than that of cereals. Less fertilizer and pest control is needed for pastures (Strauss et al. 2012).

When medics are used in rotations there is better pest, weed and disease control (Nichols et al. 2006). During the medic year the weeds were better controlled by using different herbicides than that in the cereal year and/or by grazing animals (van Heerden 2013). By having a rotation between medics and cereals the root diseases in the cereal is less the following year. This is because the grass weeds that can carry wheat diseases from the one year to the next are being suppressed by the medics and also eaten by the animals (Swart 1998). Faster germination of medics in the early winter months suppresses weeds better.

Medic pastures plays an important role in the Western Cape for improvement of SOM (Swart 1998). A large component of SOM consists out of C, which is why an increase in C in the soil also leads to an increase in SOM. In a long-term conservation study done at Tygerhoek in the Western Cape, Smith (2014) found that the highest SOC content in the top 30cm of soil was found when medics was in rotation with wheat (15.2 - 18.6 g kg^{-1} in 0-30 cm depth, $P < 0.05$). This was significantly higher than continuous cropping systems (13.3 - 14.1 g kg^{-1} in 0-30 cm depth), permanent pastures (15 g kg^{-1}) and natural vegetated soil (13.2 g kg^{-1}) (Smith 2014). Permanent pasture such as lucerne has a higher root density than that of medics, but the medic plant re-generate every season in which new roots is formed, thus the higher C input in the soil.

Medics have vigorous growth and have a high plant biomass production, resulting in it being a great potential cover crop in the Western Cape. The benefits of a cover crop range from suppressing weeds, reducing erosion, improving soil fertility and increasing water holding capacity (Flower et al. 2012) as previously mentioned. Management of cover crops is essential to maximise the positive effects it has. Medics as cover crop are not accepted by the farming community in the Western Cape because it must replace a main crop in the rotation year (Flower et al. 2012). A study should be done to see if it is economical for farmers in the Western Cape to use medics as cover crop. If is economical to use medics as a cover crop, there may be a mind shift. It is good to know that there’s an increase in medics in short rotation systems in the Western Cape because of all the benefits it has (Nichols et al. 2006). But problems have arisen in the area because of low re-establishment rates and/or production of medics.

2.5 PROBLEMS ASSOCIATED WITH CA

The practise of CA has many benefits but there are some problems associated with CA. There are some restraints for the adoption of CA by the farmers, which lead to farmers only partly adopting CA practices or not at all. As previously mentioned, CA must be practised fully for optimum benefits. A reason for the weak adaptation can be because of the great amount of input the farmer must do before starting CA. There is usually a lack of access to CA implements and very few external inputs for CA (Giller et al. 2009). The farmers are reluctant to invest in a new technology when their performance and yields are reasonable.

2.5.1 Permanent soil cover

With poor management, residues on the soil can increase the incidence of weeds and pests. Weeds especially are the 'Achilles heel' in CA. The costs to control weeds are greater and it requires greater quantities of herbicide than that of conventional practices in the initial phases of CA implementation (Giller et al. 2009). Large quantities of stubble has a beneficial effect on weed suppression however, weeds that grew through the stubbles where considerably bigger (Flower et al. 2012). This is mainly small seeded weeds like annual ryegrass, which can penetrate easily through the residue mat (Farooq et al. 2011). Residues on the top soil acts as a barrier to the herbicide and intercepts it, leading to lower weed control when weeds are in the premature phase (Flower et al. 2012). Herbicides containing the active ingredient Trifluralin (part of the dinitroaniline in group D) can be affected by the residues, with up to 70% being intercepted by the crop residues (Farooq et al. 2011). Weeds receive a lower quantity of herbicide, leading to a potential for resistance of the herbicide. Weed resistance is a major problem in CA, especially when herbicide resistant crop cultivars are being used (Farooq et al. 2011). In underdeveloped countries most of the planting, seeding and weeding is done by hand, while the stronger men usually do the ploughing. By eliminating the ploughing from the equation and by needing more hands for weeding, the work shift to more women and less male workers. In CA practices the time consumed for weeding is more and thus a great importance must be placed on weeding.

Pests like snails and isopoda are a re-occurring problem in CA practices in the Overberg and a study should be done to determine which pests increase under CA and if it has any impact on the production. Snails can cause considerable damage to a crop. Snails prefer moist areas and that is why there is an increase in snails under CA because of the high amount of moisture under crop residues (Baral 2012). In the Swartland it was found that the snails have a stunting effect on the plant and not total elimination of the plants (Lombard and Strauss 2014). With a lower plant count there is more space for weeds to germinate which further puts pressure on the cash crop. It is difficult to control these snails under CA practices because in the past the burning of residues and tillage destroyed their habitat, but by using snail bait it can be chemically controlled (Lombard and Strauss 2014).

Hunt et al. (1989) found that it only takes subtle variations in the quantity and quality of light to influence the establishment of soybean seedlings. Poor re-establishment is a problem in CA for some plants which can be caused by different factors such as residue allelopathy (Ferreira and Reinhardt 2010), waterlogged soils caused by poorly drained soils (Giller et al. 2009) and the thickness of the residue mat (Hunt et al. 1989). Poor re-establishment can have a negative effect on the crop yield. A study done by Crawford and Nankivell (1989) found that re-establishment of medics in rotation with wheat and/or barley was worse than that in permanent medic pastures.

The straw of cereals contains allelopathic agents that affect the next crop. Allelopathy from decomposing cereal plant material can inhibit germination and production of annual medics through the release of phytotoxins (Bhadoria 2011). When a minimum tillage system is used the cereal straw, if it rains, has an effect on the next crop (Wu et al. 2001). When the negatively affected next crop is of the same species than the previous year (monoculture) the type of allelopathy is called auto-allelopathy (Wu et al. 2001). For example wheat, oats, and medics cause autotoxicity to its own seedlings when minimum tillage is being used (Ferreira and Reinhardt 2010). Continuously using an allelopathic crop (monoculture) the negative compound can build up in the soil affecting the germination and seedling growth increasingly each year (Kouyaté et al. 2000). Peachey (1993) found that the higher the levels of crop residue, the more the seedlings emergence were influenced. In the experiment conducted by Ferreira and Reinhardt (2010), they found that barley residues reduced the wheat yield the following year, and that medic, wheat and barley residues decreased medic yields. The same trend was found by Wu et al. (2001) in that the residues of wheat had a negative effect on the yield of soybeans. Cereal residues in particular have a greater effect on legumes than the other way around (Wu et al. 2001).

Conservation agriculture also causes soil nutrient immobilization in the short term (Giller et al. 2009). When using only cereals in rotations, the N fertiliser needs to be increased for equivalent yields in CA as in conventional agriculture (Giller et al. 2009). This is due to the high C: N ration in cereal residues which result in a net immobilisation of N minerals in the soil (Giller et al. 2009). The C: N ratio of plant material affects the rate at which the materials decompose and releases N in the soil (Flower et al. 2012). Legumes generally have a low C: N ratio, meaning enhanced microbial activity, faster decomposition of plant material and faster N introduction into the soil (Smith 2014). Up to 40% of the N in wheat shoots, in their first year, is from the below-ground-biomass-N of legumes, and 15% in the consequent year (Flower et al. 2012). That is why it is important to introduce a legume in the rotation.

There can be a direct influence on the economy for the farmer. Usually farmers sold the residues as animal feed for extra income which is now lost in CA (Giller et al. 2009). Animals on stubbles must also be kept to a minimum or completely eliminated to get all the benefits of CA, which causes constraints for some farmers (FAO 2010).

2.5.2 Minimal soil disturbance

With CA the residues can obstruct the implement during the direct seeding of crops. This phenomenon can be caused by using the wrong seeding implement. Conservation tillage practices can cause soil compaction over time, especially on coarse-textured soils (Giller et al. 2009). Soil compaction can cause a reduction in crop yield if it is over 2 MPa in silt loam soils (Farooq et al. 2011). Conservation Agriculture can increase the penetration resistance in the top 5 cm of the soil by 0.3 -1.6 MPa, which is still under the 2 MPa threshold (Farooq et al. 2011). In drier areas soils are more prone to compaction with CT and must be ripped before CA is implemented (Hobbs et al. 2008). This is also evident in soils with low-stability aggregates (Hobbs et al. 2008). Animals have a big effect on the increased compaction of the soil if managed incorrectly. Occasional tillage, once every 4 years, may reduce soil compaction and control weed which leads to loss in yield and higher expenses.

2.5.3 Rotations

The problem with CA rotations for the farmer is that he must take away one of his cash crops that year and replace it with a legume or cover crop. Although the income in the immediate future is lower (Farooq et al. 2011), in the long run the income from the cash crop is greater, because of the benefits of legumes and cover crops. To start CA is difficult because new machinery is needed for different tasks on the farm, from a new planter to different implements to harvest the different crops (Thiombiano and Meshack 2009; FAO 2010). Planting implements must be able to plant through dense residues as well.

Farmers must begin with a small area of land on the farm when considering converting to CA. The farmer must make sure he obtains the right knowledge of CA through research and from other CA farmers. A good crop rotation needs to be in place for a CA system to work, especially when crops in rotation can cause negative effects on the next crop. For example the allelopathic effect if only cereals are planted year after year can cause a lower yield and an increase in diseases (Kouyaté et al. 2000).

When annual legumes are included in a rotation, the re-establishment is of great importance. When re-establishment is poor the benefits of rotation and legumes does not have an effect. It was found in the Western Cape that the re-establishment of annual medic species was on the decline over the past years (van Heerden 2013). The reasons for this could be that the current medic cultivars used is not well adapted to the area or that there are a lower amount of disturbance to the soil. The other explanation can be because of the greater amount of residues on the top soil which can cause an increase in pests, weeds and diseases if not managed correctly.

The reason for this study is therefore to determine if varying degrees of residue cover and the type of residue has an effect on the re-establishment of medics within the CA crop rotation system. In order to have a full understanding of the effect of CA principles on pasture production of annual legume pastures, the effect of crop residues on the establishment of these pastures should be included.

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CHAPTER 3

FIELD ASSESSMENT OF VARYING DEGREES OF PLANT RESIDUE COVER ON *MEDICAGO* SPP. PASTURE RE-ESTABLISHMENT AND PRODUCTION

3.1 INTRODUCTION

In the Overberg district of South Africa farmers have noticed variation, usually a decrease, of annual medic re-establishment and production year on year (van Heerden 2013). This trend started after conservation agriculture (CA) practices were implemented for a few years. This caused management complications (especially livestock management which consist mainly of sheep) on the farm, as annual medics is one of the primary forage crops in the area. Famers shifted away from medics as a result, losing the beneficial effects on the soil. Benefits such as the ability to fix N into the soil for subsequent crops to use (El Msehli et al. 2011; Angus et al. 2012; Kassam et al. 2012), increasing the production as well as gross margin of the following crop (Stevenson and Kessel 1996; Strauss et al. 2012), controlling the grass weed population during the pasture year (van Heerden 2013), increasing the organic fraction in the soil (Hobbs et al. 2008; Smith 2014) and also breaking the disease and pest cycles present when cereal monoculture is used (Stevenson and Kessel 1996; Thiombiano et al. 2009).

Since the decline in re-establishment and reduced production of annual medics occurred after the introduction of CA practices in the Overberg, the solution might be found in the effects of the different aspects of CA practices. The three main principles of CA includes a permanent organic soil cover from cover crops or dead residues from previous crops, continuous minimum or no soil disturbance through mechanical implements and a variety of crops in rotation with each other (Hobbs et al. 2008; Giller et al. 2009; Thiombiano et al. 2009; FAO 2010).

While annual medics re-establish year on year after only being planted once, the cultivation of crops in the previous year have an effect on the re-establishment. Cultivation practices that buried the medic seeds deeper than 40 mm doubled and even tripled the time to emergence (Kotzé 1999), which could also lead to seedling death, causing a decrease in medic re-establishment (Crawford and Nankivell 1989). Disturbance by CA implements of the soil may not be more than 25% of the soil surface, with bands not wider than 15 cm (Kassam et al. 2012), which limits the burring of annual medic seeds. CA can cause medic seed to lie on top of the soil, resulting in a decrease in germination (Baral 2012).

An acceptable crop rotation needs to be in place for a CA system to work, especially when annual medics are being considered in rotations. Rotation systems where there are too many other crops produced between medic production years causes the seed reserves to become depleted. A study done by Crawford and Nankivell (1989) demonstrated that permanent pastures had the highest annual medic re-establishment and build-up of seed reserves, followed by a medic-cereal rotation, whereas the lowest re-establishment was from a medic-fallow-wheat-barley rotation. Medic cultivars may also influence the inadequate medic re-establishment and reduced production. Hardseeded cultivars, like Robinson, usually become permeable too late in the season, causing lower seed production and reduced build-up of seed reserves; while soft seeded cultivars, like Paragosa, had the highest production in the first year, but after two years of production the cultivar was no longer in the rotation (Crawford and Nankivell 1989). When choosing medic cultivars, the best adapted cultivars to that specific environment and rotation system should be taken in consideration, as this will reduce variation in re-establishment and production.

Ineffective control of pests and insects with poor grazing management strategies control on the residues during the summer months also causes depletion in annual medic seed reserves, leading to a decreased re-establishment and production (van Heerden 2013). Mechanical disturbances of the soil, the wrong rotational system and ineffective pest and insect control combined with inadequate grazing control can be managed to a greater extent, but the negative effects of a permanent soil cover on medics are more difficult to control.

According to the Conservation Technology Information Centre (Giller et al. 2009), for a practice to be classified as CA, at least 30% of the soil surface must be covered with crop residues following the planting action, the ideal being 100% cover. Certain crop residues have an allelopathic effect which causes lower germination rates and/or a decreased yield of the following crop (Peachey 1993; Wu et al., 2001; Ferreira and Reinhardt 2010). Through the increase in crop residue cover due to CA, allelopathy may be the cause for the decrease in medic re-establishment and production in the Overberg district. Ferreira and Reinhardt (2010) found in a study (done at the Tygerhoek research farm at Riviersonderend in the Western Cape) that five tons per hectare residue cover of barley, wheat and annual medic reduced the medic yield of the following year. Abiotic and biotic stresses as well as the age or growth stage of the plant have an influence on the allelochemical content in the residues (Ferreira and Reinhardt 2010). Thus, while allelopathy from residues could have an effect on annual medic re-establishment and production, the variation of abiotic and biotic stresses differ too much to conclude that it is the only factor involved.

A dense residue mat could block seedlings to the extent that it cannot physically get through, leading to lower annual medic re-establishment. However, this dense residue mat improve the water holding capacity of the soil, reducing evaporation and making more moisture available for the plant (Farooq, et al. 2011). This increase in the soil moisture level can lead to an influx in pests like snails, because of the favourable conditions. In the Swartland region of South Africa, it was found that snails have a stunting effect on the plant and not total elimination of the plants (Lombard and Strauss 2014), but could lead to lower production levels of annual medics. Human (2008) also found, at the Tygerhoek research farm, that snails caused greater leaf damage on wheat plants under CA conditions.

Another possible negative effect may be physical obstruction of light from the residues which decreases the emergence of seedlings (Hunt et al. 1989). Not only does the residue mat obstruct the incoming light, but it could initiate temperature fluctuations as residue levels vary (Kruidhof et al. 2008). Xing et al. (2012) discovered that when residues were left on the soil surface the fluctuation between minimum and maximum temperatures in the soil was less, while the fluctuation was significantly greater when no residues were left on the soil surface. A more stable soil temperature environment could be found by leaving crop residue on the soil surface which may benefit plant growth, but may be detrimental to the breaking of medic seed dormancy. Medics germinate at their optimal between 10-16ºC, but if the temperature fluctuations are insufficient the re-establishment could be affected (Tabatabaie et al. 2007). Tabatabaie et al. (2007) showed that below ground temperatures lower than 5ºC decreased root and leaf dry matter production of annual medics, while temperatures above 20ºC decreased the root dry matter production.

Research on annual medic re-establishment and production is of utmost importance because of the benefits it brings in CA production systems. The aim of this study is therefore to determine the effect of different types and varying degrees of residue cover on annual medics pastures, to determine re-establishment and production and whether it is a contributing factor to the occurrence of weaker performing pastures with CA production systems.

3.2 MATERIAL AND METHODS

3.2.1 Locality and environmental conditions

This study was conducted at the Tygerhoek Research Farm (34° 09' 32" S, 19° 54' 30" E) near Riviersonderend in the Overberg district during 2013 (Western Cape, South Africa). This farming area is dominated by dryland production of wheat, in rotation with barley, oat, medic, canola, lupines and lucerne. According to the Köppen-Geiger climate classification, Riviersonderend is situated in a BSk climate, which means it is an arid climate with a precipitation the same as the steppe biome (250-500 mm of rain) and a cold-arid temperature (Smith 2014).

