SCREENING OF COVER CROPS UNDER CONSERVATION AGRICULTURE

By

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DECLARATION

I, Mutondwa Masindi Phophi declare that:

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Dedication

This work is dedicated to my son Orisedza Phophi, my mother Dr. Lufuno Phophi and all her siblings.

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GENERAL ABSTRACT

The practice of conventional tillage results in land degradation, reducing soil fertility due to soil erosion. Conservation agriculture aims at reducing soil disturbance which brings benefits of soil conservation. The call for promoting conservation agriculture in South Africa is important in order to reduce the negative impacts caused by frequent conventional soil tillage. Weeds compete for water, nutrients and light with the grown crops. The use of herbicide application to manage weeds has also become problematic due to herbicide resistance that has arisen. However, weed management remains one of the greatest problems that smallholder farmers are facing under conservation agriculture in South Africa. As such there is a need to introduce alternative methods that can be used to manage weeds under conservation agriculture without severe soil disturbances. The study was done in two contrasting agro ecological zones of KwaZulu-Natal, Bergville and Ukulinga. This study was aimed at evaluating three different cover crops for weed suppression and soil macrofauna abundance under conservation agriculture. *Vigna unguilata* (L.) Walp (cowpea), *Lablab purpureus* (dolichos lablab) and *Mucuna prureins* (L.) (velvet bean) were also evaluated for biomass production. The experiment was conducted in a randomised complete block design replicated three times. Herbicide treatment and bare plot served as controls. The data was analysed using the Genstat Stastical Package 17th edition. Poison distribution was used to analyse the soil macrofauna species abundance. Velvet bean produced the highest biomass in both Ukulinga (1.59 t/ha) and Bergville (0.72 t/ha). Cowpea had the lowest biomass accumulation in Bergville (0.59 t/ha) and lablab was the lowest in Ukulinga (0.88 t/ha). Lablab was effective in weed suppression in Bergville ($P<0.05$). Cowpea performed best in weed suppression in Ukulinga ($P<0.05$). Lablab showed to be the best in reducing weed species diversity and cowpea showed to be the best in reducing weed species diversity in Ukulinga. Cowpea showed to be effective in improving soil macrofauna abundance in Bergville with (39 species counts). Lablab proved to be the best in improving soil macrofauna species abundance in Ukulinga (57 species counts). Cowpea and lablab showed to be the highest in improving soil macrofauna diversity in Bergville. Lablab and Mucuna pruriens had the highest soil macrofauna species diversity in Ukulinga. It can be concluded that cowpea and lablab can be recommended for use under conservation agriculture to suppress weeds and to improve soil macrofauna species abundance and diversity in South Africa. Farmers will also improve their profit due to reduced herbicide use for weed control.

Keywords: conservation agriculture, weed suppression, soil macrofauna, cowpea, lablab

CHAPTER ONE

General introduction

1.1 Background to the study

Sustainable crop production is dependent on good agricultural practices. Tillage practices have a great impact on the soil properties and have an influence on the microbial community in the soil. Frequent soil tillage often results to land degradation as a result of soil erosion, soil compaction, and this is a major problem that farmers are facing in crop production (Hamza and Anderson, 2005). Conservation agriculture is one of the practices that can sustain soil properties and improve crop yields. Therefore there is a need to practice conservation agriculture.

Conservation agriculture is the use of agricultural practices that have minimal soil disturbance (Sarker et al., 2012). It is comprised of three pillars which are no-till, mulch and crop rotation. These practices are more sustainable because they increase crop yields, reduce soil erosion, improve soil fertility and also reduce labour requirements (Giller et al., 2009). Conservation agriculture has been practiced for more than three decades globally for its benefits to crop production (Kassam et al., 2009). In the Sub-Saharan Africa, countries such as South Africa, Ghana and Zambia are testing conservation agriculture but their adoption is limited by constraints such as weed management. There is high labour demand for weeding where chemical control is not practiced and where there is lack of mulch to suppress weeds (Giller et al., 2009). The adoption of conservation agriculture is also hindered by the lack of information on the effect of minimal soil disturbances, crop rotation and mulch (Faroq et al., 2011). Soil compaction can be a challenge for farmers to adopt conservation agriculture, especially if there is a transition from conventional tillage to conservation agriculture. This may lead to poor drainage, restricted crop emergence and poor root development of the crop (Peigne et al., 2007).

Weeds are a major problem and their management in conservation agriculture is more difficult than in conventional agriculture. Reduced soil tillage has an impact on weed population. It has an influence on germination and growth of weed seeds that are not buried

deep in the soil (Singh et al., 2015). This may result to a compromised crop production due to high infestation of weeds (Peigne et al., 2007). The types of weeds present in cropping systems determine weed management programs (Karki and Shrestha, 2014). Annual weeds are usually easy to manage than perennial weeds. Perennial weeds are most problematic and they result in loss of crop yield (Mader and Berner, 2011).

Weed management in conservation agriculture can be achieved through the use of cover crops and herbicide application. Herbicide application can be effective in conservation agriculture if application procedures are strictly followed. It can be able to reduce weed density, species diversity and species richness for a long period of time and this helps to reduce labour cost and improve crop yield (Mabasa et al., 2014).

Using cover crops can be effective in suppressing weeds. Cover crops make a canopy that can reduce the emergence of weeds by inhibiting light which is necessary for photosynthesis, growth and development (Cordeau et al., 2015). Cover crops can be legumes or non-legumes. An example of a legume cover crop is cowpea (*Vigna unguiculata* (L.) Walp). Cowpea makes a canopy that restricts germination and growth of weed seeds (Jamshidi et al., 2012). An example of non-legume cover crop is Italian rye grass (*Lolium multiflorum* L.). It is also known to be effective in suppressing weeds (Musunda et al., 2015).

Legume cover crops do not only suppress weeds. They can increase soil organic matter content and this improves the physical, chemical and biological properties of the soil. They improve soil fertility through biological nitrogen fixation and this improves crop yields. (Bloem et al., 2009).

Cover crops also play a role in improving soil macrofauna abundance. Soil macrofauna are organisms that live in the soil. Their role is to improve soil structure, improve water infiltration rate and also organic matter content (Lai, 2003). Examples of soil macrofauna are earthworms, termites and ants. These soil macrofauna are also important in nutrient cycling (Bhadauria and Saxena, 2009).

Soil macrofauna abundance is influenced by agricultural practices such as tillage, soil moisture, mulch and soil pH. Frequent soil tillage reduces soil macrofauna abundance. (Chan, 2001). Conservation agriculture has less effect on soil macrofauna abundance because there is less soil disturbance (Kladivko, 2001).