The average annual rainfall on Tygerhoek is 443 mm with a long-term average daily minimum and maximum temperature of 10.2ºC and 22.4ºC respectively. Table 3.1 shows the average annual rainfall for Tygerhoek the past 7 years (375.4 mm), which is lower than the average long-term rainfall for this area. Table 3.1 also shows that rainfall patterns differ year after year. Rainfall at Tygerhoek mostly occurs in the winter months (April to September), but summer (October to March) rainfall is common with an average distribution of 60% rainfall during the winter and 40% during the summer.

Soils at Tygerhoek are very shallow and may differ significantly from one area to the next. Smith (2014) found that the soil consists of highly weathered shale-derived soil with a depth of 30 - 40 cm and has a loamy texture with high coarse fragments, particles larger than 2 mm. Parent material in the area comprised of Bokkeveld shales (Smith 2014). The farm and experimental trial site have been implementing CA from 2002, with 2013 being the 11th year of CA practices. This site is therefore regarded as ideal for this study, as it usually takes 10 to 20 years before CA practices start to show benefits (Personal communication, JA Strauss, 2014, Western Cape Department of Agriculture).

Environmental conditions at Tygerhoek are not ideal for annual medic production because there is early seasonal rainfall during some years followed by a dry spell before follow up rain. This causes the medics to germinate and then die off, resulting in seed reserve depletion. These ‘false breaks’ of rain during the summer months are detrimental to the seed reserve as well.

Table 3.1 Monthly rainfall on Tygerhoek experimental farm during the period of 2007-2013 showing the difference in rainfall patterns year after year for the past seven years

Monthly rainfall (mm)	Year: 2007	2008	2009	2010	2011	2012	2013	Average	
Apr	31.5	15.7	18.3	11.3	12.6	75.8	20.7	26.6	**Winter months** 214.4 mm
May	56.5	1.7	21.4	24.9	57.1	21.6	28.6	30.3	
Jun	39	23.8	47.4	45.6	51.1	88.3	53.5	49.8	
Jul	70.6	28.4	53.9	43.2	29.7	20.8	31.5	39.7	
Aug	24.4	35.7	27.2	21.9	63.3	73.3	93.2	48.4	
Sep	13.9	23.7	22.7	17.5	3.5	30.5	25.7	19.6	
Oct	51.9	58.7	69	27.4	10.2	117.4	37.6	53.2	**Summer months** 161 mm
Nov	80	143.9	13.6	29.9	26.3	0	113.9	58.2	
Dec	41	0	0	6.7	15	0	0	9.0	
Jan	1	23.7	8.7	0	0	5.5	2.8	6.0	
Feb	15.7	29.1	15.1	17.9	31.5	7	19.1	19.3	
Mar	12.6	8.7	1.6	40.4	16.7	15.9	11.3	15.3	
TOTAL	438.1	393.1	298.9	286.7	317	456.1	437.9	375.4	

3.2.2 Agronomical Practices

Crops are planted during May at Tygerhoek following sufficient rainfall, and harvest is from mid-October to November, making it a winter grain production area. The annual medic cultivars planted in 2002 were Santiago (*Medicago polymorpha)*, Sephi (*M. truncatula*) and Paraggio (*M. truncatula*) after which it was not re-planted and re-establishment took place year on year by itself. In 2013 the annual medics began to re-establish itself during April and May. The medic camps were grazed by sheep throughout the year in rotation with cereal stubble. The cereal stubble that forms part of the cropping system were utilised when medic production was low during the initial re-establishment and during the seed production phase. No fertiliser was applied to the re-establishing pastures.

Before medic re-establishment, fields were sprayed with Roundup® (active ingredient glyphosate), 2.4 D Amine® (active ingredient 2.4 D dimethylamine) and Li700® (Table 3.2). Roundup is a water soluble non-selective post emergence herbicide while 2.4 D Amine is a selective broadleaf herbicide. Li700 is a surfactant which binds to the herbicide and allows effective penetration into leafs of weed, causing greater damage and improved weed control. Spraying before medic re-establishment is done to improve competitiveness of annual medics later in the season. After annual medic seed production the crop was "topped" by spraying Roundup Turbo® to prevent further growth and to control weeds which was about to set seed (Table 3.2). Some of the fields needed an extra spraying late in the year because of delayed rains which caused a surge in weed production (Table 3.2). Glygran SG® (active ingredient glyphosate) was used as a water soluble non-selective post emergence herbicide. Garlon® (active ingredient triclopyr) is a broad-spectrum broadleaf weed killer with 2.4 D Amine a selective broadleaf herbicide.

Table 3.2: Herbicide application during annual medic year at Tygerhoek during 2013

Date	Action	Rate/Ha
2013/02/01	Spray Roundup®	3 Kg
"	2.4 D Amine®	1 L
"	Li700®	0.2 L
2013/10/01	Spray Roundup Turbo®	1 L
2013/12/13	Spray Glygran 710®	1 Kg
"	2.4 D Amine®	0.5 L
"	Garlon®	0.5 L

3.2.3 Experimental design and treatment

The re-establishment and production of annual medics was recorded following different cereal crops as well as following on a medic production year. Varying degrees of residues of each of the previous crops were included in the measurements. The different crops on which medics was left to re-establish were wheat (WM), barley (BM), oats (OM) and medics (MM). The letters in brackets refer to the sequence of the crops and pasture, with WM denoting a medic (M) production year following on a wheat (W) production year (WM). Five different residue cover percentages (100%, 75%, 50%, 25% and 0%, thus 5 treatments) (Figure 3.1) were placed on the soil surface from each previous crop, except MM. The residue left from the previous medic production season was not altered because of the low amount of residue left after grazing. The WM treatment was replicated eight times, BM was replicated six times, OM was replicated four times and MM was replicated eight times. The reason for the difference in replications was due to the layout of the long-term crop rotation trial and the different crop rotation systems tested. In each of the replicates of the different cropping sequences a 5 m x1 m exclosure (Figure 3.1), which was divided into five 1 m x 1 m blocks, one block for each of the different treatments, were erected. The treatments (the five different residue cover percentages) were allocated randomly within each exclosure. Soil temperature and soil moisture were measured in five of the wheat following medic treatments, using continuous logging soil probes. One probe was allocated to each of the five WM residue cover percentages.

Figure 3.1: The 5 m x1 m exclosure (left) within which residues were manipulated to establish the five different treatment percentages (right)

3.2.4 Measurements, data collection and data analysis

In February 2013, 26 exclosures were erected at Tygerhoek research farm and were divided into five treatments in each exclosure except the MM exclosures. The medic residues were left unchanged because of the low amount of annual medic residues available during the MM production year. Exclosures were erected to keep out sheep during the duration of the trail. Residue percentage for the different treatments (WM, BM and OM) was measured at the end of February using the line-transect method (Shelton *et al.* 2009). The line-transect method involves a measuring tape which is placed at

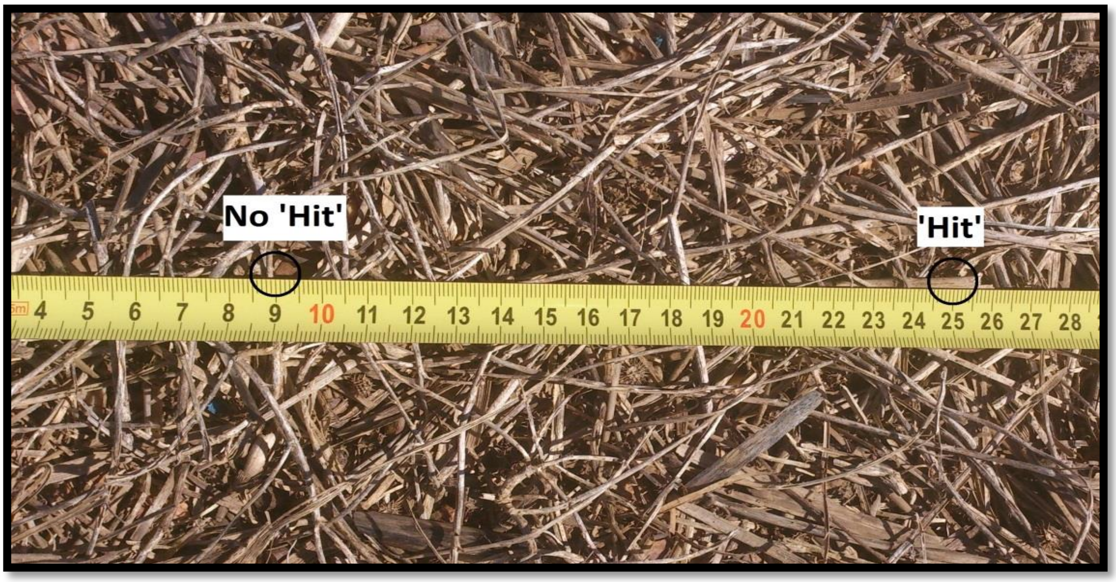

Figure 3.2: The line-transect method explaining a 'hit" (residue underneath) and no "hit" (no residue underneath

a 45° angle across each treatment within a cage. For every 1 cm, at the precise point under the black marking on the tape, a 'hit' is counted when a piece of residue is directly underneath it (Figure 3.2). For a piece of residue to be counted as a 'hit', it must be larger than 2 mm x 2 mm. At each treatment a count out of 100 is done to determine a percentage cover out of 100%. For example, the residue count for a wheat treatment was 52 'hits' out of a 100, giving a 52% residue cover to the specific plot. Following residue percentage determination of each treatment plot, five plots of WM, BM and OM residues were weighed with a portable scale. The mass of the residues within each treatment plot of each different crop was then correlated with the percentage cover, and from there the amount of residues needed for each treatment was determined and applied to create the needed cover percentage (Table 3.3).

Table 3.3: Mass of different residue types at different cover percentages calculated for a square meter on the field in 2013

Residue type	Percentage cover (%)	Residue weight (g)
WM	100	888.65
	75	666.49
	50	444.33
	25	222.16
BM	100	858.66
	75	644
	50	429.33
	25	214.66
OM	100	924.06
	75	693.05
	50	465.03
	25	231.02

The mass varied between the different residue types due to the inherent difference of the physical properties. Residues inside the exclosure were adjusted to the specific treatment in the plot i.e. 100%, 75%, 50%, 25% and 0%. Calculations of all percentage residue cover of the different plant residues can be seen in the Appendix (Pg. 101-102). Calculations of percentage cover were done by taken five random square meter plots on the field and determining the percentage cover. Then the residues of the square meter are weighed, which gives the percentage cover a specific weight correlated to it. By taking the five replicas of residue weight and cover percentage of each crop, the different treatment weights of each crop can be determined.

On the 2nd of May 2013 five continuous logging soil moisture probes were installed into the different residue treatments of wheat. Holes where excavated 40 cm deep in the soil in which the probes were placed. Slurry (a mixture of soil and water) was poured in the hole for optimum connection between probe and soil, which is critical for accurate results. Probes were placed in the hole and data was obtained bi-weekly through a handheld data logger till the 4th of December. Data which was collected included temperature and moisture at 10 cm, 20 cm, 30 cm and 40 cm depths (one probe per percentage wheat cover).

The first plant count was conducted on the 4th of April in a 0.5 m x 0.5 m steel frame. The steel frame was allocated randomly inside every treatment plot (130 plots) and the medic seedlings were counted. Plants per square meter were calculated for each treatment. The second plant count was conducted during harvest of the medics (2nd week of October). At the end of the season the medic seed bank in the soil was determined in germination trays to calculate the potential medic re-establishment for each camp. Soil was collected by hammering a hollow steel pipe; 4 cm in diameter, 5 cm deep into the soil and 40 cores were pooled for each camp. The pooled soil sample was placed on top of weed-free treated nursery bark in germination trays. Trays were kept moist under a shaded cloth after which the medic plants were counted. The number of annual medic plants in the trays (converted to plants per square meter) were used as a comparison as the potential of medics at that specific plot. Re-establishment was calculated using the following formula:

$$\frac{Medic\ \alpha\ (plants\ m^{-2})}{Medic\ \beta\ (plants\ m^{-2})} \times 100$$

Where Medic α is the actual medic counts (second plant count) obtained in the treatment plots and Medic β is the medic plant count per square meter obtained from the seedling trays.

Harvest of the annual medics was during the 2nd week of October as described earlier. All the plants in the frame were harvested and put into paper bags. Plants were harvested at the base of the plant and annual medics and weeds fractions separated. All plant material from each treatment plot was oven dried at 60 °C for 72 hours and dry weight recorded. Weighed material of annual medics and weeds were converted to production per hectare. This is the annual production of annual medics referred to in the manuscript.

A Latin square design was used for the plots (Appendix). Data was analysed through *Satistica 11* using ANOVA and means comparison ($P<0.05$) using Fisher's least significant-difference test.

3.3 RESULTS AND DISCUSSIONS

3.3.1 Medic plant count and re-establishment

Results

There were no significant interaction between residue type and residue cover percentage and results must be looked at separately. The residue cover percentage results are from all the different residue types combined. Annual medic plant counts per square meter were significantly reduced by barley (47 plants m^{-2}), oat (35 plants m^{-2}) and medic (16 plants m^{-2}) residues compared to wheat (85 plants m^{-2}) residues (Table 3.4), with MM having the lowest count.

Annual medics had the highest plant count at 0% (98 plants m^{-2}) residue cover although not significantly higher than 25%, followed by 25% (69 plants m^{-2}), 50% (58 plants m^{-2}), 75% (53 plants m^{-2}) and 100% (27 plants m^{-2}) (Table 3.4). Therefore residue covers from 50% to 100% significantly reduced medic plant count.

Table 3.4: Annual medic plant count (plants m^{-2}) following different residue types and percentage cover at Tygerhoek during 2013

		Medic plant count (plants m^{-2})
Residue type	Wheat	85a*
	Barley	47b
	Oats	35bc
	Medic	16c
Percentage Residue Cover	0%	98a
	25%	69ab
	50%	58bc
	75%	53bc
	100%	27c

*Values followed by the same letter in each parameter do not differ at p = 0.05

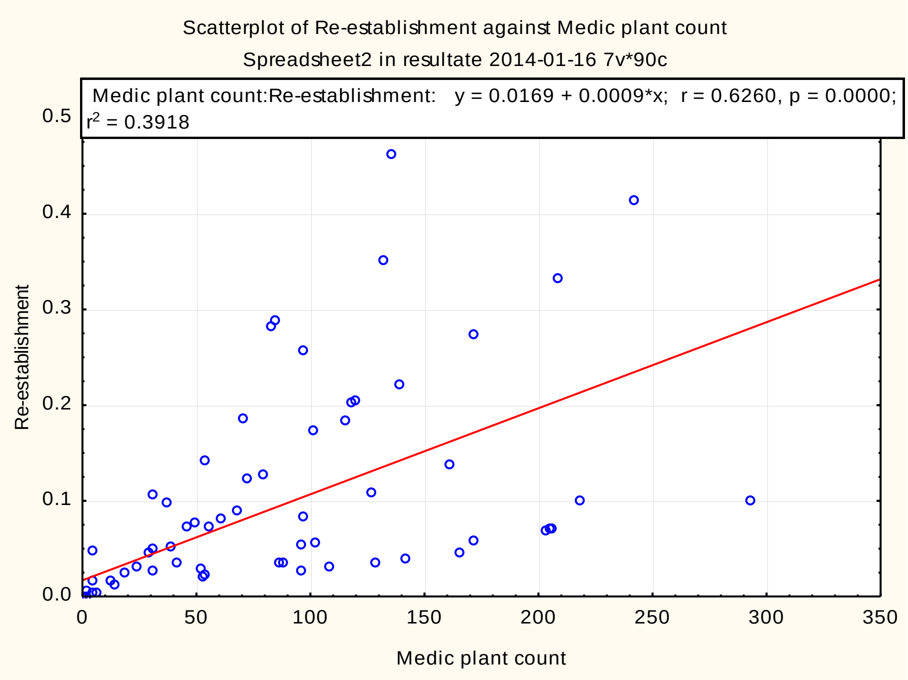

Figure 3.3: Correlation between annual medic plant count m^{-2} and re-establishment.

There were a positive correlation (r = + 0.63) between annual medic plant count at harvest and annual medic re-establishment. As the medic plant count increases, so does the percentage medic re-establishment (Y = 0.0169 + 0.0009X) (Figure 3.3).

Table 3.5: Annual medic re-establishment (%) following different residue types and percentage cover at Tygerhoek during 2013

		Medic re-establishment (%)
Residue type	Wheat	11a
	Barley	4b
	Oats	4b
	Medic	6b
Percentage Residue Cover	0%	12a
	25%	9ab
	50%	7ab
	75%	6ab
	100%	2b

*Values followed by the same letter in each parameter do not differ at p = 0.05

Re-establishment of annual medic plants under wheat residues (11%) was significantly better than re-establishment under medic (6%), oat (4%) and barley (4%) residues (Table 3.5). Re-establishment of annual medics under a 100% residue cover (2%) was significantly less than at 0% (12%) residue cover, while the 25% (9%), 50% (7%), 75% (6%) did not differ significantly from 0% and 100% (Table 3.5). The different percentage residue cover consist out of all the residue types together.

Discussion

Annual medic second plant count and re-establishment had a positive linear correlation to each other. A prominent annual medic pasture establishment in the Western Cape will exceed 600 plants m^{-2}, but the acceptable level is between 200 and 300 plants (van Heerden 2013).When annual medics sward density falls below 78 plants m^{-2}, the seed production will not be enough to sustain an efficient cereal/medic rotation system (Kotzé 1999). A total of at least 700 kg seed ha^{-1} must be produced for a successful pasture re-establishment the following year (Puckridge and French et al., 1983). Crawford and Nankivell (1989) found that *M. truncatula* cv. Cyprus average re-establishment was 30.5% in a BM rotation system and 42.5% in a continuous pasture system over a 7 year period. Van Heerden (2013) found that the average re-establishment of annual medics in the Western Cape area was 20.5% which could be used as comparison to the current study. Most of the annual medic plant counts were below the sustainable level of 78 plants m^{-2}, except the plant counts following a wheat production year and 0% residue cover. All the re-establishments in the trials were way below the average for the Western Cape.

One of the reasons for the overall low plant count and re-establishment is the overall survivability of the medic germinated plants. Irregular rainfall patterns are a common phenomenon in the Overberg, with rainfall more evenly spread throughout the year. ‘False breaks’ of rain during the late summer early autumn months cause a percentage of the annual medic seeds to germinate, lowering the amount of seed available in the seed bank (van Heerden 2013). Five out of the last seven years on Tygerhoek had ‘false breaks’ of rain during the summer measuring more than 50 mm per month (Table 3.1). Early winter rainfall followed by extended dry periods caused medic seed to germinate and then die off, for example during 2012 (Table 3.6).

The main factor which contributed to the overall low plant count was the high weed pressure. Weeds were not fully controlled after the early season rainfall and directly competed with medic seedlings. The high grass weed pressure could have caused medic seedling death early in the season because of faster growth. Grass weeds, penetrates more easily through the residue mat than other weeds (Farooq et al. 2011).

The decrease in plant count and re-establishment of annual medics as the residue percentage increases was expected (Peachey 1993). At the 100% cover the re-establishment was significantly worse than the 0% cover percentages. Large amounts of residues act as a barrier between the soil and the environment and therefore an increase in residue increases the barrier thickness which lowers the annual medic re-establishment. This was noted by Ferreira and Reinhardt (2010) in their study and caused a decrease in re-establishment. The dense mat at 100% residue cover of the soil may have caused variation in quantity and quality of light, which could have affected the re-establishment of annual medics (Hunt et al. 1989). With the increase in residue cover and the obstruction of sun light, there are less temperature fluctuations in the top soil during the medic germination period (Xing et al. 2012), which is detrimental to breaking the dormancy of medic seeds. This can be another reason why the re-establishment of the 100% residue cover was significantly lower than that of the rest.

The other possibilities that were not studied, but could have had an effect on the medic plant count and re-establishment were the time of the last planting, management of grazing animals and a double cereal rotation system. The annual medic pastures were last planted during the start of the trail in 2002. The medics re-established every year for 11 years. It is beneficial to replant annual medic pastures every 5-7 years (Personal communication, JA Strauss, 2014, Western Cape Department of Agriculture). Crawford and Nankivell (1989) found that the annual medic plant count in their study after 7 years was 85 plants m^{-2} in permanent medic pastures and 30 plants m^{-2} in BM rotation system, which correlates well with what has been observed in this trial.

Stocking rates of sheep on annual medic pastures should be altered according to the potential production of that year (Michalk and Beale 1976). Stocking rates during the summer months, when seed pods are the main food source, could have influenced the amount of seeds available for re-establishment. The cultivars Sephi and Paraggio planted in 2002 have a low recovery rate (4% survival) after the ingestion of sheep, which could have caused a diminishing effect on these cultivars over the 11 year time frame.

Table 3.6: Rainfall during April, May and June at Tygerhoek (2012)

Month	**Day**	**Rainfall (mm)**
April	1-5	21
	6-10	18.3
	11-15	0
	16-20	0
	21-25	3.8
	26-31	33.7
	Total	**75.8**
May	1-5	11.4
	6-10	0
	11-15	5
	16-20	4.1
	21-25	0
	26-31	1.1
	Total	**21.6**
June	1-5	0
	6-10	48.3
	11-15	4.3
	16-20	21.5
	21-25	7.8
	26-31	6.4
	Total	**88.3**

Cultivation has a positive effect on annual medic germination, because of the scarifying effect which breaks down the hard seed coat (Crawford and Nankivell 1989). The problem is that cultivation of fields where medics are in rotation only occurs during the cash crop production year in CA systems. The effect is that medics germinate during the cash crop year and herbicide application result in seedling death. When the rotation sequence has two cereal years following one another the seedling deaths of two years has a large effect on the reduction of the medic seed bank. Deep cultivation of soils with medic seeds is detrimental to the re-establishment (Puckridge and French et al. 1983). Burying of medic seeds deeper than 40 mm leads to seedling death and a reduced seed bank, resulting in lower future re-establishment (Kotzé 1999).

Cereals have on average high concentrations of allelopathic agents in its residues (Wu et al. 2006) which put annual medic re-establishment under pressure. A study done by Bertholdsson (2004) found that barley material had higher potential for allelopathic activity than that of wheat, which could explain the lower re-establishment of annual medics in BM. Autotoxicity is when the same crop is planted in succession with the residues from the previous year negatively influencing the next year (Wu et al. 2006). This might explain why the MM re-establishment was weaker than in the WM sequence.

It is evident that the annual medic re-establishment after wheat residues and under no residue cover was significantly greater than the rest. The overall medic plant count and re-establishment was not acceptable and re-plant should be priority. Management of weed early in the season is especially important for a good medic plant count and re-establishment.

3.3.2 Medic dry matter production and weed dry matter infestation

Results

A poor positive correlation (r= 0.51) between annual medic re-establishment and production was found. (Y = 0.5858 + 6.3625X) (Figure 3.4).

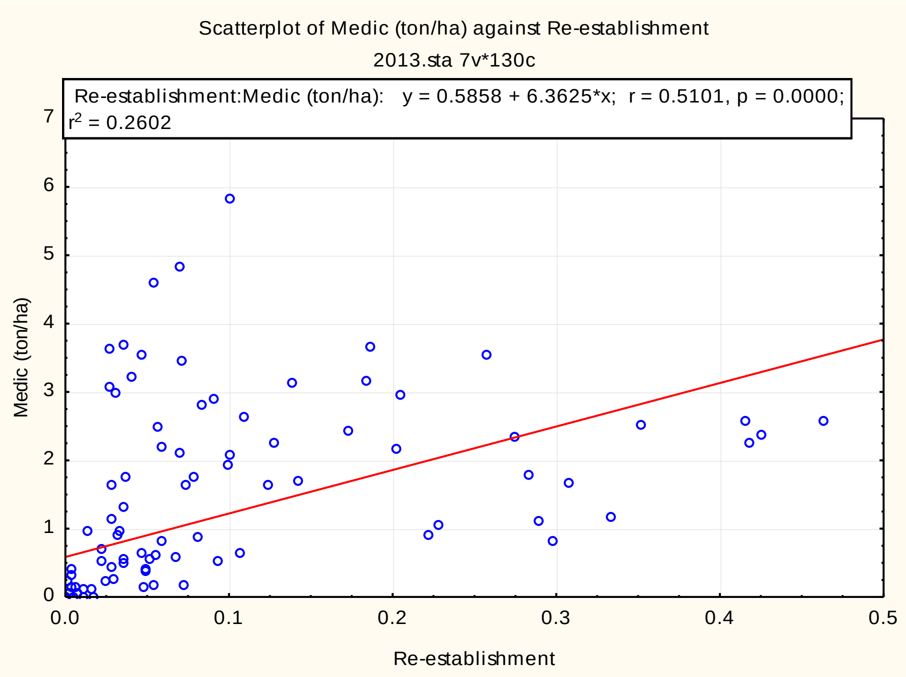

Figure 3.4: Correlation between annual medic re-establishment (%) and dry matter production (ton ha^{-1}).

The production of annual medics in BM (0.88 ton ha^{-1}), OM (0.66 ton ha^{-1}) and MM (0.38 ton ha^{-1}) differ considerably from the production in WM (1.92 ton ha^{-1}) (Table 3.7). Annual medic production showed a declining trend with increasing residue cover as indicated by the 0% (1.69 ton ha^{-1}), 25% (1.35 ton ha^{-1}), 50% (1.29 ton ha^{-1}), 75% (1.25 ton ha^{-1}) and 100% (0.88 ton ha^{-1}) residue levels. Weed infestation in medic pastures had a negative effect (r = -0.33) on the annual medic production (Figure 3.5) (Y = 1.8379 – 0.2352X). Weed dry matter production did not differ between WM (1.67 ton ha^{-1}), MM (1.94 ton ha^{-1}) and BM (2.00 ton ha^{-1}) residue cover, while in the OM (4.09 ton ha^{-1}) sequence weed dry matter was significantly higher (Table 3.8). Percentage residue cover did not influenced weed DM (Table 3.8). The weed dry matter productions at the different % covers were: 0% = 2.70 ton ha^{-1}; 25% = 2.39 ton ha^{-1}; 50% = 2.10 ton ha^{-1}; 75% = 2.09 ton ha^{-1}; 100% = 2.31 ton ha^{-1}. Medic residues were left unchanged, because of the low amount of residues available in the MM year.

Table 3.7: Annual medic production (ton ha^{-1}) following different residue types and percentage cover at Tygerhoek in 2013

		DM Production (ton ha^{-1})
Residue type	Wheat	1.92a*
	Barley	0.88b
	Oats	0.66b
	Medic	0.38b
Percentage Residue Cover	0%	1.69a
	25%	1.35a
	50%	1.29a
	75%	1.25a
	100%	0.88a

*Values followed by the same letter in each parameter do not differ at p = 0.05

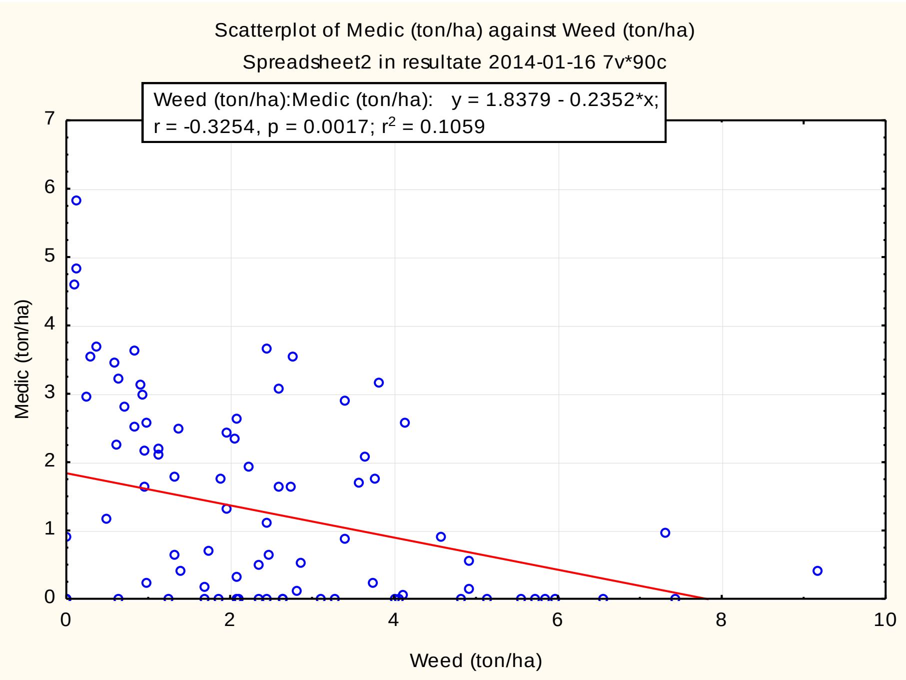

Figure 3.5: Correlation between weed dry matter (ton ha^{-1}) and annual medic dry matter production (ton ha^{-1})

Table 3.8: Weed infestation (ton ha^{-1}) in annual medic pastures following different residue types and percentage cover at Tygerhoek in 2013

		Weed DM (ton ha^{-1})
Residue type	Wheat	1.67b*
	Barley	2b
	Oats	4.09a
	Medic	1.94b
Percentage Residue Cover	0%	2.7a
	25%	2.39a
	50%	2.1a
	75%	2.09a
	100%	2.31a

*Values followed by the same letter in each parameter do not differ at p = 0.05

Discussion

A relative high and constant production of annual medic is important for the maintenance of animals on the farm. Stocking rate should be decided upon by calculating the fodder on offer and adjust stocking rate. Annual medics can produce 6-10 tons of dry matter (DM) ha^{-1} during the winter months under optimal conditions (Kotzé 1999). The average production for the long term on Tygerhoek ranges between 2 to 4 tons per hectare, which is sufficient for a good seed production (Personal communication, JA Strauss, 2014, Western Cape Department of Agriculture). None of the annual medic production in this trial corresponded with those found by Kotzé (1999) and Strauss (Personal communication, 2014, Western Cape Department of Agriculture). The lower production can be directly attributed to the lower levels of re-establishment, as the two are positively correlated to each other, and the high weed pressure.

During the medic pasture year weeds are usually controlled through grazing and by using selective herbicides which cannot be used during the cereal year. The high overall weed infestation could be contributed to the lack of grazing on trial plots and residues which could have affected the herbicide efficiency (Figure 3.6). During the OM production year, oat plants were the main weed which has a high DM mass. Animals would have grazed the oat plants during OM, but could not, which explains the significant difference in weed DM production within this crop sequence. While the cages used in this study kept the sheep from grazing the annual medic pasture, the benefits of grazing were suppressed. Farooq et al. (2011) found that grass weeds grew more easily through weed residues than broadleaves. Grass weeds were the predominant weed in all the camps used in this study (Figure 3.6). This could have been because of grass weed resistance to herbicides or herbicide application during the wrong time. A recent study found that residues can act as a barrier between herbicides and weeds (Flower et al. 2012) and cause an increase in weed pressure in medic pastures.

The different residues had an effect on the medic production and on the re-establishment. Ferreira and Reinhardt (2010) found that medic, barley and wheat residues lowered the production of medic pasture, but did not differ significantly from the control. While allelopathy from residues does not kill plants, it suppresses its growth (Ferreira and Reinhardt 2010).

Other reasons for the low DM production of medics that was not studied may have been the fact that an increase in pests were observed and that a dry spell during May (Table 3.6) may have resulted in moisture stress, which could have caused foliar diseases. An increase in residue cover reduces water evaporation (Farooq et al. 2011) creating more favourable conditions for pests like snails, isopoda and weevils (Puckridge and French et al. 1983; Lombard and Strauss 2014). Pests are a reoccurring problem in early years in CA systems and when not managed could decrease annual medic dry matter production.

Early in the growing season the medics grew profusely and dense creeping pastures were observed. A dense creeping pasture is prone to moisture stress and the medic pastures showed this during the dry spell in May. The moisture stress could have caused the foliar diseases which were observed.

Figure 3.6: High grass weed infestation during 2013 inside exclosure where sheep were kept out

3.3.3 Soil moisture and temperature differences under treatments

Results

The average temperatures and soil moisture for each treatment under wheat were collected from the start of establishment in April till medic harvest.

Table 3.9: Average soil moisture percentage and temperature in top 10cm op the soil, at Tygerhoek, taken from start of medic germination until medic harvest.

Soil probe at 10cm depth		
Wheat residue cover percentage (%)	Average soil moisture (%)	Average soil temperature (°C)
0%	46.65	14.9
25%	34.76	15.6
50%	35.38	14.8
75%	45.12	15
100%	33.36	14.7

Table 3.10: Average soil moisture percentage and temperature in top 10cm op the soil, at Tygerhoek, taken from start of medic germination until medic harvest.