1.2 Problem statement

Weed infestation in conservation agriculture is a major challenge in crop production and can reduce yields by about 80% (Cousens and Mortimor, 2001). The use of herbicides is a common practice to control weeds in conservation agriculture. The continuous application of these herbicides with the same mode of action is problematic and could lead to herbicide resistance (Vencil et al., 2012). This is particularly a major problem on smallholder farms under no-till, and smallholder farmers who often cannot afford herbicides. These farmers often times apply the wrong rate of herbicides thus making the herbicides to be ineffective in weed management. The combined effects of misapplication and continuous use of herbicides can lead to herbicide resistance. This means that weed management in smallholder farms is problematic. There is therefore a need to investigate alternative methods for weed management in no-till practices among smallholder farmers. Such alternative practices include the use of different cover crops. There is little information on the mechanisms that may explain cover crops and their effect on weed suppression, soil macrofauna abundance and diversity on smallholder farmers practicing no-till systems. It is proposed that different legume crop species planted as cover crops may vary in their ability to create niche conditions that are unfavourable for weed growth and thus suppressing weeds, while at the same time creating conditions favourable for increased soil macrofauna abundance for improved soil fertility and crop yield.

1.3 Aim of the study

The main aim of the study is to gain further understanding on the ability of different legume crops to act as cover crops and their effect on weed suppression and relative abundance of soil macrofauna and maize under conservation agriculture.

1.4 Specific Objectives

To assess the effect of three different legume cover crops under conservation agriculture on weed species dynamics.

To investigate the effect of three different legume cover crops under conservation agriculture on soil macrofauna abundance and diversity.

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CHAPTER TWO

Literature review

2.1 Introduction

Tillage is the manipulation of soil in order to provide conditions that are favourable for seed germination, seedling emergence, establishment and crop growth. However tillage practices can influence weed seed germination by mixing weed seeds in the soil profile and exposing them to light. As a result, there has been a growing trend in the past few years towards reducing frequent soil tillage in cropping systems to allow stubble retention and improvement of soil structure (Chauhan et al., 2006).

Conservation tillage is any cropping system which results in a sustainable agriculture and conservation natural resources. These tillage systems are socially acceptable by both commercial and smallholder farmers for their benefits such as reduced compaction and soil property improvement (Hobbs, 2007). No-till is defined as a tillage practice that leaves the soil undisturbed from harvest to planting (Anastasios et al., 2009). Triplett and Dick (2008) defined no-till as a process whereby crops are planted in unprepared soils with at least 30 % mulch cover. No-till has brought a thorough change in agricultural systems, allowing farmers to manage great amounts of land with so many benefits. This type of tillage is advantageous to smallholder farmers because it reduces labour costs and machinery inputs (Triplett and Dick, 2008). Land degradation is one of the biggest problems which farmers are concerned with and it leads to loss of nutrients that are essential for crop production. No-till can be used as an effective control measure for land degradation, furthermore it can improve water and fertilizer use efficiency and this helps to improve crop yield (Triplett and Dick, 2008).

If no-till is used properly it can improve crop yield in time through conserving moisture; this can be possible even under areas where rainfall is erratic. (Corbeels et al., 2014). However, it is important that both commercial and smallholder farmers should take note that planting when soils are too wet may result in soil compaction (Karki and Shestha, 2014). In a long term study of no-till that was done in Gaochan in the North China Plain, it has been found that no-till practice resulted in improved crop yield and significant improvement of soil quality. There was an improvement of soil properties such as soil organic matter, soil nutrient status, soil porosity and soil moisture after practicing no-till. (He et al., 2011).

Crop production is affected by soil pH, soil nutrients, insect pest, diseases and weeds. Weeds pose a big threat in crop production and can cause a major reduction in yield. In Bergville, weeds and soil acidity are the biggest challenges that smallholder farmers are facing. This is further exacerbated by the fact that smallholder farmer's still lack skills and information on how to manage weeds and soils in order to get good crop production (formal farmers meeting). The potential of pest damage to crop production has been compared globally, and results show that weeds have the highest potential to reduce crop production compared to insect pests and diseases (Oerke, 2006). Weeds have a high potential to compete with the main crops for limited resources such as light, nutrients and water and this result to poor crop yield. Competition caused by high infestation of weeds can reduce crop yield even when rainfall is adequate (Abdin, 200).

2.2 Classification of weed species

Weeds can be annual, biennial or perennial and they differ in the ability to survive with soil disturbances. Annual weeds may take one season to complete their life cycle. They are able to invest in generative structures and they produce seeds that are durable and easily dispersible (Klimesova et al., 2007). An example of annual weed is *Bidens pilosa* L. commonly known as black jack. Biennial weeds complete their life cycle in two seasons. An example of biennial weed is bull thistle (*Cirsium vulgare* (Savi) Ten). It has a branched tap root that makes it to be competitive in crop production (Holm et al., 1997). Perennial weeds take more than two seasons to complete their life cycle. They invest in underground storage organs and they bear buds which may serve for vegetative propagation, these help them to be more competitive and more aggressive even after disturbance (Klimesova et al., 2007). Some perennial weeds have long tap roots that make them to be competitive, utilizing the limited nutrients in the soil. An example of a competitive perennial weed that has a long tap root is *Sida cordifolia* L. (Grabandt, 1985).

Weeds can be parasitic. Weeds such as *striga asiatica* (L.) Kuntze, commonly known as the witch weed is known to be the worst parasitic weed in maize and sorghum production. This weed is capable of removing resources from the crop and this leads to a severe crop yield reduction (Teasdale et al., 2007). Some weeds are alleopathic and may have a negative effect on the cultivated crops. For example; methanolic extracts of tubers of *cyperus esculentus* L. contain compounds that reduce crop growth. These extracts inhibit the growth of oat

coleoptiles, and germination of *Beta vulgaris* L., *Lactuca sativa* L., *Pisum sativum* L., and *Lycoperiscum esculantum* (Tames et al., 1972).

2.3. Weed management

The management of weeds need attention and must be directed at managing weed seedlings because they compete with cultivated crops later in the season. Keeping the environment free of weeds is expensive. The expense of controlling weeds includes the use of herbicides, human labour, as well as machinery (Zaviehmaradat et al., 2013). In the Sub-Saharan Africa, weed management is a challenge especially for smallholder farmers, this is due to insufficient and inadequate weed management strategies and this leads to poor crop yields (Chauhan et al., 2012). For example, wrong application of herbicide is a sign of poor weed management due to lack of knowledge. Management of weeds should not be done only for direct effect that weeds cause on cultivated crops, like competing for limited resources. Special attention should also be given to management of weeds that harbour insect pests and diseases that may have an impact in reducing crop yield. Weeds that harbour insect pests and diseases should be managed at an early stage of their growth before insect pest and diseases infest them. If they are not controlled they may harbour high levels of pest and disease infestation that may be difficult to control. Usually, the incidence of insect pest attack on crop production is influenced by weeds that are of the same family with the cultivated crops, this makes it easier for insect pests to disperse and feed on the crops (Capinera, 2005).