Soil probe at 20cm depth		
Wheat residue cover percentage (%)	Average soil moisture (%)	Average soil temperature (°C)
0%	49.61	14.9
25%	46.81	15.6
50%	41.42	15.5
75%	49.40	15.5
100%	40.88	15.1

Table 3.11: Average soil moisture percentage and temperature in top 10cm op the soil, at Tygerhoek, taken from start of medic germination until medic harvest.

Soil probe at 30cm depth		
Wheat residue cover percentage (%)	Average soil moisture (%)	Average soil temperature (°C)
0%	49.57	14.8
25%	52.70	15.8
50%	43.29	15.4
75%	41.85	15.4
100%	41.52	15.3

Table 3.12: Average soil moisture percentage and temperature in top 40cm op the soil, at Tygerhoek, taken from start of medic germination until medic harvest.

Soil probe at 40cm depth		
Wheat residue cover percentage (%)	Average soil moisture (%)	Average soil temperature (°C)
0%	42.86	15.5
25%	64.86	16.4
50%	58.18	15.6
75%	55.34	15.2
100%	49.86	15.6

Discussion

No significant differences were found between all the soil moistures and soil temperatures at the different depths. The average data over the whole season was taken to see if an increase in soil residue cover would improve water holding capacity of the soil (Giller et al. 2009; Farooq et al. 2011; Sommer et al. 2012) and reduce soil temperatures (Kassam et al. 2012; Xing et al. 2012). There was no clear trend between the percentage wheat cover and soil moisture content and average soil temperature. This is because there was only one replication at each residue cover percentage wheat cover. This might explain the difference in results from the literature. Soils in the area can differ considerably in just a few meters within this trial site. Smith (2014) found that soils at Tygerhoek experimental farm could be an Oakleaf or Glenrosa soil type. Different soils have different water holding capacities at different depths and clay content can affect the temperature at different levels. With the DFM probes being on different areas on the farm, this could explain the variation in results.

3.4 CONCLUSION

For a practice to be classified as CA at least 30% of the soil surface must permanently be covered under residues, the ideal being 100% (Giller et al. 2009). This has lots of benefits like reduced soil erosion (Hobbs et al. 2008; Giller et al. 2009; Farooq et al. 2011), an increase in soil organic matter (Kassam et al. 2012; Smith 2014) and better water holding capacity (Sommer et al. 2012; Smith 2014). Annual medic pastures on the other hand are an important pasture crop in rotation (Kotzé et al., 1995), it fixes N to the soil (Kassam et al. 2012; McDonald et al. 2003) which in turn increase the yield of the next crop (Stevenson and Kessel 1996; Strauss et al. 2012) and grass weeds can be controlled during the medic pasture year (van Heerden 2013).

Residue type and percentage cover had an effect on annual medic re-establishment and DM production as well as weed infestation. Overall annual medic re-establishment in the trial was lower than that found by Crawford and Nankivell (1989) and van Heerden (2013). Weed infestation was the main reason for the low plant count and weed management should be in place to keep the medic camps weed free. The other possible reason was the last time the medic pastures were re-planted. Annual medic pastures should be re-planted every 5- 7 years, while the medics in this trail was in its 11th year. In this study the highest re-establishment for annual medics, keeping in mind at least 30% of the soil must be covered with residues because of CA practices, was a 75% wheat residue cover. For an annual medic pasture to maintain itself the stocking rates should be altered correctly during the different seasons, weed control should be effective during the medic year through using herbicides or animals and soil disturbance should be kept as low as possible to prevent annual medic germination during the cereal year.

The DM production of annual medics was negatively influenced by weed infestation. The more weeds present in the trail plots, the lower the annual medic production became. This was evident especially when annual medics followed an oat production year, which had the highest weed infestation (volunteer oats counted as weeds) and lowest medic production. Animals were kept off the trial plots, which would have controlled the weeds. Weed infestation did not differ at the different amounts of residues. The annual medic DM production was the highest when medic pastures followed a wheat production year, because of the positive correlation between re-establishment and DM production. It was interesting to find that the amount of residues did not have an effect on the production, thus a producer can strive for 75% to 100% wheat residue cover without it hampering his DM production under CA practices.

Data from this study suggest that medic plant counts and re-establishment was the highest following a wheat production year. While the re-establishment did not differ between 0% cover up to 75% cover. As it is beneficial for CA practises to have higher cover percentages a 75% is preferred. With the positive correlation between re-establishment and DM production of annual medics, the highest DM production of medics was after a wheat production year. Percentage residue cover did not have an effect on medic DM production. The main fact was that weed pressure put the annual medic pasture re-establishment and production under pressure and that the right management practises must be in place to control weeds. It may also be advisable to re-plant medics if plant count is below 78 plants per square meter, but further research needs to be done.

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CHAPTER 4

FIELD ASSESSMENT OF VARYING DEGREES OF PLANT RESIDUE COVER ON *MEDICAGO* SPP. AND *TRIFOLIUM* SPP. PASTURE ESTABLISHMENT AND PRODUCTION FOLLOWING RE-PLANTING

4.1 INTRODUCTION

Unsuccessful re-establishment of annual medic/clover pastures during conservation agricultural (CA) practices caused farmers to move away from including it in rotation systems in the Overberg district of South Africa. This trend is not just observed in South Africa, but is evident in South Australia as well (Angus and Peoples 2012). It is important for annual legume pastures to establish successfully for optimum future re-establishments and production. Benefits of annual pastures are being sacrificed by removing the legume component in the CA systems. Smith (2014) found at the Tygerhoek research farm that a medic/wheat rotation had the highest total SOC level, which also increased the most rapidly since the start of CA practices on the farm in 2002. In the same trial Smith (2014) found a positive relationship between increased C levels and wheat yield. In addition an increase in wheat yields when planted after annual medics was observed (Strauss et al. 2012; Stevenson and Kessel 1996). Not only do annual legumes increase the wheat yield, but the quality of grain improved because of the higher N levels in the soil (Smith 2014). This increase of N in the soil is due to the N fixation ability of annual legumes like medics, which can fix up to 80 kg N per hectare per year (Angus and Peoples 2012). Increased yields and lower application of N fertiliser as well as the introduction of sheep in the rotation systems resulted in a greater, more stable gross margin (Strauss et al. 2012).

Annual legumes such as medics and clovers re-establish every year after being planted just once, but benefits of annual legumes can only be obtained when a reasonable sward is maintained year after year. It is recommended to re-plant annual legume pastures every 5 to 7 years, depending on the plant count (Personal communication, JA Strauss, 2014, Western Cape Department of Agriculture). When the pasture sward density falls below 78 plants m^{-2}, the seed production will not be sufficient for a sustainable cereal/medic rotation system (Kotzé 1999).

To ensure successful establishment of legume pastures an average of 4 to 6 kg ha^{-1} of medic/clover seeds should be planted for a pure annual legume sward or 2-3 kg ha^{-1} medic/clover in combination with grass seeds for a grass/legume mix pasture (Puckridge and French 1983). Pastures are usually sown in combination with grass seeds to prevent bloat in ruminants, which are a common phenomenon in legume pastures (McCartney and Fraser 2010). This is not the case in the Overberg area, with no grasses forming part of the pasture, since most of the new medic and clover cultivars have a much lower bloat risk factor than lucerne (McCartney and Fraser 2010).

It is optimal for medic/clover seeds to be planted at a depth of 10 to 25 mm (Puckridge and French 1983). A depth deeper than 30 mm would cause a longer time for seedlings to emerge, which causes reduced rates of seedling survival (Kotzé 1999). During planting the soil disturbance should not exceed 25% of the designated area with bands not wider than 15 cm to be classified as CA, with low disturbance no-till (NT) or zero-till (ZT) planters (Kassam et al. 2012). No-till is seeding with a narrow knife-pointer (FAO 2010) (Figure 4.1 left) while ZT is seeding with a disc opener (Farooq et al. 2011) (Figure 4.1 right), both being conservation agriculture tillage methods, when soil is left without disturbance from harvest to planting (Botha 2013). Planting of small seeded legumes like annual medics and clovers are exceptionally challenging, especially the calibration of the planter. Adaptions should be made to planters regarding annual legume pastures for example a wheel press at the end to ensure good seed-soil contact (Nair et al. 2006).

It is beneficial to plant different cultivars of annual medics and clovers in combination. This ensures survival rates over a long period of time and since clovers prefer wetter conditions than medics the pasture is more adapted to produce under different levels of available soil moisture. With inconsistent rainfall year on year in the Overberg area, sowing different cultivars should be beneficial, because of different levels of hardseededness and time from emergence till flowering. Higher hardseededness in medics and clovers is beneficial for build-up of the seed reserve in the soil, while lower levels of hard seeds is useful during the initial production year. Longer time from emergence till flowering is beneficial during an extended rainfall period throughout the production season, whereas shorter flowering cultivars would be favoured when rain is not sufficient during the production season (Young et al. 1994).

Seeds should be treated with inoculants (N fixating bacteria, phosphorus-solubilizing bacteria and mycorrhiza) before re-plant, which are live organisms that improve legume plant production (Shabani et al. 2011). All inoculants have an expiry date and must not be used after the used-by date. Annual legumes do not usually require fertiliser during re-establishment, but it is beneficial to supply fertiliser during re-plant.

With the new CA planters the fertiliser is placed beneath the legume pasture seeds during planting, giving it a competitive edge over weeds. Some of the planters used for CA practices in the Overberg are based on other models from around the world, where the environment differs. Using the wrong planter model, which is not adapted to that specific environment, could be detrimental to the medic/clover pasture stand during the initial and future years. Some of the planters do not effectively cut through crop residues from the previous year, resulting in obstruction of the planter and an uneven residue distribution on the land. Most CA planters cause some degree of uneven residue distribution

Figure 4.1: Difference in residue cover between AUSPLOW (left) and disc plough (right) at Riversdal Green Tour day

on the land which may lead to irregular medic/clover pastures establishment. In the planting row of the AUSPLOW there is usually none or few crop residues compared to the disc planter (Figure 4.1). In Chapter 3 it was shown that 100% residue cover caused lower annual medic plant counts per square meter than lower cover percentages. The effect of the type of residue on the plant count during normal re-establishment of medic/clover pastures is also important. It was decided to re-plant the medic/clover pastures since the results from Chapter 3 also indicated that the seedbank of the pastures was too low, following several sub-optimal production years during a trial management meeting. Thus, the question was raised what will the effects of the percentage cover and type of residue on the medic/clover pasture establishment and production following re-planting be?

4.2 MATERIAL AND METHODS

4.2.1 Locality and environmental conditions

Refer to locality and environmental conditions in chapter 3. Information that is included in the material and method in chapter 4 differ from chapter 3.

4.2.2 Agronomical Practices

The annual legume pasture trial plots in 2014 were first sprayed with Glygran 710® (active ingredient glyphosate), Garlon® (active ingredient triclopyr) and 2.4 D Amien® (active ingredient 2.4 D dimethylamine) combination (Table 4.1). Glygran 710 was used as a non-selective post emergence herbicide which is water soluble. Garlon is a broad-spectrum broadleaf weed killer, while 2.4 D Amien a more selective broadleaf herbicide. The field needed to be clear of any broadleaf and grass weeds in preparation for re-plant. The broadleaf herbicide cannot be used just before planting, because it will have an effect on the medic/clover pasture. Paragon® (active ingredient MCPA) was applied just before re-plant of the pasture to lower the competitiveness of broadleaf weeds during the initial growth of medics and clover, which are broadleaves as well (Table 4.1). Paragon® is a post-emergence herbicide which is absorbed through leaves and has a short soil residual activity. It may in favourable conditions have a pre-emergence activity.

Annual medic/clover pastures were planted on the 4th of April (Table 4.1) using an AUSPLOW. The Rûens seed mixture from Agricol was used which consisted of cultivars Jester (*Medicago truncatula*), Cavalier (*M. polymorpha*), Minataro (*Trifolium subterraneum*), Taipan (*T. michelianum*) and Zulu II (*T. vesiculosum*). During planting mono-ammonium phosphate (MAP) fertiliser was placed beneath the seed to provide the pasture with the much needed nutrients (Table 4.1) at the start and Cyperphos® was given as a fungicide. Sluggem® was applied just after re-plant and again on the 24th of April (Table 4.1). Slugs and snails negatively influenced the medic/clover pastures in the area during the previous few years. A month later the pasture was treated with Cysure® (active ingredient imazamox), which is a water soluble herbicide that control grass and broadleaf weeds in legume pastures (Table 4.1). The adjuvant Imiboost® (active ingredient Ammonium sulphate) was added with Cysure® for improved effectivity. During August pastures was treated with a herbicide called Select® (active ingredient clethodim), which control annual grasses in legume pastures (Table 4.1). Herbicides were used in rotation to each other and to previous years, to prevent herbicide resistance from developing in weeds.

Table 4.1: Herbicide actions used on annual legume pastures at specific dates and rates at Tygerhoek during 2014

Date	Action	Rate/Ha
2014/01/31	Spray Glygran®	0.75 Kg
"	2.4 D Amien®	0.5 L
"	Garlon®	0.5 L
2014/04/08	Spray Paragon®	2 L
2014/04/10	Plant Medic/Clover mixture	9 Kg
"	Mono-ammonium phosphate application	100 Kg
"	Spray Cyperphos®	1 L
2014/04/11	Application of Sluggem®	8 kg
2014/04/24	Application of Sluggem®	8 kg
2014/05/29	Spray Cysure®	1.2 L
"	" Imiboost	4 L
2014/08/11	Spray Select	0.8 L

4.2.4 Experimental design and treatment

Refer to experimental design and treatment in chapter 3. The legume pastures were re-planted on fields following a wheat (WM) production year, barley (BM) production year, an oat (OM) production year and a medic pasture (MM) production year. The residues from the previous crop were manipulated into five different treatment levels (100%, 75%, 50%, 25% and 0% cover). A randomised block design was used with four replications for WM (camp 2.5, 2.7, 7.2 and 21.2), BM (camp 2.4, 5.1, 7.3 and 16.4), OM (camp 2.6, 7.1, 16.3 and 21.8) and MM (camp 1.2, 1.3, 4.3 and 4.4) (Figure 4.2). Within every replication a 5x1m cage was allocated, which was divided into five 1x1m plots, with one plot for each treatment (80 treatment plots in total). Replications and treatments were assigned randomly within the different camps of the trial and within cages. Temperatures were taken beneath every treatment weekly.

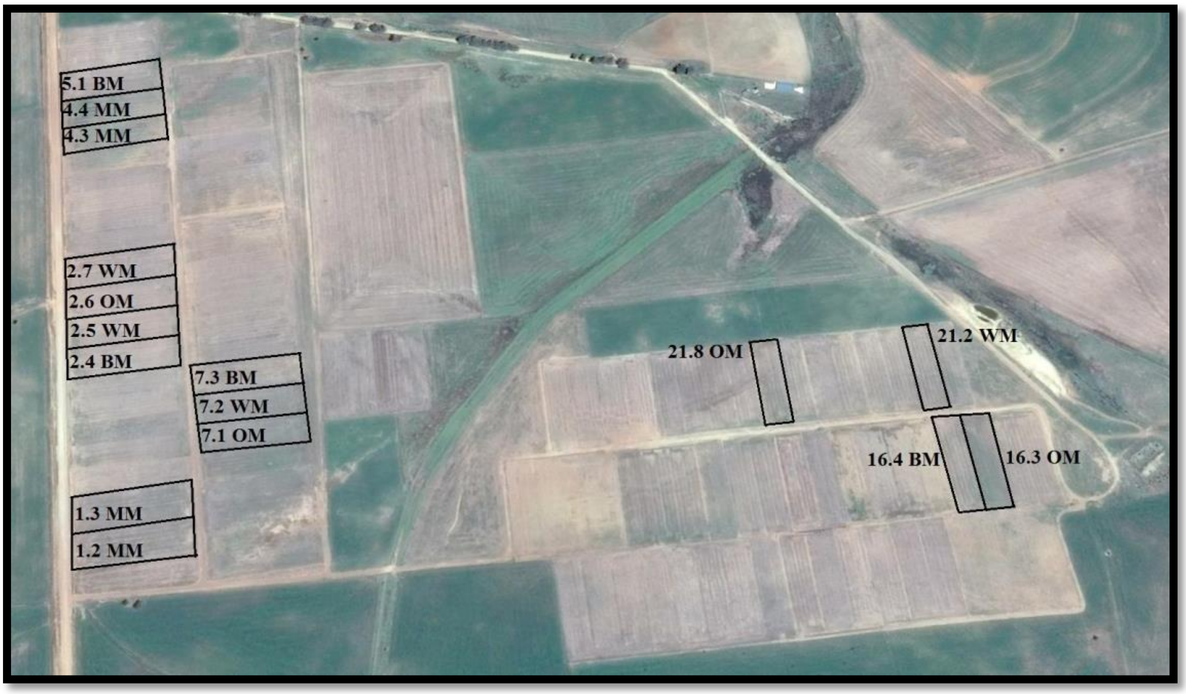

Figure 4.2: Tygerhoek Research Farm experimental layouts for treatment cages

4.2.5 Measurements, Data collection and Data analysis

The 16 cages with the 80 treatment plots were built during January 2014. Treatment plots residues were manipulated to the desirable levels using the estimated weights calculated during 2013 (weights of WM, BM and OM). During the 2013 year the different cover percentages of medic residues could not be calculated because of too few residues available. During 2014 the different residue treatment weights of MM were determined. Table 4.2 shows the weights of each residue treatment under the different residue types. The difference in weight between the different residue types are due to the physical properties of the residues. Calculations for the different percentage cover from the different residue types can be seen in the Appendix (Pg 101-102).

Table 4.2: Weight (g) of different residue types at different cover percentages weighed on the field during 2014 on Tygerhoek

Residue type	Percentage cover (%)	Residue weight (g)
Wheat	100	888.65
	75	666.49
	50	444.33
	25	222.16
Barley	100	858.66
	75	644
	50	429.33
	25	214.66
Oats	100	924.06
	75	693.05
	50	465.03
	25	231.02
Medic/clover	100	821.75
	75	616.31
	50	410.88
	25	205.44

Temperatures were taken weekly by means of a handheld thermometer (Major tech MT605) from before germination until the week before harvest. This was done for every treatment plot. The handheld temperature meter measured the top 5 cm of the soil, through inserting the needle straight into the soil. The first medic/clover pasture plant counts were conducted on the 2nd of July in a 0.5x0.5m steel frame, which was allocated randomly inside every treatment plot. The second plant count was during harvest in the 2nd week of October. The second plant count was used to calculate plants per square meter from the different types of reside under different cover percentages.

The amount of seeds planted per square meter were 0.9 g m^{-2} (9 kg ha^{-1}) with an 80-85% germination percentage, resulting in a potential of 176-187 plants m^{-2} (1 000 seed mass was equal to 4.1g). The medic seed bank was measured at the beginning of February 2014 for each camp and was taken into consideration when determining the potential plant counts as shown in Table 4.3. The medic seed bank was determined for each camp. Production was determined by harvesting the

medic/clover pastures during the 2nd week of October.

Table 4.3: Potential medic/clover establishment (%) following different production years at the different camps on Tygerhoek during 2014

		Potential medic/clover plant count per square meter		
Production year	Camp	Re-planted	Seed bank	Establishment (re-plant + seed bank)
WM	2.5	187	1333	1520
	2.7	187	1167	1354
	7.2	187	1792	1979
	21.2	187	667	854
BM	2.4	187	375	562
	5.1	187	1417	1604
	7.3	187	750	937
	16.4	187	1292	1479
OM	2.6	187	667	854
	7.1	187	1542	1729
	16.3	187	625	812
	21.8	187	125	312
MM	1.2	187	917	1104
	1.3	187	458	645
	4.3	187	167	354
	4.4	187	542	729

4.3 RESULTS AND DISCUSSIONS

4.3.1 Medic/clover plant count and establishment

Results

Plant count between the different residue types did not differ significantly from each other, but MM (168 plants m^{-2}) had tend to be higher than OM (134 plants m^{-2}), BM (132 plants m^{-2}) and WM (131 plants m^{-2}) (Table 4.4).

When all residues were removed from the soil surface (0% cover), the plant count (179 plants m^{-2}) was significantly higher than that of a 50% (136 plants m^{-2}), 75% (131 plants m^{-2}), and 100% (122 plants m^{-2}) cover (Table 4.4). The plant count from the 25% (137 plants m^{-2}) residue cover did not differ significantly from the other cover percentages.

Table 4.4: Annual medic/clover plant count (plants m^{-2}) following different residue types and percentage cover on Tygerhoek during 2014

		Medic plant count (plants m^{-2})
Residue type	Wheat	131a*
	Barley	132a
	Oats	134a
	Medic	168a
Percentage Residue Cover	0%	179a
	25%	137ab
	50%	136b
	75%	131b
	100%	122b

*Values followed by the same letter in each parameter do not differ at p = 0.05

The percentage establishment of annual medic/clovers showed the same trend than that of the plant count, with MM (27%) performing significantly better than OM (18%), BM (13%) and WM (10%) (Table 4.5). WM was significantly lower than OM, while BM did not differ from both. Establishment declined from 21% (at 0% residue cover) to 16% (25% and 50% residue covers), 17% (75% residue cover) and 14% (100% residue cover) respectively but none of these differences were statistically significant (Table 4.5).

Table 4.5: Annual medic/clover establishment (%) following different residue types and percentage cover on Tygerhoek during 2014

		Establishment (%)
Residue type	Wheat	10c*
	Barley	13bc
	Oats	18b
	Medic	27a
Percentage Residue Cover	0%	21a
	25%	16a
	50%	16a
	75%	17a
	100%	14a

*Values followed by the same letter in each parameter do not differ at p = 0.05

Discussion

For a medic/clover pasture to be exceptional in the Western Cape it must exceed 600 plants per square meter, but the average acceptable plant count is between 200 and 300 plants per square meter (van Heerden 2013). When the sward density falls below 78 plants m^{-2}, the seed production will not be sufficient to sustain an effective cereal/pasture crop rotation (Kotzé 1999). Establishment of medic/clover pastures were calculated using the following formula:

$$\frac{Medic\ \alpha\ (plant\ m^{-2})}{Medic\ \beta\ (plant\ m^{-2})} \times 100$$

Where Medic α is the actual medic counts obtained in the treatment plots and Medic β is the potential medic plant count per square meter obtained from the seedling trays as well as the amount of planted medic/clover seeds. Medic/clover pastures were planted on previous years medic pastures and the soil seed bank was incorporated in the calculation to determine percentage establishment. In the Western Cape the establishment found by van Heerden (2013) was 20.5% and was subsequently used as comparison. Establishment from OM, BM and WM did worse than that found by van Heerden (2013) on Western Cape soils, with only MM exceeding van Heerden's (2013) findings. This might be due to a seasonal effect, since the data was generated from a single season. The same downward trend (P>0.05) was observed between percentage establishment and plant count as residue cover percentage increased (except 75%), but there were no statistical difference between the different percentage residue cover and establishment. Only when all the residues were removed from the soil, did the establishment surpass that of van Heerden (2013). This might indicate that a higher seeding rate might be useful when establishing medic/clover pastures under CA conditions.

Plant count and establishment had a positive relationship to each other, with the same trend following annual medic/clover plant count and percentage establishment (data not shown). Differences in significant were observed between plant count and establishment, because of the influence of the medic seed bank. Overall plant count at all treatments was lower than the acceptable level of 200 plants m^{-2} (van Heerden 2013), but it must be remembered that van Heerden's data was generated from trials done in a CT situation. Porqueddu et al. (2000) and Crawford and Nankivell (1989) found that medic/clover pasture plant counts increased following initial establishment for the next two years and then gradually declined until re-planting was needed. This does depend on the grazing management. While the plant count was below the acceptable level at Tygerhoek during 2014, the literature indicates that it could possibly increase during 2015 and 2016. Further research should support this claim. All the medic/clover plant counts in the trials were above the minimum required for a sustainable cereal/pasture rotation (78 plants m^{-2}).

The medic/clover pasture was re-planted on top of previous seasons medic pastures and the potential medic plant counts from the seed bank played a role in the establishment. Table 4.5 shows that MM and 0% cover had higher establishments than that found by van Heerden (2013) in the Western Cape (20.5% establishment).

The data shows that the plant counts did not differ when different types of residues (WM, BM, OM and MM) were left on the soil surface, but the type of residue had an effect on the percentage establishment. The medic/clover plant counts differed when different levels of residue cover (0%, 25%, 50%, 75% and 100%) was left on the soil, but the level of residues had no significant effect on the percentage establishment. This could be because of the different amounts of medic seeds in the seed bank at the different plots (Figure 4.3). The potential medic plants per square meter from the seed bank were the highest in WM (1240), followed by BM (959), OM (740) and MM (521). The rankings were exactly the opposite when percentage establishment was calculated, with MM having the highest establishment (27%), followed by OM (18%), BM (13%) and WM (10%). This could indicate that some of the medic seeds in the seed bank germinated, but died off during the beginning of the year. The medic seed bank was determined at the beginning of February, just after a 'false break' of rain during January (Table 4.6). The 'false break' in combination of high day and night temperature fluctuations caused an increase in permeability of the medic/clover seeds in the soil (Puckridge and French 1983), resulting in the high potential medic/clover plant count from the seed bank. Following seedbank determination in the seedling trays, a dry spell was observed. On the trials the medic seedlings germinated and then died off. Furthermore the application of broadleaf herbicides applied to control summer weeds in the medic/clover camps contributed to the killing of the surviving seedlings. This needed to be done to control the potential heavy weed infestation observed the previous year. A second flush of medics from the seed bank germinated just after planting, because of the scarifying effect from the AUSPLOW (Crawford and Nakivell 1989) as well as normal expected germination at this time. Following planting, another dry period was observed (Table 4.6), leading again to seedlings mortality. A third germination of medics occurred during June when soil temperatures were low, causing slower growth of medic and clover plants. Plant counts in the trial were conducted when pastures looked to be well established at the beginning of July. During the 2014 season drier months were experienced during crucial times of plant growth, not just for the annual pastures, but all crops on Tygerhoek (Table 4.6).

Table 4.6: Monthly rainfall on Tygerhoek experimental farm from January to September during 2014

Month	**Rainfall (mm)**
January	200.9
February	10.5
March	30.3
April	39.6
May	16.7
June	72.5
July	20.4
August	24.9
September	60.6

The underlined months in Table 4.6 just shows the problematic months which caused medic seed bank depletion such as early season rain followed by drier months (January and February) and a dry month after re-plant (May). Cereal residues have an allelopathic effect on the next crop in rotation (Ferreira and Reinhardt 2010), which could be the reason why the plant count decreases as the residue amount increases and why the WM, BM and OM plant count was lower than the MM plant count. Autotoxicity is when the same crop is planted in succession with the residues from the previous year negatively influencing the next production year (Wu et al. 2001), explaining the below average MM plant count. As residues increase on the soil surface, so does the barrier affect that physically block seedlings from establishing (Ferreira and Reinhardt 2010) and receiving decent quality light (Hunt et al. 1989). This results in seedling death and lower establishment under field conditions. The residue barrier is not just a physical barrier, but has an effect on the soil temperature as well. An increase in residue thickness results in a more stable soil temperature during day night temperature fluctuation (Xing et al. 2012). Annual medic/clover seeds need large temperature fluctuations during the summer for its dormancy to break, which means an increase in the residue percentage would cause a lower germination rate and plant count.

4.3.2 Medic/clover dry matter production and weed dry matter infestation

Results

MM had the lowest production (2.8 tons ha^{-1}), while BM (4.8 tons ha^{-1}), OM (4.5 tons ha^{-1}) and WM (4.4 tons ha^{-1}) had the highest production with no significant differences between them (Table 4.7).

The annual medic/clover production did not differ significantly from each other under different levels of residue cover, with 0% (4.2 ton ha^{-1}), 25% (3.9 ton ha^{-1}), 50% (4.3 ton ha^{-1}), 75% (4.2 ton ha^{-1}) and 100% (4.0 ton ha^{-1}) cover having no statistically significant differences in production.

Weed infestation in the 0% (0 ton ha^{-1} which means there were no weeds present in trials), 25%, (0.11 ton ha^{-1}), 50% (0.23 ton ha^{-1}), 75% (0.10 ton ha^{-1}) and 100% (0.29 ton ha^{-1}) residue cover did not differ from each other. While weed infestation in WM (0.23 ton ha^{-1}), BM (0.05 ton ha^{-1}), OM (0.11 ton ha^{-1}) and MM (0.20 ton ha^{-1}) did not differ significantly from each other as well (Table 4.8).

Table 4.7: Annual medic/clover dry matter production (ton ha^{-1}) following different residue types and percentage cover on Tygerhoek during 2014

		DM Production (ton ha^{-1})
Residue type	Wheat	4.4a*
	Barley	4.8a
	Oats	4.5a
	Medic	2.8b
Percentage Residue Cover	0%	4.2a
	25%	3.9a
	50%	4.3a
	75%	4.2a
	100%	4a

*Values followed by the same letter in each parameter do not differ at $p = 0.05$

Table 4.8: Weed dry matter infestation (ton ha^{-1}) following different residue types and percentage cover on Tygerhoek during 2014

		DM Weed infestation (ton ha^{-1})
Residue type	Wheat	0.23a*
	Barley	0.05a
	Oats	0.11a
	Medic	0.2a
Percentage Residue Cover	0%	0a
	25%	0.11 a
	50%	0.23a
	75%	0.1a
	100%	0.29a

*Values followed by the same letter in each parameter do not differ at p = 0.05

Discussion

An exceptional annual medic/clover pasture can produce between 6 to10 tons of dry matter (DM) per hectare during the winter months (Kotzé 1999). The average production for the long term on Tygerhoek is between2 to 4 tons per hectare, which is sufficient for a good seed production (Personal communication, JA Strauss, 2014, Western Cape Department of Agriculture). All of the annual medic/clover productions in this trial were below exceptional production, but for this area and the long-term existing production data it was an excellent season. This might be attributed to the moisture conservation effect of the residue cover during the drier periods and low weed pressure during 2014.

From literature it is expected that the medic/clover pasture production will increase in the following two years due to the possibility of higher seedbank numbers which will be present. Drought during the active growing phase of annual medics will negatively influence the production (Swart 1998). A drought was observed at Tygerhoek during 2014 just after the re-planting of the medic/clover pastures (May) and a drier than usual July and August. Although this was the case it did not hamper overall production as one would expect, but rather a clear indication that the moisture retention due to residue cover (associated with CA production systems) might have helped in maintaining production. The main reason for the better than average DM production was the low weed infestation. Weeds were well managed just after the ‘false break’ of rain (during January, Table 4.6). Although medic seedlings from the seed bank were also eliminated, the newly planted seedlings flourished because of the low weed competition.

The reason for the lower production during the MM pasture year could be due to the fact they were denser than WM, BM and OM at the active growing period (June). It was observed that the MM pastures had moisture stress during July, which could have caused the lower production. Another reason why MM had the lowest production despite the high plant count, may be because of the residue composition. Legumes, like annual medics, has a low carbon to nitrogen ratio (C: N) (19:1), while cereals, like wheat, have a very high C: N (165:1) (Smith 2014). The lower the ratio of C: N, the faster the plant residues decompose. With a cereal/medic rotation, the combination of a slow and fast decomposing rate of residues is positive for microbial build up in the soil (Personal communication, JA Strauss, 2014, Western Cape Department of Agriculture). When a medic production year follows another medic production year, the residues may decompose too fast in the beginning of the season to sustain an adequate microbial level throughout the year, which may results in less nutrients due to less mineralisation and thus availability of nutrients to the plants (especially in the case of two or more consecutive years of legume pastures).

Production under different types of cereal crop residues had no significant difference to each other and was above the average at Tygerhoek. The allelopathic effect of cereal residues can lower the production of medic/clover pastures (Ferreira and Reinhardt 2010), but this effect was not really evident.

With an increase in residues, the conditions become more favourable for pests like weevils and snails (Puckridge and French 1983; Lombard and Strauss 2014). During the previous years at Tygerhoek snails were a major problem, which could have contributed to the yield losses under medics during 2013 (Chapter 3). Pests, especially snails, were correctly managed during 2014 (Table 4.1), with no visible losses. Weed management were exceptionally well during 2014, with really low weed infestations in pastures (Table 4.8). While residues can act as a barrier between herbicides and weeds (Flower et al. 2012), statistically the weed infestation did not differ as residue cover percentage on the top soil increased. Altering the herbicides between years proved to have had a positive effect on the control of weeds, especially grass weeds which were visibly less in 2014 than in 2013. This also ensures no herbicide resistance build up by weeds.