Weed management is one of the biggest challenges in conservation agriculture and it is more difficult to manage than in conventional systems, due to high weed seed bank, high weed densities, their complex competition trend and their growing pattern (Bajwa, 2014). Weed seeds that are not buried in deeper soil layers may have the ability to emerge earlier because of more favourable conditions for germination near the soil surface (Singh et al., 2015). Problems in weed management range from the control of the pre-plant fallow vegetation, the choice of herbicides and herbicide resistance. Herbicide resistance on weed populations began in the 1940s with the introduction of synthetic herbicides. In 1995, glyphosate herbicide was reported to be resistant to some weed populations (Shanner, 2014). On the other hand frequent tillage is being reduced in conservation agriculture and this may provide an environment where weeds survive and reproduce (Chauhan et al., 2012). Therefore this may lead to an increase in herbicide reliance by farmers, leading to difficulties in controlling

weeds that are resistant to herbicide. Alternative weed management practices to annual weeding should be used in conservation agriculture to control weeds.

2.4. Weed management practices in conservation agriculture

2.4.1. Herbicide application

Controlling weeds through herbicide application in conservation agriculture can reduce weed density and weed diversity; and this is advantageous because it can have a long term effect in saving labour costs (Muoni et al., 2014). However perennial weeds are the most problematic in all tillage systems and this result in great dependence on herbicide application by farmers. According to Chauhan et al. (2006), the amount and cost of herbicide that farmers use in conservation agriculture is the same as that used in conventional agriculture. Perennial broadleaf weeds should be controlled by systemic herbicides at a growth stage when translocation towards the underground plant structure is maximized. In terms of perennial grass weeds, they can be managed by post emergence herbicide such as glyphosate and nicosulfuran. (Karki and Shestha., 2014).

Glyphosate is essential in crop production, because it kills a broad spectrum of weeds. The suppressive effect of glyphosate herbicide is effective when the herbicide is applied more than once (Muoni et al., 2014). However, continuous application of glyphosate herbicide may lead to herbicide resistance to some of the weeds. Some weeds are able to adapt to frequent glyphosate application, causing it to be less effective for control (Green et al., 2011). Herbicides of different modes of action should be applied to avoid herbicide resistance. It has been reported that weeds such as *Amaranthus spp*. have developed resistance against glyphosate herbicide. Farmers need to understand that continuous application of glyphosate herbicide without alternative weed management strategies may lead to an evolution of more weeds resistant to glyphosate (Nandula et al., 2005).

2.4.2. Allelopathy

Allelopathy is the adverse effect of one plant on the other plant due to direct or indirect release of chemicals from live or dead plants (Bhadoria, 2011). Allelopathy has been described by the Romans as a process that results in sickening of the soil, and De Candolle, one of the early plant scientists, described allelopathy as the ability of plant roots to produce toxic exudates (Weston, 2005). Farooq et al. (2013) defined allelopathy as a naturally ecological phenomenon of interference that occurs amongst organisms. These organisms may be used to manage weeds, insect pests and diseases in field crops. This is a very important aspect and has lately been focused on as a weed management strategy (Weston, 2005).

Allelopathy is environmentally friendly can be used as an alternative to herbicide application for weed management (Farooq et al., 2010). Management of weeds in conservation agriculture through allelopathy can be done using cover crops, mulch and plant extracts that are allelopathic or by using allelochemicals as a natural herbicide (Singh et al., 2003). Allelochemicals can be extracted from seeds, leaves, flowers, stems and roots of living or decomposing plant materials (Khalid et al., 2002). Examples of plants that contain allelopathy include mexican marigold, carlifonia pepper and mulberry; these plants have the potential to manage weeds, diseases and insect pests (Farooq et al., 2010). Plants that are allelopathic can also be incorporated in the soil for weed management, this may reduce the need of herbicide application. Some agricultural crops are allopathic and have been recorded to be effective in controlling some of the agricultural weeds. Khaliq et al., (2010), showed that a combination of sorghum (*Sorghum bicolour* L.) and brassica residues at 7.5 t/ha provided 90% suppression on density and biomass of horse purslane weed (*Trianthema portulastrum* L.) and purple nutsedge (*Cyperus rotundus* L.). In Pakistan, crop residues of sorghum, sunflower and brassica residues were incorporated in the soil. They delayed the germination and seedling growth of jungle rice (*Echinochloa colona* (L.) Link). These observation shows that crop residues can be effective provided that maximum levels of phytotoxins entering the soil find the early growth and development of jungle rice (Khaliq et al., 2011). Some legumes that can be used as cover crops also contain allelopathic chemicals, for example leaves of cowpea (*Vigna unguiculata* (L.) Walp), sunhemp (*Crotalaria juncea* L.) and velvet beans (*Mucuna pruriens (*L.) DC) are allelopathic. Their extracts that can reduce the germination of goose grass weed (*Eleusine indica* (L.) Gaerth). The extracts from cowpea leaves can also suppress *Amaranthus spp*. weed by 50% and the velvet bean extracts can suppress *Amaranthus spp*. weed by 22% (Adler, 2007).

2.4.3. Cover crops

Cover crops are important for sustainable crop production. Their attribute is to be able to establish rapidly under less ideal conditions as well as to provide a good soil cover (Frageria and Bailey, 2005). Cover crops provide many benefits in crop production, they enhance soil quality by improving biological, chemical and physical properties of the soil such as organic matter content and cation exchange capacity. They also improve soil water infiltration (Dabney et al., 2001) and can be used as green manures where they can be ploughed into the soil. Cover crops can be legumes or non-legumes. Non-legume cover crops have a high utilization of nitrogen while legume cover crops utilize low nitrogen available in the soil profile (Frageria and Bailey, 2005). Low utilization of soil available nutrients by legume plants help to increase the concentration of plant nutrients in the surface layer of the soil (Frageria and Bailey, 2005). Legumes such as cowpea, pigeonpea and soybean can be used as cover crops in maize production (Tsubo et al., 2003). They improve crop yield and profitability by enhancing soil fertility and repelling insect pest and disease that attack maize crop (Matusso et al., 2014). Legumes such as Crimson clover (*Trifolium incarnatum* L.) can serve as a habitat for predator insects and may also act as a non-host for nematodes (Lu et al., 2000). This can help to reduce the impact of damage that may be caused by insect pests that may feed on cultivated crops.