When choosing the best rotation and percentage residue cover after re-plant of annual medic/clover pastures, the CA classification of at least 30% residue cover and 100% cover being the ideal should be taken in consideration (Giller et al. 2009). Residues as well as annual medic/clover pastures have many benefits on the soil health properties, which is why there needs to be a way to incorporate both optimally in the CA system.

4.3.3 Soil temperature differences under treatment levels

Results

Results showed a decrease in temperature as the percentage residue cover increases, but the difference was not significant (Table 4.9).

Table 4.9: Temperature differences in the top 5 cm of the soil under different percentage residue cover on Tygerhoek during 2014

		Temperature (°C)
Percentage Residue Cover	0%	13.9a*
	25%	13.85a
	50%	13.8a
	75%	13.75a
	100%	13.65a

*Values followed by the same letter in each parameter do not differ at p = 0.05

Discussions

The handheld device used to measure the average seasonal temperature took the average temperature of the top 5cm of the soil during the day. Weekly measurements of all the treatments, thus 16 per percentage cover, were made. Medic/clover seeds germinate best in the top 2-3 cm of the soil surface (Puckridge and French 1983; Kotzé 1999), with percentage emergence significantly decreasing when medic/clover seeds are buried deeper than 5 cm (Kotzé 1999). Most, if not all, the medic/clover seeds which germinated should thus have been in the top 5 cm, where the temperature differences were measured. In the literature it was found that an increase in residue cover would reduce the day/night temperature fluctuations, meaning the day time temperature would be lower and the night time temperatures would be higher than the average (Kassam et al. 2012; Xing et al. 2012). High temperatures during the day play an important role in breaking the dormancy of medic and clover seeds (Puckridge and French 1983). Temperature is not the only reason why the plant count was lower under the higher residue percentages, as there are several other effects which could cause the decrease in plant count as the residue level increase. Optimal germination of annual medics and clovers were observed between 10-16 °C (Tabatabaie et al. 2007). The average day time temperature was well between these levels with no significant differences as residue levels increase, which means that temperature may have had no effect on the medic/clover plant count.

4.4 CONCLUSION

Data from this study suggest that it may be advisable to re-plant medic/clover pastures following a cereal crop rather than a previous pasture year. For a practice to be classified as CA it should have at least 30% soil cover after planting, with higher levels being beneficial for CA effects. This data suggest that medic pastures should be re-planted following a cereal production year with a residue cover between 50% and 75%. Remember that research in only done over one season and replications should be done to clarify results.

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CHAPTER 5

LABORATORY ASSESSMENT OF VARYING DERGEES OF PLANT RESIDUE COVER AND LEACHATE ON *MEDICAGO* SPP. ESTABLISHMENT AND PRODUCTION

5.1 INTRODUCTION

The field studies summarised in Chapters 3 and 4 showed that the type of residue in the rotation and amount of residues on the top soil had an effect on annual medic establishment. For a production to be classified as a Conservation Agriculture (CA) practise, different annual crops need to be used in rotation with each other (Kassam et al. 2012). Legumes, like annual medics, play an important role in rotations as it has the ability to fix N (El Msehli et al. 2011). Development of crop rotation system is important, because the crops of the present year can affect the subsequent crops in the rotation. Rotation can have a positive effect on the next crop such as increasing yield (Stevenson and Kessel 1996; Strauss et al. 2012), breaking the disease cycle (Thiombiano et al. 2009) and suppression of weeds (Ferreira and Reinhardt 2010; Kassam et al. 2012). Crops in rotations can also have negative effects on the next crop, such as decreasing germination and production through crop allelopathy (Wu et al. 2006; Ferreira and Reinhardt 2010). Allelopathy is the process of chemicals (allelopathic chemicals), produced by plants to inhibit other plants (Ferreira and Reinhardt 2010). Allelopathic chemicals can derive from the plant seeds, pollen, roots, leaves and/or residues (Benyas et al. 2010). Allelopathy from decomposing plant material can inhibit germination and production of annual medics through the release of phytotoxins (Bhadoria 2011).

In a CA practise at least 30% of the soil surface must be covered with crop residues following the planting action, the ideal being 100% cover (Giller et al. 2009). By increasing crop residues on the fields a barrier effect between the air and soil is formed. This residue cover barrier can act as a physical barrier which suppresses annual medic establishment by preventing seedling to break through the residue mat (Flower et al. 2012). This physical barrier could also prevent medic seeds from reaching the soil, resulting in lower germination rates (Baral 2012). The residue mat negatively affects the quality and quantity of light as well, negatively influencing seedling establishment (Hunt et al. 1989). Soil temperatures become more stable as residue amount on top of the soil increases (Kruidhof et al. 2008). However, a stable temperature could lead to lower annual medic germination rates, because high temperature fluctuations is required to break dormancy of annual medic seeds (Puckridge and French 1983).

Other field variables could have affected the annual medic pasture establishment and production during the 2013 and 2014 seasons in the Overberg. These could include pest, weeds, unpredictable rainfall and management.

Different cultivars also differ in water, nutrient and pH requirements, meaning in different parts of the farm where soils differ there may be a different population of medic/clovers over time. Cavalier (*Medicago polymorpha*) for example grows in a more acid soil than other medic species (Del Pozo et al. 2002). Cavalier is one of the cultivars which naturalised in South Africa over time, making it more adaptable to environmental conditions in the Overberg (Wasserman 1974). It has a high production with a relative short time from plant till flowering compared to other medic cultivars.

Annual medics and clovers might show differences in allelopathic tolerance from wheat, barley, oats and medic residues, as well as differences in the ability to break through the residue mat at different percentage cover. The aim of this part of the study was to look at the reaction of a single cultivar, from the seed mix used to establish medics in the field, to possible allelopathic effects of the different preceding crops. Secondly to determine the effect of the preceding crop residue, as a possible barrier, on establishment. Therefore a study was done in a controlled environment where only the effect of these two possible negative factors could be examined.

5.2 MATERIAL AND METHODS

Experiment 1: Effect of residue cover on annual medic establishment and production under controlled conditions

Plant material

Residues of wheat, barley, oat and annual medics were obtained following harvest on the Tygerhoek Experimental Farm near Riviersonderend. The experiment was conducted at Welgevallen Experimental Farm. Residues were collected in paper bags and air dried. After the residues were completely dry, it was cut into 25 mm pieces which were used in this experiment. The experiment was conducted in controlled environment. The experiment was done to reduce the variables from the field condition. Variables like unpredicted rainfall patterns, different soils, pests and weeds and difference in nutrient levels were all removed. The variables that could have an influence on the results are the allelopathic or autotoxicity effect of crop residues and the thickness of the residue mat.

Treatment and experimental design

The same residue types (wheat, barley, oat and annual medic) and percentage cover (100%, 75%, 50%, 25% and 0%) as in Chapter 3 and Chapter 4were used in the trial. The calculated weights of the different field residue cover percentage for each crop were converted to the same residue cover percentage per pot. The weights of residues in a square meter on the field needed to be converted to weight per pot.

To do this the following equation was used:

$$X1(1m^{-2}) = X2(\pi r^2)$$

$$X2 = \frac{\pi \times 0.075^2 \times X1}{1}$$

X2 is the needed weights of the residues on the pots and X1 is the calculated weights of the residues in field conditions in a square meter. The surface area of the pots was calculated by multiplying π (pi) with the radius (0.075m) to the power of two. Table 5.1 shows the different weights of residues from the field compared to the pot trials.

Table 5.1: The conversion of residue weights from field to pot trials

Residue type	Percentage cover (%)	Weight in field (g)	Weight in pot (g)
Wheat	100	888.65	15.7
	75	666.49	11.78
	50	444.33	7.85
	25	222.16	3.93
Barley	100	858.66	15.17
	75	644	11.38
	50	429.33	7.59
	25	214.66	3.79
Oat	100	924.06	16.33
	75	693.05	12.25
	50	462.03	8.16
	25	231.02	4.08
Annual Medic	100	821.75	14.52
	75	616.31	10.89
	50	410.88	7.26
	25	205.44	3.63

The air dried residues were weighed and altered for each treatment. The experiment consisted of 20 treatment pots, and replicated three times. The planting of annual medics occurred on the 20th

October 2014. The pots were filled with river sand and 15 seeds of Cavalier were planted 2 cm deep in each pot. Irrigation was given daily at 17:00 with the nutrient solution in Table 5.2. The macro nutrients in the nutrient solution consisted out of K^{+} (237.70 parts per million), Ca^{2+} (180.00 ppm), Mg^{2+} (48.60 ppm), NO^{3-} (661.33 ppm), H_2PO_4 (116.40 ppm) and SO_4^{2-} (390.40 ppm). The pots were placed outdoors inside a green netting to protect the seedlings and residue from the wind. Treatments were placed in a random block design (Appendix).

Table 5.2: Composition of nutrient solution used on pot trials at Welgevallen during 2014

EC = 2.00

Nutrients	g/ 1000L
KNO_3	303
K_2SO_4	261
$Ca(NO_3)_2.2H_2O$	900
$MgSO_4.7H_2O$	492
KH_2PO_4	136
Fe: Libfer (Fe EDTA)	6.54
Mn: Manganese sulphate	2.23
Zn: Zink sulphate	1.33
B: Solubor	1.46
Cu: Copper sulphate	0.2
Mo: Sodium Molibdate	0.13

Measurements, harvest and statistical analyses

Germination rate of medic seedlings was observed daily from the 20th of October to the 10th of November. At the 10th of November (3 week stage) all medic seedlings were removed except one, which was left to grow fully till the 24th of November (5 week stage). Seedling shoot length were measured after 3 weeks and above ground dry mass was calculated for each treatment. To determine the dry mass, seedlings were removed at the base of the plant and dried at 60 °C for 72 hours. Dry mass per plant as well as total dry mass were determined. After 5 weeks the one remaining plant was removed and weighed the same way as the three week plants. Table 5.3 shows the daily maximum and minimum temperatures for the first 3 weeks (before the first harvest).

Table 5.3: Daily maximum and minimum temperatures (°C) for the first 3 weeks of Experiment 1

Date	Temperature Max (°C)	Temperature Min (°C)
20/10/2014	27.16	9.18
21/10/2014	29.58	15.1
22/10/2014	26.17	13.39
23/10/2014	25.22	11.67
24/10/2014	24.33	14.33
25/10/2014	27.79	14.83
26/10/2014	26.85	18.6
27/10/2014	30.75	15.4
29/10/2014	30.29	12.02
30/10/2014	24.45	15.06
31/10/2014	17.96	13.12
01/11/2014	22.46	13.68
02/11/2014	27.01	16
03/11/2014	29.88	14.29
05/11/2014	20.32	13.75
06/11/2014	23.25	14.26
08/11/2014	33.29	14.72
09/11/2014	25.09	14.74
10/11/2014	28.97	14.57
Average	**26.36**	**14.14**

Experiment 2: Effect of residue leachate on annual medic germination in a controlled environment

Plant material

Residues of wheat, barley, oat and annual medics were obtained following the harvest on Tygerhoek experimental farm near Riviersonderend. Residues were collected in paper bags and air dried at Welgevallen experimental farm in Stellenbosch. After the plants were completely dry, it was cut into 25 mm pieces which were used in two experiments. The experiment was conducted at Welgevallen experimental farm.

Treatment

The air dried plant material of wheat, barley, oat and annual medics were put in separate 1.5 L Erlenmeyer flasks. 100g of each residue type were soaked with 1 L of distilled water at room temperature in the dark for 24 hours (Mkula 2006). The flasks were shook with a Griffin flask shaker throughout the 12 hours (Figure 5.1). Subsequently the solutions were sieved through a cheese cloth to remove all the solid particles and passed through a single layer of Whatman No. 1 filter paper. From the 100% solution of wheat, barley, oat and annual medic filtrates, a dilution of 75% (solution to water of 3:1), 50% (1:1) and 25% (1:3) were prepared. This makes the treatments a 100%, 75%, 50%, 25% and 0% (distilled water; Control), leachate of wheat, barley, oat and annual medics.

The experiment was first conducted using the Rûens medic/clover mixture (Trial A), but the results could have been influenced by the difference in cultivar combinations and species. Thus the experiment was repeated using only the medic cultivar Cavalier (Trial B). The same procedure for both repeated experiments were followed.

Twenty five seeds were placed inside a 9 cm diameter Petri dish which was lined with two Whatman No. 1 filter papers. To each Petri dish, 10 ml of each treatment solution were added after which the Petri dishes were placed in plastic bags to limit moisture loss. Every treatment was replicated four times. All the Petri dishes were kept in a LABEX growth chamber at 20^{o}C under a light/dark cycle of 12h/12h.

Measurements

Germination rate of Trial A was measured daily for 14 days, after which the radicle and plumule lengths were measured. Germination rate of Trial B was measured daily for 9 days, after which the radicle and plumule lengths were measured. In Trials A and B the germination stopped after seven days. Trial B only lasted 9 days and lengths could not be compared to Trail A. Germination was only recorded as successful if the radicle was longer than 2 mm (Mkula 2006).

Statistical analyses

Data was analysed through *Satistica 11* using one-way ANOVA and means comparison (P<0.05) using Fisher's least significant-difference test.

Figure 5.1: Flasks with soaked residues (1 litre of water and 100 grams of each residue type) shaken by the Griffin flask shaker

5.3 RESULTS AND DISCUSSIONS

Experiment 1

Results

Germination started three days following plant and rapidly increased between day 3 and 7, after which the rate declined and reached their full establishment after day 11. There were no significant interactions between type of residue and residue cover percentage. When no residues were left on the soil surface (control), the start of germination was slower than when residues were left on the surface. The start of germination was similar regardless of the residue type. The germination in the control treatment exceeded that of the other treatments at day 6 and continued to be higher till the end of the experiment. There were no significant differences in germination between die different residue type treatments (Figure 5.2).

The final establishment in the end did not differ between the different types of residue cover as well as the control. The establishment of Cavalier was the highest in the control treatment (85%), followed by the B (83%), W (78%), O (76%) and M (76%) treatments. Table 5.4 depicts the lengths and weights of the seedlings three and five weeks respectively after planting.

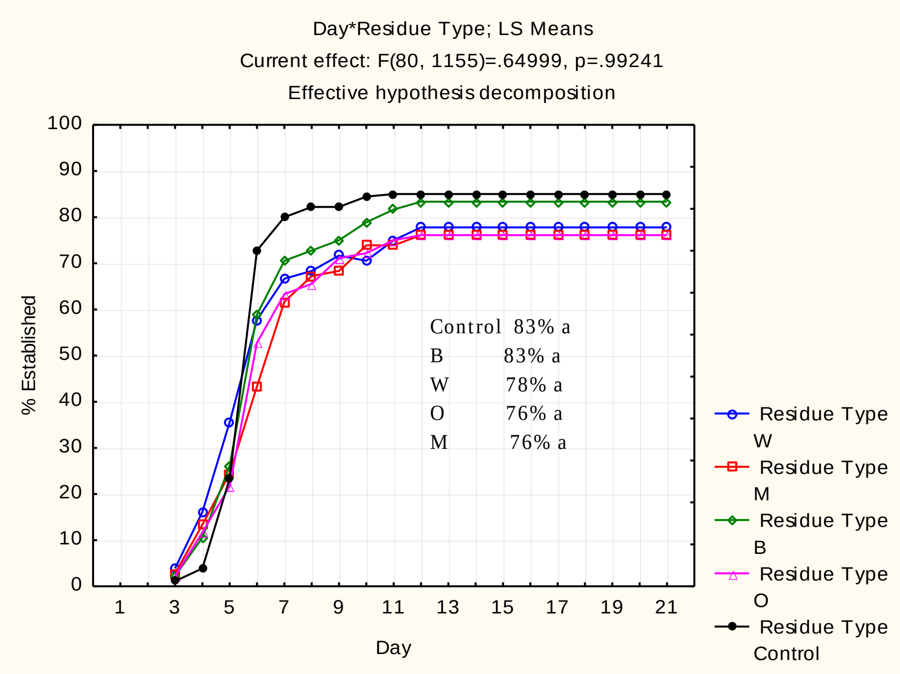

Figure 5.2: Germination over time of medic cultivar Cavalier under different types of residue cover in a pot experiment

Table 5.4: Shoot lengths (mm) and weights (g) of Cavalier annual medic following different residue types on Welgevallen

Residue type	3 week shoot length (mm)	3 week shoot DM mass: Total (g)	3 week mass shoot DM per plant (g)	5 week shoot length (mm)	5 week mass shoot DM per plant (g)
Wheat	80.32a*	3.8a	0.32a	162.83a	1.1a
Barley	74.68bc	3.37a	0.27a	157.5a	0.99a
Oats	73.09c	3.23a	0.28a	157.75a	1.17a
Medic	78.23ab	3.2a	0.26a	150.33a	0.98a
Control	72.49c	3.16a	0.25a	155.55a	0.98a

* Values followed by the same letter do not differ significantly at the p = 0.05

The 3 week shoot length of annual medic with wheat (80.32 mm) residue cover had the longest shoot length, followed by medic (78.23 mm), barley (74.68 mm), oats (73.09 mm) residue cover and the control (72.49 mm) (Table 5.4). The 3 week total and weights per plant did not differ significantly from each other under the different residue types.