Weed suppression by cover crops can be used as an alternative to herbicide application in conservation agriculture (Wortman et al., 2013). They help in reducing weed germination, growth and development and they achieve this by restricting the incoming radiation which is needed by weeds for growth. Competitive cover crops have the potential to fix carbon and capture nutrients and thus leading to a change in the dynamics and availability of nutrients for the weeds to grow and develop (Teasdale et al., 2007). An example of such cover crop is Hairy vetch (*Vicia villosa* Roth) which has been shown to suppress weed emergence eliminating the need of applying pre-emergence herbicide in cropping systems (Lu et al., 2000). Although cover crops suppress weeds, they can also be of disadvantage when they start competing for limited resources with crops. It is therefore important to grow cover crops that have less adverse effects on the crops. The potential of cover crops to suppress weeds may depend on the growth habit of the cover crop and the season in which it is planted (Uchino et al., 2009).

Cowpea is an effective cover crop that can be used for weed suppression and is suitable to be used in crop production. Its effectiveness to suppress weeds is influenced by its growth habit as well as the planting spacing used. Cowpea has the ability to develop over-ground runners which can occupy the inter-row spaces of maize (Bilalis et al., 2010). This leads to a decrease of light interception by weeds often resulting to a reduction in weed biomass and density. Cowpea also has the potential to restrict the germination on weed seeds (Jamshidi et al., 2013). This cowpea has been found to be effective in suppressing *Amaranthus Spp* species growth and development which is known to be resistant to glyphosate herbicide (Zaviehmaradat et al., 2013).

Although cover crops are known to be effective in weed suppression, weed types also play a role in the effectiveness of the cover crop to suppress them. A study that was done in New York showed that annual weeds are better suppressed than perennial weeds by cover crops (Mishler et al., 2010). This hairy vetch was effective in suppressing annual broad leaf weeds and annual grass weeds but failed to suppress perennial weeds (Mishler et al., 2010). This is because perennial weeds have larger nutritional reserves and their faster establishment makes them to be better competitors than annual weeds (Teasdale, 2001). There is limited information on the quality of cover crops in South Africa regarding weed suppression; hence this study addressed this knowledge gap.

2.4.4. Cover crops as mulch

Cover crop mulch is defined as the technology whereby at least 30% of the soil is covered by organic residues at the time of crop emergence (Erenstein, 2003). Cover crop mulch is often associated with reduced soil tillage. Using this technique is more likely to be accepted by farmers, because of the benefits it brings such as, improvement of soil fertility, improved cost savings from reduced soil tillage (Erenstein, 2003). The cover crop residues can also be used to improve soil moisture by creating a cover and this makes it an effective measure for mitigating negatives effects of erratic rainfall (Corbeels et al., 2014).

Cover crop mulch can be used as a measure to manage weeds in farms where no-till is practiced. Legume mulch that produces large biomass even in hottest months of the year can be advantageous to smallholder farmers for weed suppression. Cowpea mulch applied in pepper production (*Capsicum annuum* L.), provided weed control without herbicides being

applied, and this also improved plant growth and fruit production (Hutchinson and McGiffen, 2000). This can be beneficial to smallholder farmers who cannot afford herbicide costs and labour costs for weeding. Velvet bean (*Mucuna pruriens* L.) cover crop mulch can also be used to control weeds. It has the ability to suppress weeds by at least 68%, reducing the cover that can be formed by weeds. Velvet bean mulch can also reduce weed seed germination by inhibiting light needed by the weed seeds (Caamal-Maldonado et al., 2001). Some weed seeds require light to break their dormancy, so when light is inhibited to weed seeds, germination is most likely not to happen. The delaying of weed seed germination improves the crop yield, because there will be reduced competition between the weeds and the cultivated crops.

2.5. Cover crops and biological nitrogen fixation

Nitrogen is the most important element that is required for crop production, especially cereal production. Smallholder farmers in South Africa are mostly dependent on available organic resources to maintain their soil fertility while wealthy farmers depend on mineral fertilisers to maintain their soil fertility (Mtambanengwe and Mapfumo, 2002). Live cover crops enhance nitrogen availability through biological nitrogen fixation. Biological nitrogen fixation occurs in nature and is the cheapest source of nitrogen especially for humid acid soils (Cordora-Sanchez et al., 2013). Legume cover crops fix nitrogen and this reduces the need to apply nitrogen fertilizer, saving costs for buying mineral fertilisers (Liu et al., 2011). Biological nitrogen fixing legumes contribute significantly amounts of nitrogen in both natural and managed ecosystems (Mpepereki and Pompi, 2002). For example velvet bean enhances soil fertility by fixing nitrogen, however its competition with maize crop can be high due to its twirling behaviour resulting in low maize yields (Sakala and Mhango, 2002). *Mucuna deerengiana* L. has the ability to withstand unfavourable conditions such as acid soils. It has the ability to fix nitrogen, and it performs best when compared with other legumes such as *Cajanus cajan* L., *Phaseolus lunatus* L. and *Sesbania emerus* (L) Kuntze. *Mucuna deerengiana* L. also became best in increasing the level of nitrogen in the soils without application of chemical fertilisers (Codora-sanchez et al., 2013). Okito et al (2004) also confirm that *Mucuna* species have high ability of fixing nitrogen since they have the highest nitrogen uptake when compared to groundnut. Cowpea also fixes nitrogen and can be

effective in both low and high rainfall areas. Its benefits to the soil can be used to improve crop yields when used as rotational crop (Nhamo and Mupangwa, 2002).

2.6. Soil macrofauna abundance

Soil is known to be made up of organic matter and minerals. It provides a habitat where soil macrofauna can survive and this can influence their abundance and hence improve soil health (Begum et al., 2014). Soil health is defined as the capacity to function as a vital living system, within ecosystem and land-use boundaries, to sustain plant and animal productivity and to promote plant and animal health (Doran and Zeiss, 2000). Soil macrofauna plays an important role in improving soil health, this contributes significantly to a sustainable crop production. They are useful for improving soil structure, and nutrient cycling. Impacts caused by human beings and natural events change soil health over time, therefore soil health needs to be maintained (Doran, 2002). Integrated soil fertility management can be used to improve soil health, agricultural productivity and macrofauna abundance (Ayuke, et al., 2011).

Soil fauna are catergorised into three groups namely: microfauna, mesofauna and macrofauna, hence in this review the focus is on macrofauna. Examples of soil macro-fauna include: earthworms, termites, ants, millepedes and centipedes. Earthworms are known as soil engineers because of their activity in most soils worldwide (Rombke et al., 2005). They are essential in nutrient cycling, incorporating detritus into mineral soils more rapidly. They secrete mucus which enhances the activity of other soil micro-organisms (Bhadauria and Saxena, 2009). Earthworms are also essential in improving soil structure, soil chemistry and decomposing organic matter (Rombke et al., 2005). Earthworms are classified into three categories namely: Epigeics, aneics and endogeics. Epigeic earthworms are small and reddish in colour. They live above the mineral soil surface and they do not make any burrows. Epigeic earthworms have a short life cycle. Aneic earthworm lives in the mineral soil layers and makes burrows up to 3 M. They are dark in colour, large and slow moving. Endogeic earthworms are whitish in colour and they live in mineral soils in the upper most 10-15 cm making horizontal burrows that are not permanent (Rombke et al., 2005).

Termites fall under the family Isoptera and they are also known to be soil engineers that have the ability to survive in arid and semi-arid environments. They are beneficial to the ecosystem by distributing natural resources such as nutrients, water and soil microbes

(Jouquet et al., 2011). The benefits of termites to the ecosystem are more important in dry land agriculture and their importance becomes increasingly important in sustainable smallholder agriculture. Termites help to improve soil water infiltration through the tunnels they make. These tunnels can be deep, helping to reduce evaporation from the soils. Lower evaporation helps to improve water utilisation by the plant resulting in improved crop yield. However all these benefits that the termites bring to the ecosystem depend on the soil type and organic matter content in different seasons and climates (Evans et al., 2011). There is little information on the effect of cover crops on soil macrofauna abundance, hence this study addressed the knowledge gap in this field.

2.7. Factors that influence soil macrofauna abundance

Macrofauna abundance is the total number of individuals per unit area (Mutema et al., 2013). The abundance of macrofauna can be influenced by several factors such as tillage practices, pesticide applications, soil moisture content and soil pH.

2.7.1. Tillage practices

The primary objective of tillage is to prepare the seedbed for planting, however tillage systems can affect the physical and chemical properties of the soil. Tillage affects soil water content, soil temperature and soil aeration as well as the environment in which soil organisms lives. The understanding of soil ecology is needed in order to manage soil macrofauna for agricultural production purposes. If soil macrofauna are affected, this means that the ecological processes in the soil will be disturbed, especially soil nutrient cycling (Black and Okwakol, 1997). Frequent soil tillage practices have an impact in changing the dynamics and diversity of soil macro-fauna. Larger soil organisms such as earthworms are more sensitive to soil disturbance than the smaller organisms found in the soil (Kladivko, 2001). Deep burrowing earthworms are sensitive to deep ploughing and this reduces their number. Their abundance and activity can be reduced when the burrows are destroyed, and when the soil physical conditions such as moisture and temperature is changed (Chan, 2001). Frequent soil tillage also reduces the number and diversity of termites. This means that the activities carried out in the soil by termites will be reduced. This can have a negative impact in soil organic matter decomposition and nutrient cycling resulting in reduced soil fertility (Black

and Okwakol, 1997). Soil compaction which mainly results after frequent soil tillage can affect the survival of soil macrofauna. Radford et al. (2001) found that heavy machinery such as tractors working in wet soil can cause soil compaction, reducing earthworm populations and abundance of other types of soil macro-fauna. Soil compaction results in poor aeration of the soil resulting in poor survival of the soil macrofauna.

In conservation agriculture, reduced tillage practices have a positive effect in soil macrofauna abundance than frequent tillage practices. A study was done in Zimbabwe were tillage practices were reduced, this had a positive effect on soil macrofauna abundance, also improving the species richness of soil macrofauna. Reduced tillage practices helps to protect the soil and this improves macrofauna activity (Mutema et al., 2013). In another study conducted in Zimbabwe, minimal soil disturbances had a less impact on the termite nest, and this increased the abundance of termites (Mutsamba et al., 2010). This means that the adoption and practice of conservation agriculture can result in good soil health as a result of improved decomposed organic matter, improved water infiltration and improved soil fertility due to an increase in soil macrofauna abundance.

2.7.2 Cover crops

Cover crops can be used to improve soil macrofauna activity. The earthworms are regarded as the major components of soil fauna communities. Earthworms are known to be more active in humid and sub-humid tropics. A study has been done in the southern part of Benin at Agonkanmey, on sandy-clay soil using maize and velvet bean cover crop. Velvet bean improved the development of earthworms, millepedes, centipedes and beetles and that improved soil structure and nutrient availability. Furthermore, velvet bean cover crop managed to restrict the phytophagus nematodes such as meloidogyne, which is known to have harmful effects on crops (Lai, 2003). There is little information on the effect of cover crops on soil macrofauna abundance, hence this study addressed the knowledge gap.

2.7.3. Soil moisture

Not many studies have documented the effect of soil moisture on soil macrofauna abundance. Most soil invertebrates are known to be highly vulnerable to low soil moisture caused by erratic rainfall (Staley et al., 2007). Rainfall has an influence in the abundance of soil macrofauna and the way that they behave. It has been found that high soil moisture has the potential to increase termite activity in the soil. This helps to improve the breaking down of organic matter, improve the turning over of the soil as well as nutrient cycling (Black and Okwakol, 1997). Beetles are also known to increase in number in soils that have high moisture level while ants can tolerate dry soil conditions (Staley et al., 2007). These means that in dry soils the improvement of organic matter decomposition will be less compared to moist soils due to low abundance of soil macrofauna.

2.7.4. Soil pH

Soil pH affects the survival and abundance of soil macrofauna. Soil macrofauna cannot adapt to all soil types and pH, they only adapt and increase their population in areas where soil pH is favourable for them. The survival of soil macrofauna is often limited in soils that have a very low pH. In tropical soils, soil macrofauna can tolerate a pH of 3.8 to 4.0 than soils in temperate areas. Soil burrowing macrofauna such as earthworms and termites have a very low potential to survive in acidic soils (Lavelle et al., 1995). Their population tends to decrease in acidic soils and this will have an impact on the decomposition of organic matter and nutrient cycling thus reducing the quality of the soil.

2.7.5. Pesticide application

Application of pesticides is very important in crop production. Pesticide application enhances the production of crops provided they are applied at the right time and correctly. Insecticides have an impact in the survival of soil macrofauna, their abundance as well as their diversity. Chloropyrifos, an organophosphate insecticide that is meant to control insect pest has a negative impact in the life of soil macrofauna. Earthworms, termites and ants are also susceptible to this insecticide application, and it reduces their abundance (Ouedraogo et al., 2006). Insecticide application that reduces this kind of soil macrofauna results in a major reduction of soil improvement because earthworms and termites are known to be the key engineers in soil health.