At the 5 week harvest, the shoot length of Cavalier following wheat (162.83 mm), oats (157.75 mm), barley (157.50 mm), medic (150.33 mm) residues and the control (155.55 mm) did not differ significantly from each other.

The 5 week mass of Cavalier following different residues types also did not differ significantly from each other. The mass of Cavalier following oats (1.17 g), wheat (1.10 g), barley (0.99 g), medic (0.98 g) residues and the control (0.98 g) being statistically the same.

Germination rate under the different residue cover percentages followed the same trend as under different residue types (Figure 5.3). Germination started 3 days after plant and increased up to day 7. A gradual decline in germination was then perceived till day 11, when germination stopped. Again the control (0% cover) germination started slower than the rest of the treatments, but overtook the other treatments at day 6 and stayed the highest till the experiment was terminated.

Establishments did not differ significantly under different cover percentages, with 0% cover having the best establishment (85% establishment) followed by a 75% (83% establishment), 100% (79% establishment), 50% (78% establishment) and 25% (73% establishment) cover.

Table 5.5 shows the lengths and mass of the plants three and five weeks after planting. At three weeks the lengths at different levels of residue cover had a significant difference between each other. 50% (79.73 mm), 25% (78.36 mm) and 75% (77.39 mm) residue cover had a longer length than 0% (72.49 mm) and 100% (70.89 mm). The 3 week total and weights per plant did not differ significantly from each other under different residue percentage cover.

The 5 week shoot lengths under different percentage residue cover did differ from each other with 25% (170.8 mm) having a significant greater length than 75% (137.92 mm) cover. The 0% (155.33 mm), 50% (163.67 mm) and 100% (156.75 mm) having statistically the same length and did not differ from the 25% and 75% cover.

The 5 week shoot DM mass of Cavalier under different percentage cover did differ significantly from each other; with shoot DM mass under 25% cover (1.20 g) weighing more than under 75% residue cover (0.86 g). The shoot DM mass under 0% (0.98 g), 50% (1.12 g) and 100% cover (1.07 g) not differing from each other and 25% and 75% residue cover.

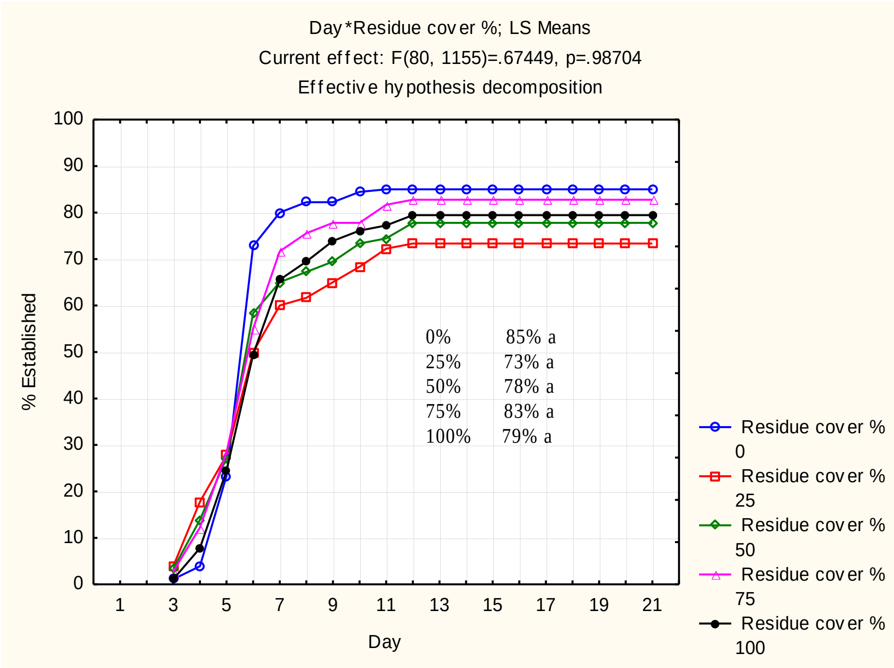

Figure 5.3: Germination over time of medic cultivar Cavalier under different percentages of residue cover in controlled conditions

Table 5.5: Shoot lengths (mm) and weights (g) of Cavalier annual medic following different residue cover percentages

Residue cover %	3 week shoot length (mm)	3 week shoot DM mass: Total (g)	3 week shoot DM mass per plant (g)	5 week shoot length (mm)	5 week shoot DM mass per plant (g)
0%	72.49b*	3.16a	0.25a	155.33ab	0.98a
25%	78.36a	3.42a	0.3a	170.08a	1.2a
50%	79.73a	3.63a	0.3a	163.67a	1.12ab
75%	77.39a	3.52a	0.28a	137.92b	0.86b
100%	70.89b	3.04a	0.25a	156.75ab	1.07ab

* Values followed by the same letter do not differ significantly at the p = 0.05

Discussion

The germination rate of Cavalier was measured under different types and percentage residue cover. Cavalier has an 80-85% establishment rate which is the compared germination rate. Germination of annual medics usually starts three days after planting (Clark 2008) under favourable conditions. Environmental conditions in experiment 1 were optimum for annual medic germination, resulting in quick germination at the start. The greater the day night temperature fluctuations the more effective the dormancy break of the seeds (Taylor 2005), but constant high temperatures cause a decrease in germination rate (Azizi 2013). While the air temperature was given in Table 5.3, the soil temperature would have been a lot different. During the day the soil temperature measured at the beginning of the trial was on average 3-5 °C more than the air temperatures, while early morning soil temperatures were about 2-3 °C below that of the air temperatures. These measurements were made for interest sake, but were not used in the study. Residues on the top soil have a cooling effect on the soil (Farooq et al. 2011) as it reflects the heat away. When there is no residues on the soil surface, temperatures reached much higher levels (Taylor 2005). Both these two reasons could be why the control (0% cover) and 100% cover had a slower germination rate at the beginning of the trial. While temperature plays an important role in the germination rate, the effect thereof between the different treatments was negligent, as all had the same tendency.

Seeds were planted 2 cm deep which is within the optimum sowing depths (Puckridge and French 1983). By placing residues on top of the soil surface, there is no light penetration to the soil (100% cover). This means the sowing depth indirectly increases because the seedling needs to grow through the residue mat as well. This could have caused the slower germination at the 100% residue cover compared to the other cover percentages. After day 7 the germination rate decreased, as most of the viable seeds already germinated. The final establishment was observed at day 11, after which establishment ceased.

All treatments had greater establishment percentages than the field trials in 2013 and 2014. The expected establishment of Cavalier is 80-85% with most of the treatments being in or close to this range. In Experiment 1 the field trial of 2014 was simulated, being the effect of residue cover on establishment after planting of annual legume pastures. By looking at the different types of crop residues the allelopathic or autotoxicity effect can be taken in consideration and with the different percentage cover the residue mat thickness can be taken in consideration. The control had the highest germination percentage (85%), while germination under residues was just below the recommended germination rate of 80-85%. This could indicate a hint of allelopathy and autotoxicity from residues. The type of residues did not affect the germination of annual medics.

The 0% residue cover having a slightly higher germination could be because there are no physical obstructions preventing seedlings to establish and cause seedling death. The lower establishments under the residues could be because of the physical barrier effect (Flower et al. 2012). Ferreira (2011) conducted almost the same experiment in his study, but only used one cover percentage throughout (15 g of residue per pot) of all residues. Results could correlate to each other, as 3 week shoot lengths and weights followed mainly the same trends.

When residues are left on the soil, medic seedlings needed to grow through the residues to reach sunlight, leading to longer shoot lengths. Looking at the different percentage cover this was noticed, with the exception of Cavalier shoot length at 100% (70.89 mm) cover. The reduced shoot length at the 100% cover could be the result of the seedlings using a substantial amount of energy to break through the residue mat. The longer shoot lengths resulted in higher shoot mass, except under medic residues. This could be an indication of an allelopathic effect (autotoxicity). Ferreira (2011) found the same trend with medic shoot mass under medic residues (2.23 g) having a significantly lower 5 week weight than under wheat (6.10 g) and barley (3.52 g) residues.

At 5 weeks Cavalier shoot lengths and weights following different types of residues did not differ significantly from each other. This could indicate that an increase in maturity of the plant results in the allelopathic effectivity of the residues decreasing. Under varied percentage cover the Cavalier lengths and weights did differ from each other. The reason for the result found at the 75% cover was the fact that one of the replicates lengths was reduced by snail damage.

Experiment 2 was conducted to see if the results in experiment 1 could be because of allelopathic effects from the different crop residues, should it be positive or negative.

Experiment 2

Trial A

Trial A was executed with the Rûens seed mixture. The interaction between leachate type and concentration were significant, thus the two treatments influenced each other. The control and the 25% concentration of wheat, barley and medic had the highest germination (Table 5.6). As wheat leachate increased, so did the medic germination decreased (except between 50% and 75%). Different levels of barley leachate concentrations did not have an effect on germination. Oat leachate at a 100% had a lower germination than the other leachate concentrations. Medic leachate had the most dramatic effect on the germination with no germination at 50%, 75% and 100%.

Table 5.6: Interactive effect of leachate concentration and residue type on germination (%) of the Rûens seed mixture

		Leachate concentration			
		25	***50***	***75***	***100***
Leachate type	***Wheat***	89ab*	65ef	69de	37g
	Barley	84abc	71cde	77bcde	83abcd
	Oat	75bcde	76bcde	78abcde	53f
	Medic	82abcd	0h	0h	0h
Control = 92%a					

*Values followed by the same letter do not differ significantly at the p = 0.05

Radicle length decreased as wheat leachate increased (except between 50% and 75%) (Table 5.7). Radicle lengths were inconsistent under barley and oat leachates. As there was no germination at 50 to 100% medic leachate, there were no radicle lengths.

Table 5.7: Interactive effect of leachate concentration and residue type on radicle length (mm) of the Rûens seed mixture

		Leachate concentration			
Leachate type		***25***	***50***	***75***	***100***
	Wheat	83.08ab*	60.75c	62.5c	24.17g
	Barley	79.92bc	88.67a	90a	78.83bc
	Oat	72.55c	87.42a	79.25bc	52.33e
	Medic	36f	0h	0h	0h
Control = 77.50 mm bc					

*Values followed by the same letter do not differ significantly at the p = 0.05

Plumule lengths were shorter at 100% wheat leachate than the other wheat leachates (Table 5.8). Barley leachate at 25% concentration plumule length was longer than at higher barley leachate concentrations. Oat leachate showed inconsistencies under different leachate concentrations. 50% to 100% medic leachate had no germination, thus no plumule lengths.

Table 5.8: Interactive effect of leachate concentration and residue type on plumule length (mm) of the Rûens seed mixture

		Leachate concentration			
Leachate type		***25***	***50***	***75***	***100***
	Wheat	28.67cde*	25.75ef	27.75def	11.75h
	Barley	36.31a	32.75b	32.75b	31.25bc
	Oat	33.45b	28.97cde	30.17bcd	22.17g
	Medic	24.25fg	0i	0i	0i
Control = 26.33 mm ef					

*Values followed by the same letter do not differ significantly at the p = 0.05

Trial B

Trial B was executed with the medic cultivar Cavalier. The interaction between leachate type and concentration were significant, thus the two treatments influenced each other. The germination decreased as wheat leachate increased (except between 50% and 75%) (Table 5.9). 100% barley leachate had a lower germination than 25% and 50% barley leachate. 100% oat leachate also had a lower germination than the 25% and 50% oat leachate. Germination decrease as medic leachate increased and there was no germination at 75% and 100% leachate concentrations.

Table 5.9: Interactive effect of leachate concentration and residue type on germination (%) of Cavalier

		Leachate concentration			
Leachate type		***25***	***50***	***75***	***100***
	Wheat	86ab*	71cd	64d	34ef
	Barley	86ab	92a	81abc	71cd
	Oat	83ab	79bc	76bc	39e
	Medic	77bc	23ef	0g	0g
Control = 86% ab					

*Values followed by the same letter do not differ significantly at the p = 0.05

Radicle length decreased as wheat concentrations increased (except between 50% and 75% leachate concentrations) (Table 5.10). As barley leachate concentration increase, so did the radicle lengths decreased. Oat leachate did not show any clear trend in radicle length. Medic leachate caused radicle length to decrease as leachate concentration increase.

Plumule lengths were shorter at a 100% wheat leachate than under 25%, 50% and 75% leachate concentrations (Table 5.11). A 100% barley leachate also had a shorter plumule length than under 25%, 50% and 75% leachate concentrations. And a 100% oats leachate concentration plumule length was shorter than under a 25%, 50% and 75% leachate concentration as well. Plumule length decreased as medic leachate concentration increased.

Table 5.10: Interactive effect of leachate concentration and residue type on radicle length (mm) of Cavalier

		Leachate concentration			
Leachate type		***25***	***50***	***75***	***100***
	Wheat	45.08bc*	22.83gh	24.67gh	6.17j
	Barley	58.58a	39.25cde	28.67fg	19.50hi
	Oat	37.08de	42.42cd	34.25ef	15.33i
	Medic	26.67g	4.67j	0j	0j
Control = 51.83 mm ab					

*Values followed by the same letter do not differ significantly at the p = 0.05

Table 5.11: Interactive effect of leachate concentration and residue type on plumule length (mm) of Cavalier

		Leachate concentration			
		25	***50***	***75***	***100***
Leachate type	***Wheat***	30.83ef*	28.92fg	27.75fg	3.25h
	Barley	39.5ab	42.67a	37.67bc	26.33g
	Oat	36.17bcd	31.92def	33.5cde	26.33g
	Medic	29.33efg	0.5h	0h	0h
Control = 39.67 mm ab					

*Values followed by the same letter do not differ significantly at the p = 0.05

Discussion

Experiment 2 was conducted to investigate the allelopathic effect of crop residues on annual medic germination and early seedling growth. The different concentration leachates were included to mimic Experiment 1's different cover percentages. This emphasized the interesting fact that the type and leachate concentration together played a significant interactive role affecting the germination, radicle length and plumule length of annual medics. Allelopathy and osmolality could be the reason why the combination of leachate type and concentration affected annual medics the way it did.

Mkula (2006) found that by increasing the concentration of silverleaf nightshade solution, the osmolality increased as well. In his study it showed that different cultivars show different levels of sensitivity to higher levels of osmolality and that a higher osmolality level has a negative effect on germination, radicle length and plumule length (Mkula 2006). When considering the different leachate types, osmolality levels could vary between different residues causing the results observed. Osmolality tests could not be conducted due to lack of appropriate equipment and should also be investigated in the future.

The germination of the Rûens medic mixture and Cavalier showed almost the exact same germination pattern. Low levels of leachate concentration did not have an effect on medic germination. However, at increased leachate concentrations differences were detected. Medic germination decreased drastically when medic leachate concentration increased, showing increased allelopathic or osmolality effects. Medic germination followed the same, but less pronounced trend when wheat leachate concentration increased. This indicates that wheat could also have a negative allelopathic and increased osmolality effect. With oat leachate the medic germination did not decrease except when 100% concentrate was used, which could indicate an osmolality effect instead of allelopathic effect. Annual medic germination following barley leachate showed no effect as concentration increased, sometimes even increasing. This shows that barley leachate has no or a positive allelopathic or osmolality effect on medic germination.

Although the radicle and plumule lengths could not be compared between the Rûens seed mixture and Cavalier because of the different times of measurements, almost the same responses were observed. Radicle and plumule lengths following medic and wheat leachate followed similar trends as the germination following medic and wheat leachate. Medic leachate had a greater allelopathic effect on radicle and plumule lengths of annual medics than wheat leachate. The radicle and plumule length trends of medics did differ between the Rûens mixture and Cavalier following barley. An increase in barley leachate caused Cavalier radicle and plumule lengths to decrease, while the lengths of the Rûens mixture remained constant. This may be an indication that the Cavalier medic cultivar in the Rûens mixture is more sensitive to allelopathic and osmolality effects from barley residues. Cavalier being *Medicago ploymorpha* (burr medic) has been shown to be more sensitive to increased wheat leachate than that of *Medicago truncatula* (barrel medic), with germination and radicle lengths being lower in burr medic than in barrel medic (Halsall et al. 1995). Radicle and plumule lengths of medics following oats showed the same trend by the Rûens mixture and Cavalier, with an abrupt decrease at the 100% leachate concentration.