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CHAPTER THREE

Screening for cover crops for conservation agriculture and weed dynamics

Abstract

Weeds are problematic in conservation agriculture where herbicides are expensive for smallholder farmers. The use of cover crops can help to suppress weed growth and development by creating an environment which is not suitable to weeds survival. Cowpea (*Vigna unguiculata* (L.) Walp) dolichos lablab (*Lablab purpureus* L.) and velvet bean (*Mucuna pruriens* (L.) DC) were evaluated for biomass accumulation and weed suppression under conservation agriculture system in two contrasting agroecological zones: Ukulinga and Bergville in KwaZulu-Natal. Bare plot and herbicide treatments served as controls. Treatments were laid in a randomised complete block design, replicated three times. *Mucuna pruriens* (L.) DC had the highest biomass accumulation in both sites Bergville (0.72 t/ha) and Ukulinga (1.59 t/ha). Cowpea had the lowest biomass accumulation in Bergville (0.59 t/ha) and lablab was the lowest in Ukulinga (0.88 t/ha). Lablab was effective in suppressing weed biomass in Bergville ($P<0.05$). Cowpea performed best in suppressing weed biomass in Ukulinga ($P<0.05$). It was concluded that cowpea and lablab can be effective for weed suppression and therefore can be recommended for use in conservation agricultural systems.

Keywords: weed suppression, cover crop, weed biomass, weed abundance, weed diversity.

3.1 Introduction

Weed management in conservation agriculture is more problematic than in conventional agriculture because weeds that are not buried deep in the soil have the ability to germinate and emerge vigorously (Singh et al., 2003). This is more so with perennial weeds and this results in loss of crop yield (Mader and Berner, 2011). Weeds compete with crops for limited resources such as water, light and nutrients. The use of herbicides is a common practice to control weeds in conservation agriculture. However the continuous application of herbicides with the same mode of action is problematic and could lead to herbicide resistance (Vencil, et al., 2012). This is particularly a major problem on smallholder farmers practicing no-till since some cannot afford to use herbicides with different mode of action. The use of manual weeding can be used to manage weeds but it is labour demanding.

Cover crops can be used as an alternative to herbicide application by smallholder farmers. Cover crops are important for sustainable crop production providing various benefits such as soil quality improvement by improving biological, chemical and physical properties (Dabney et al., 2001). Legume cover crops help in improving soil fertility through biological nitrogen fixation (Matusso et al., 2014). Legume cover crops have the potential to utilize low available nutrients compared to cereal cover crops that utilize a lot of nitrogen (Frageria and Bailey, 2005). Smallholder framers can use legumes as cover crops because they result in high economic returns with minimal fertiliser application in crop production (Murungu, 2012). A number of legumes have been tested for weed suppression and can be applicable for smallholder farmers practicing conservation agriculture. Cowpea is known to be effective in weed suppression and can be suitable to be used in crop production systems. Its ability to suppress weeds is influenced by its growth habit. Cowpea develops a spreading canopy which can decrease light interception for weeds, thus reducing weed biomass and weed density (Bilalis et al., 2010). Cowpea has been found to be effective in suppressing *Amaranthus spp* (Zaviehmaradat et al., 2013). Grazing vetch is also known to be effective in weed suppression reducing weed species diversity. A study done in South Africa found that grazing vetch reduced weed density by 80% (Murungu et al., 2010).

Most of the work on cover crops has concentrated on conventional tillage systems and in other countries other than South Africa. However there are few studies which have documented performance of legume cover crops across different ecological zones in South

Africa. Hence the objective of this study was to evaluate the effect of legume cover crops on weed biomass and weed species diversity in South Africa.

3.2. Materials and methods

The study was carried out in two contrasting areas (Bergville and Ukulinga) both situated in KwaZulu-Natal province. The two sites were different in soil properties. Annual rainfall of Bergville was 643 mm and the temperature ranged from 19.3º C to 27.9º C. The monthly data for rainfall and temperature in Bergville could not be found. Monthly rainfall and temperature are shown in Table 3.1 while soil chemical and properties are shown in table 3.2.

Table 3.1: Monthly rainfall and temperature in Ukulinga 2015.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Min temp º C	16.03	15.60	15.68	12.02	11.88	8.93	8.94	10.92
Max temp º C	27.66	26.47	27.04	23.90	25.96	22.20	21.13	24.51
Rainfall mm	132.80	143.00	82.20	0	5.02	2.02	32.99	3.04

Table 3.2: Soil chemical and physical properties in Bergville and Ukulinga before planting

Site	sand %	silt %	clay %	pH (KCI)	Total N%	Org C %	P (mg/kg)	K (mg/kg)
Bergville	26	17	59	3.83	0.23	2.2	7.9	165
Ukulinga	38	26	36	9.61	0.23	2.5	13.59	133

3.3. Experimental design

Four legume cover crops were evaluated for weed suppression and biomass accumulation. The cover crops were cowpea (V*igna unguiculata* (L.) Walp), velvet bean (*Mucuna pruriens* (L.) DC, dolichous (*Lablab purpureus* (L.)) and grazing vetch (*Vicia darsycarpa*). However grazing vetch had a poor germination and thus resulted in poor growth and development. This led to grazing vetch being removed from the comparison to other cover crops. The treatments were laid in a randomised complete block design, replicated three times. Bare plot and herbicide treatments served as control where no cover crops were grown. Each plot size was 10 m x 5 m. Glyphosate was applied once in herbicide treatment at a rate of 1.5% per 10 L. The maize and cover crops were planted at the same time in holes opened up by a hand hoe.

Planting was done during the second week of January 2015. The maize cultivar used was Nelson's Choice open pollinated variety, planted at a spacing of 75 cm x 35 cm and all cover crops were planted at a spacing of 15 cm x 30 cm to create a dense cover. Superphosphate fertiliser was applied during planting at 20 kg/ha in Ukulinga and 55 kg/ha in Bergville. Weeding was done once in all treatments, by hand hoeing after 4 weeks of planting. Urea (46% N) was applied two days after weeding at a recommendation of 120 kg/ha to maize crop. However in Bergville maize did not germinate and thus sole maize treatment is reported as bare plot in the results section. In Ukulinga the maize germinated; however there was no yield collected due to uncontrollable circumstance of wild pigs that fed on the maize crop.

3.4. Sampling

Soil samples were taken prior to commencement of study. The dry matter production for cover crops was determined at 8, 12 and 16 weeks after planting. The potential of the cover crops to suppress weeds was determined by measuring the weed biomass at 8, 12 and 16 weeks after planting. Both the weed biomass and cover crop biomass was estimated from a sample by harvesting the above-ground vegetative growth in a quadrat of 0.5 m^2 that was placed randomly on three sampling points in each plot. The weed samples were oven dried at 70^o C for 72 hours. The cover crop dry matter was also oven dried at 70^o C for 72 hours. Weed species counts were measured and harvested within the 0.5 m^2 quadrat. Weed species were identified according to their growth habit using their biological nomenclature.

3.5. Data analysis

Weed biomass, cover crop biomass, weed species richness, weed species diversity and abundance were square root transformed before the analysis to meet the assumption of ANOVA. Weed biomass and cover crop biomass were subjected to analysis of variance (one way ANOVA) using the Genstat 14th edition. Weed species diversity was calculated using Shannon-Wiener diversity index. Species richness was calculated using Margalef Index (Margalef, 1958) and was then subjected to Genstat 14th edition for analysis of variance. The formula used for Margalef Index is: d= (S-1) In N. Where:

S = number of species

N = total number of individuals in the sample

Least significance difference (LSD) was used to detect mean differences amongst the treatments at $P<0.0.5$

3.6. Results

3.6.1. Cover crop biomass accumulation in Bergville and Ukulinga

There was no significant interaction between treatments and sampling time in Bergville ($F_{(4,16)}$ =2.86, P= 0.05) (ANOVA in appendix A). Cover crop biomass showed significant difference across treatments (P< 0.05) (Table 3.3). Velvet bean (0.72 t/ha) had the greatest biomass and was significantly different to cowpea (0.59 t/ha) and lablab (0.65 t/ha).

There was no significant interaction between treatments and sampling times in Ukulinga ($F_{(4,16)}$ = 1.48, P=0.25) (ANOVA in appendix B). Cover crop biomass showed significant difference across treatments (P<0.05) (Table 3.3). Velvet bean had the highest biomass (1.59 t/ha) and was significantly different to cowpea (0.98 t/ha) and lablab (0.88 t/ha) which showed no significant difference.

Table 3.3: Cover crop biomass accumulation in Bergville and Ukulinga (t/ha)

Treatment	Bergville	Ukulinga
Cowpea	0.59 a	0.98 a
Lablab	0.65 b	0.88 a
Velvet bean	0.72 c	1.59 b
LSD	0.05	0.39

Means with different letters show significant difference at P<0.05.

3.6.2. Weed species dynamics in Bergville and Ukulinga

3.6.2.1. Weed species identified.

Different weed species were observed and identified in this study. The weed species range from annual to perennial weed species. Ukulinga had 32 weed species and Bergville had 14 weed species (Table 3.4). The most dominant weeds in Ukulinga were: *Oxalis latifolia* H.B.K, *Bidens pilosa* L., and *Commelina benhelansis*. In Bergville the most dominant weeds were: *Acanthospermum australe* (loefl.) Kuntze, *Leucas martinicensis* R.Br and *Cleome monophylla* L.

Table 3.4: Weed species identified in Bergville and Ukulinga

weed species	Annual	Perennial	Family	Bergville	Ukulinga
Acanthospermum australe (loefl.) Kuntze	x		Asteraceae	x	x
Ageratum conyzoides L.	x		Asteraceae	x	x
Alternanthera pungens H.B.K		x	Amaranthaceae	x	x
Amaranthus thunbergii Moq	x		Amaranthaceae	x	x
Bidens pilosa L.	x		Asteraceae	x	x
Cleome monophylla L.	x		Capparidaceae	x	x
Commelina benghalensis L.	x		Commelinaceae		x
Conyza bonariensis (L.) Cronq	x		Asteraceae		x
Conyza cadanadensis (L.) Cronq	x		Asteraceae		x
Corchorus olitorius L.	x		Tiliaceae		x
Datura stramonium L.	x		Solanaceae	x	x
Euphorbia inaequilatera Sond	x		Euphorbiaceae		x
Hibiscus trionum L.	x		Malvaceae		x
Hypochoeris radicata L.		x	Asteraceae		x
Ipomoea purpurea (L.) Roth	x		Convolvilaceae	x	x
Lactura serriola L.		x	Asteraceae		x
Lagenaria sphaerica (Sond.) Naud		x	Cucurbitaceae	x	x
Leucas martinicensis R.Br	x		Labiatae		
Nicandra physaloides Gaertn.	x		Solanaceae		x
Oxalis latifoila H.B.K		x	Oxalidaceae		x
Plantago lanceolata L.		x	Plantaginaceae	x	x
Portulaca oleracea L.	x		Portulacaceae		x
Richadia brasillensis Gomes		x	Rubiaceae	x	x
Schkuhria pinnata (Lam.) Kuntze	x		Asteraceae		X
Sida cordifolia L.		x	Malvaceae	x	X
Sida rhombifolia L.		x	Malvaceae	x	X
Solanum nigrum L. (Complex)	x		Solanaceae		X
Sonchus asper (L.) Hill	x		Asteraceae		X
Tagetes minuta L.	x		Asteraceae		X

3.6.3. Weed biomass in Bergville and Ukulinga

There was significant interaction between treatments and sampling times in Bergville ($F_{(8,28)}$ =3.99, P= 0.003) (Table 3.5) (see ANOVA in appendix C)

At week 8 lablab had the lowest weed species biomass in Bergville (0.47 t/ha) and was significantly different to bare plot but was not significantly different to cowpea, velvet bean and herbicide treatment. The highest weed biomass was obtained in bare plot (0.98 t/ha). At week 12 lablab had the lowest weed biomass in Bergville (0.58 t/ha) and was significantly different to bare plot, velvet bean and herbicide treatments. Bare plot had the highest weed biomass (1.29 t/ha) and was not significantly different to herbicide treatment (1.16 t/ha). At week 16 lablab had the lowest weed biomass in Bergville (0.32 t/ha) but was not significantly different to cowpea (0.48 t/ha) and velvet bean (0.61 t/ha). Bare plot had the highest weed biomass (1.40 t/ha) but was not significantly different to herbicide treatment (1.28 t/ha).