5.4 CONCLUSION

Stubbles were collected just after harvest, which could have had an influence on the results. In the fields the stubbles are exposed to environment conditions for five to six months before medic germination starts. These ‘fresh’ stubbles could have a higher allelopathic effect that the weathered stubbles on the field. Data from this study suggest that the thickness of residue mat does have an effect on annual medic shoot length, but not on the germination and weight. Thus a residue cover of 100% should not have an effect on the plant count and production according to this study. Data also suggests that the allelopathic effect of residues has an effect on the germination and length of seedlings. Lower residue cover percentages (25%) is preferred when medic pastures follows a wheat or medic pastures production year, while a 75% oats residue cover and100% barley residue cover should have no allelopathic effect on the subsequent medic pasture production year.

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CHAPTER 6

6.1 SUMMARY

Annual medic pastures play an important role in short rotations in the Overberg district of South Africa. While annual medics can re-establish year on year after being planted just once, certain factors can negatively affect the re-establishment. Factors such as environment, type and amount of residue cover from the previous crop, pests and weeds, cultivating and medic cultivars combinations used during planting. All affect the re-establishment and establishment of annual medic pastures. Reduced establishment success can result in lower production, negatively affecting carrying capacity on the field and thus the gross margin.

During the initial establishment of medic pastures the right cultivar combination should be used that is best adapted to that specific area and environment. Cultivars prefer different types of soil at different pH and different amounts of rainfall. This is beneficial in the Overberg especially, because soils can differ from camp to camp and the unpredictable rainfall patterns year on year. Planting different cultivars ensures optimal survival rates over a long period of time, because of different levels of hardseededness and time from emergence till flowering. Higher hardseededness in medics is beneficial for build-up of the seed reserve in the soil, while lower levels of hard seeds is useful during the initial production year. Longer time from emergence till flowering is beneficial during an extended rainfall period throughout the production season, whereas shorter flowering cultivars would be favoured when rain is not sufficient during the production season. The right combination of cultivars should be used with the appropriate CA planter, which ensures good seed soil contact and planting at the correct depth and density. Management of animals and weeds are especially important during the initial production year.

Plant count should be conducted during the re-establishment years of medic pastures to see when re-plant is needed. The data suggest that the previous year crop residues (mostly cereals) can be grazed to between 50% and 75% cover (minimum of 30% after planting required to be classified as CA) during the summer without affecting the medic establishment and production. Residue cover percentage should be determined as frequently as possible during this time. During the autumn and beginning of winter grazing on the medics should be restricted. This promotes establishment and has a positive effect on production. Winter grazing pressure should be increased to control grass weeds and promote prostrate growth. At spring the medic pasture will growth profusely and stocking rate should be increased even more. During flowering the stocking rate must be lowered to ensure sufficient seed production. In the summer residues and pods can be consumed, but consumption must be managed to ensure enough seeds are available to replenish the medic seed bank. It is suggested that annual medic pastures should be re-planted if plant count is lower than the sustainable level (below 78 plants per square meter).

Different rotation sequences play an essential part on annual medic pasture establishment and production, as different residues has different effects on medics. Data suggests that when a medic pasture followed another medic pasture production year (MM), the production was negatively affected. This was due to the residue composition. Medic residues have a strong auto-allelopathic effect which has a negative effect on medic pasture establishment and production. Wheat residues were found to have a moderately negative effect on the medic establishment as residue cover increased, thus it would be preferred to graze wheat residues down to between 30% and 50% cover. Data suggest that oat residues at 100% could have an allelopathic effect on the medic germination, but 75% should not. Thus oat residues should be grazed to a 75% to 30% cover. The percentage barley residues do not affect the medic establishment and production and a 100% cover can be left on the soil surface. Keep in mind that barley should not be planted after medics because of the high N in the soil.

Depending on the repeatability or follow-up research, data suggest an initial or re-plant of medic pastures should be done when plant count drop below sustainable levels. Management of weed during the medic pasture year is important for a good stand and production. Annual medic pastures should be planted after a cereal production year rather than a previous medic production year. It is thus beneficial to have a single medic rotation rather than a double, for example WMWM rather than WMM. Although greater amounts of residues are beneficial for CA effect, care should be taken in consideration with high amounts of wheat and oat residues, because of the higher allelopathic effect which could influence germination.

6.2 FUTURE RESEARCH

Testing for repeatability or follow-up studies is of cardinal importance to confirming current results, because of environmental conditions which can alter year after year. Future testing of what time interval (amount of years) it is beneficial to re-plant medic pastures in the Overberg would benefit the farmers.

A study can be done to look at the effect of pests on medic pasture re-establishment and production under different amounts of residue cover and type of residue. The different types of pests and what the effect on the medic plant can be can also be studied.

When looking at the allelopathic effect of the new crops at different levels of concentrations, an osmolality test should be conducted as well. This should determine if osmolality plays a role as the percentage leachate increased or if only allelopathy played a role.

APPENDIX

Calculations of all percentage residue cover of the different plant residues (Chapter 3 and 4).

Treatment weight of wheat

$$\frac{75\% + 67.31\% + 55.77\% + 51.92\% + 69.23\%}{5} = 63.85\%\ crop\ residue\ ave\ for\ wheat$$

$$\frac{668g + 580g + 460g + 512g + 617g}{5} = 567.4g\ crop\ residue\ ave\ for\ wheat$$

$$\frac{567.4g}{63.85\%} X\ 100\% = 888.65g\ needed\ for\ a\ 100\%\ residue\ cover\ for\ wheat$$

$$\frac{888.65g}{100\%}\ X\ 75\% = 666.49g\ needed\ for\ a\ 75\%\ residue\ cover\ for\ wheat$$

$$\frac{888.65g}{100\%}\ X\ 50\% = 444.33g\ needed\ for\ a\ 50\%\ residue\ cover\ for\ wheat$$

$$\frac{888.65g}{100\%}\ X\ 25\% = 222.16g\ needed\ for\ a\ 25\%\ residue\ cover\ for\ wheat$$

Treatment weight of barley

$$\frac{80.77\% + 82.69\% + 78.85\% + 98.08\% + 82.69\%}{5} = 84.62\%\ crop\ residue\ ave\ for\ barley$$

$$\frac{721g + 712g + 730g + 806g + 664g}{5} = 726.6g\ crop\ residue\ ave\ for\ barley$$

$$\frac{726.6g}{84.62\%} X\ 100\% = 858.66g\ needed\ for\ a\ 100\%\ residue\ cover\ for\ barely$$

$$\frac{858.66g}{100\%}\ X\ 75\% = 644.00g\ needed\ for\ a\ 75\%\ residue\ cover\ for\ barley$$

$$\frac{858.66g}{100\%}\ X\ 50\% = 429.33g\ needed\ for\ a\ 50\%\ residue\ cover\ for\ barely$$

$$\frac{858.66g}{100\%}\ X\ 25\% = 214.66g\ needed\ for\ a\ 25\%\ residue\ cover\ for\ barley$$

Treatment weight for oats

$$\frac{71.15\% + 71.15\% + 44.23\% + 61.45\% + 63.46\%}{5} = 62.29\%\ crop\ residue\ ave\ for\ oats$$

$$\frac{668g + 649g + 415g + 562g + 584g}{5} = 575.6g\ crop\ residue\ ave\ for\ oats$$

$$\frac{575.6g}{62.29\%} X\ 100\% = 924.06g\ needed\ for\ a\ 100\%\ residue\ cover\ for\ oats$$

$$\frac{924.06g}{100\%}\ X\ 75\% = 693.05g\ needed\ for\ a\ 75\%\ residue\ cover\ for\ oats$$

$$\frac{924.06g}{100\%}\ X\ 50\% = 462.03g\ needed\ for\ a\ 50\%\ residue\ cover\ for\ oats$$

$$\frac{924.06g}{100\%}\ X\ 25\% = 231.02g\ needed\ for\ a\ 25\%\ residue\ cover\ for\ oats$$

Treatment weight for medics

$$\frac{90\% + 67\% + 94\% + 77\% + 72\%}{5} = 80\%\ crop\ residue\ ave\ for\ medics$$

$$\frac{684g + 612g + 736g + 665g + 590g}{5} = 657.4g\ crop\ residue\ ave\ for\ medics$$

$$\frac{657.4g}{80\%} X\ 100\% = 821.75g\ needed\ for\ a\ 100\%\ residue\ cover\ for\ medics$$

$$\frac{821.75g}{100\%}\ X\ 75\% = 616.31g\ needed\ for\ a\ 75\%\ residue\ cover\ for\ medics$$

$$\frac{821.75g}{100\%}\ X\ 50\% = 410.88g\ needed\ for\ a\ 50\%\ residue\ cover\ for\ medics$$

$$\frac{821.75g}{100\%}\ X\ 25\% = 205.44g\ needed\ for\ a\ 25\%\ residue\ cover\ for\ medics$$

The Latin square design used for the plots in Chapter 3.

Table A1: Wheat Latin square design

	Sub camp position on farm							
Treatment (%)	**3**	**14**	**31**	**32**	**46**	**57**	**77**	**80**
	75	50	50	100	50	75	25	25
	100	75	25	50	75	0	50	100
	25	100	75	25	25	100	0	75
	50	25	0	0	0	50	75	0
	0	0	100	75	100	25	100	50

Table A2: Barley Latin square design

	Sub camp position on farm					
Treatment (%)	**1**	**13**	**29**	**45**	**60**	**76**
	25	50	50	50	0	50
	0	100	25	75	75	75
	75	75	0	100	50	0
	100	0	75	0	25	25
	50	25	100	25	100	100

Table A3: Oats Latin square design

	Sub camp position on farm			
Treatment (%)	**4**	**36**	**48**	**75**
	75	100	75	25
	50	75	100	0
	0	0	25	75
	100	50	50	50
	25	25	0	100

ANOVA's of Chapter 3:

Table A4: ANOVA of Re-establishment of annual medics during 2013

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	3364.248	1	3364.248	37.46405	0.000000
Residue type	1273.404	2	636.702	7.09027	0.001512
Cover %	844.282	4	211.071	2.35047	0.061758
Residue type*Cover %	138.096	8	17.262	0.19223	0.991253
Error	6734.952	75	89.799		

Table A5: ANOVA of Plant count of annual medics during 2013

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	254171.6	1	254171.6	56.56614	0.000000
Residue type	51124.1	4	12781.0	2.84443	0.029750
Cover %	42540.2	2	21270.1	4.73368	0.011587
Residue type*Cover %	13499.8	8	1687.5	0.37555	0.930409
Error	337001.4	75	4493.4		

Table A6: ANOVA of Weed infestation during 2013

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	555.9529	1	555.9529	168.0911	0.000000
Residue type	82.3559	2	41.1780	12.4501	0.000021
Cover %	4.9271	4	1.2318	0.3724	0.827595
Residue type*Cover %	12.6334	8	1.5792	0.4775	0.868448
Error	248.0587	75	3.3074		

Table A7: ANOVA of Medic production during 2013

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	110.2711	1	110.2711	58.21682	0.000000
Residue type	29.1312	2	14.5656	7.68980	0.000917
Cover %	6.9653	4	1.7413	0.91932	0.457308
Residue type*Cover %	4.3567	8	0.5446	0.28751	0.968152
Error	142.0608	75	1.8941		

ANOVA's of Chapter 4:

Table A8: ANOVA of Establishment of annual medics during 2014

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	22943.14	1	22943.14	215.6441	0.000000
Residue type	3229.40	3	1076.47	10.1178	0.000017
Cover %	411.86	4	102.96	0.9678	0.431901
Residue type*Cover %	333.90	12	27.83	0.2615	0.992948
Error	6383.61	60	106.39		

Table A9: ANOVA of Plant count of annual medics during 2014

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	1593160	1	1593160	428.0566	0.000000
Residue type	19558	3	6519	1.7516	0.166119
Cover %	30840	4	7710	2.0715	0.095744
Residue type*Cover %	18255	12	1521	0.4087	0.954625
Error	223311	60	3722		

Table A10: ANOVA of Weed infestation during 2014

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	1.71124	1	1.711242	7.880570	0.006731
Residue type	0.43289	3	0.144298	0.664517	0.577124
Cover %	0.87250	4	0.218124	1.004499	0.412388
Residue type*Cover %	2.82349	12	0.235291	1.083555	0.390003
Error	13.02882	60	0.217147		

Table A11: ANOVA of Medic production during 2014

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	1358.087	1	1358.087	796.0871	0.000000
Residue type	46.113	3	15.371	9.0103	0.000051
Cover %	2.100	4	0.525	0.3078	0.871687
Residue type*Cover %	17.075	12	1.423	0.8341	0.615555
Error	102.357	60	1.706		

Table A12: Randomise block design of pot trial treatments in Chapter 5

		Treatment									
Replication		M 25%	M 50%	W 50%	O 75%	B 75%	B 50%	W 25%	W 0%	W 100%	O 50%
		B 75%	B 100%	B 0%	M 25%	O 25%	W 0%	O 100%	W 75%	B 50%	W 50%
		W 100%	M 25%	W 25%	O 100%	B 25%	B 50%	O 50%	M 100%	M 0%	M 75%
Replication		B 100%	O 25%	B 25%	O 100%	M 100%	M 0%	O 0%	W 75%	M 75%	B 0%
		W 50%	M 50%	O 0%	M 100%	W 100%	M 0%	W 25%	O 75%	B 25%	M 75%
		M 75%	B 0%	B 75%	W 75%	W 0%	O 0%	M 50%	W 50%	O 75%	B 100%

ANOVA's of Chapter 5:

Experiment 1:

Table A13: ANOVA of Establishment of Cavalier in pots trial

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	415556.3	1	415556.3	2101.127	0.000000
Residue type	899.3	4	224.8	1.137	0.348899
Cover %	1136.3	4	284.1	1.468	0.224348
Residue type*Cover %	2903.704	9	322.6337	1.870084	0.082885
Error	7418.519	43	172.5237		

Experiment 2:

Table A14: ANOVA of Germination of Rûens seed mixture

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	213531.1	1	213531.1	402.2985	0.000000
Leachate type	36820.5	4	9205.1	17.3427	0.000000
Leachate %	17696.5	4	4424.1	5.3026	0.000958
Leachate type * %	14244.25	9	1582.694	14.22083	0.000000
Error	5676.00	51	111.294		

Table A15: ANOVA of Radicle length of Rûens seed mixture

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	545488.9	1	545488.9	1831.396	0.00
Leachate type	163663.2	4	40915.8	137.369	0.00
Leachate %	26997.9	4	6749.5	6.8549	0.000034
Leachate type * %	20909.38	9	2323.264	26.19710	0.00
Error	16583.92	187	88.684		

Table A16: ANOVA of Plumule length of Rûens seed mixture

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	83190.38	1	83190.38	1390.690	0.00
Leachate type	20623.21	4	5155.80	86.189	0.00
Leachate %	5233.34	4	1308.33	9.5391	0.000000
Leachate type * %	3382.125	9	375.7917	20.51568	0.00
Error	3425.333	187	18.3173		

Table A17: ANOVA of Germination of Cavalier

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	213204.5	1	213204.5	434.0426	0.000000
Leachate type	31813.5	4	7953.4	16.1915	0.000000
Leachate %	21185.5	4	5296.4	8.0260	0.000027
Leachate type * %	8825.000	9	980.5556	14.47000	0.000000
Error	3456.000	51	67.7647		

Table A18: ANOVA of Radicle length of Cavalier

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	140683.6	1	140683.6	630.5112	0.00
Leachate type	30953.1	4	7738.3	34.6811	0.00
Leachate %	32710.1	4	8177.5	38.1599	0.00
Leachate type * %	5376.02	9	597.3356	7.836796	0.000000
Error	14253.50	187	76.2219		

Table A19: ANOVA of Plumule length of Cavalier

Effect	SS	Degr. of Freedom	MS	F	P
Intercept	114816.7	1	114816.7	1054.395	0.00
Leachate type	26278.7	4	6569.7	60.331	0.00
Leachate %	12253.5	4	3063.4	17.0783	0.000000
Leachate type * %	6490.833	9	721.2037	24.67044	0.00
Error	5466.667	187	29.2335		