Bare plot had the lowest weed biomass in week 8 (0.98 t/ha) and was significantly different to week 12 (1.29 t/ha) and week 16 (1.40 t/ha) which did not show significant difference in them. Cowpea showed the lowest weed biomass in week 16 (0.48 t/ha) which was not significantly different to week 8 (0.63 t/ha). The highest weed biomass was found in week 12 (0.80 t/ha). Lablab did not show any significant difference in sampling times. The lowest weed biomass was found in week 16 (0.32 t/ha) and the highest weed biomass was found in week 12 (0.58 t/ha). Velvet bean had the lowest weed biomass in week 16 (0.61 t/ha) which was not significantly different to week 8 (0.74 t/ha). The highest weed biomass was found in week 12 (0.94 t/ha). Herbicide had the lowest weed biomass in week 8 (0.62 t/ha) and was significantly different to week 12 (1.16 t/ha) and week 16 (1.28 t/ha) which did not show significant difference in them.

Table 3.5: Weed biomass in Bergville (t/ha).

	Time of sampling		
Treatment	week 8	week 12	week 16
Bare plot	0.89 def	1.29 g	1.40 g
Cowpea	0.63 bcd	0.80 cde	0.48 ab
Lablab	0.47 ab	0.58 abc	0.32 a
Velvet bean	0.74 bcde	0.94 ef	0.61 abcd
Herbicide	0.62 bcd	1.16 fg	1.28 g
LSD	0.29		

Means with different letter show significant difference at P<0.05.

There was no significant interaction between treatment and sampling times in weed species biomass in Ukulinga ($F_{(8,28)}$ = 2.02, P=0.08) (Table 3.6) (see ANOVA in appendix D). Weed species biomass was significantly different across treatments (P<0.05). Cowpea had the lowest weed species biomass (0.53 t/ha) but was not significantly different to lablab (0.60 t/ha) and velvet bean (0.65 t/ha). Herbicide treatment had the highest weed biomass (0.92 t/ha) and was not significantly different to bare plot (0.84 t/ha).

Table 3.6: Weed biomass in Ukulinga (t/ha).

Treatment	Weed Biomass
Bare plot	0.84 bc
Cowpea	0.53 a
Lablab	0.60 a
Velvet bean	0.65 ab
Herbicide	0.92 c
LSD	0.23

Means with different letter show significant difference at P<0.05.

3.6.4. Weed abundance in Bergville and Ukulinga

There was no significant interaction with weed species abundance between treatments and sampling time in Bergville ($F_{(8,30)}$ = 1.37, P=0.24) and there was also no significant difference with weed species abundance across treatments ($F_{(4, 30)}$ = 1.94, P=0.13) (Table 3.7) (see ANOVA in appendix E).

There was no significant interaction with weed species abundance between treatments and sampling time in Ukulinga ($F_{(8, 30)}$ = 0.69, P=0.69) (see ANOVA in appendix F). Treatments showed significant difference in weed species abundance (P<0.05). Cowpea had the least weed species abundance (4.63 species) and was not significantly different to lablab (5.43 species). Herbicide had the highest weed species abundance (8.01 species) and was significantly different to the rest of the treatments.

Table 3.7: Weed species abundance in Bergville and Ukulinga

Weed species abundance		
Treatment	Bergville	Ukulinga
Bare plot	2.34 a	6.13 ab
Cowpea	1.97 a	4.63 a
Lablab	1.72 a	5.43 ab
velvet bean	2.28 a	6.30 b
Herbicide	1.75 a	8.01 c
LSD	0.59	1.58

Means with different letter show significant difference at P<0.05.

3.6.5. Weed species diversity in Bergville and Ukulinga

There was significant interaction between treatments and sampling time with weed species diversity in Bergville ($F_{(8, 120)} = 10.06$, P =.001) (Table 3.8) (see ANOVA in appendix J).

At week 8 in Bergville, lablab had the least weed species diversity (0.80 species) and was significantly different to bare plot (1.02 species), velvet bean (0.95 species) and herbicide (0.92 species). Lablab was not significantly different to cowpea. Bare plot had the highest weed species diversity (1.02 species). At week 12, herbicide had the least weed species diversity (0.95 species) and was not significantly different to the rest of the treatments. The highest weed species diversity was found in velvet bean and lablab (1.04 species). At week 16 the least weed species diversity was found in velvet bean (0.62 species) and was not significantly different to lablab (0.65 species). Herbicide had the highest weed species diversity (1.06 species) and was not significantly different to bare plot (1.04 species) and cowpea (0.99 species).

Bare plot did not show any significant difference across sampling time. The highest weed species diversity was found in week 16 (1.04 species) and the lowest weed species diversity was found in week 12 (1.01 species). Cowpea showed significant difference across sampling time with the least weed species diversity found in week 8 (0.87 species) and the highest in week 12 (1.06 species). Lablab showed significant difference across sampling time with the least weed species diversity found in week 16 (0.65 species) and the highest weed species diversity found in week 12 (1.04 species). Velvet bean showed significant difference across sampling time with the least weed species diversity found in week 16 (0.62 species) and the highest found in week 12 (1.04 species). Herbicide showed significant difference across

sampling time with weed species diversity. The least weed species diversity was found in week 8 (0.92 species) and the highest was found in week 16 (1.06 species).

Table 3.8: Weed species diversity in Bergville

	Time of sampling		
Treatment	week 8	week 12	week 16
Bare plot	1.02 de	1.01 de	1.04 de
Cowpea	0.87 bc	1.06 e	0.99 de
Lablab	0.80 b	1.04 de	0.65 a
Velvet bean	0.95 cde	1.04 de	0.62 a
Herbicide	0.92 cd	0.95 cde	1.06 e
LSD	0.11		

Means with different letter show significant difference at P<0.05.

There was significant interaction between treatments and sampling time with weed species diversity in Ukulinga ($F_{(8, 120)} = 30.23$, P =.001) (Table 3.9) (see ANOVA in appendix I).

At week 8 in Ukulinga, herbicide had the least weed species diversity (0.84 species) and was significantly different to the rest of the treatments. The highest weed species diversity was found in bare plot (1.16 species). At week 12 velvet bean had the least weed species diversity (0.75 species) and was significantly different to the rest of the treatments. The highest weed species diversity was found in bare plot (1.28 species). At week 16 velvet bean had the least weed species diversity (0.54 species) and was not significantly different to lablab (0.57 species). The highest weed species diversity was found in bare plot (1.39 species).

Bare plot showed significant difference across sampling time. The least weed species diversity was found in week 8 (1.16 species) and the highest was found in week 16 (1.39 species). Cowpea had the least weed species diversity in week 12 (0.93 species) which was significantly different to week 8 and week 16 (1.05 species). Lablab showed significant difference across sampling time. The least weed species diversity was found in week 16 (0.57 species) and the highest weed species diversity was found in week 8 (1.13 species). Velvet bean showed significant difference across sampling time. The least weed species diversity was found in week 16 (0.54 species) and the highest was found in week 8 (0.99 species). Herbicide showed significant difference across sampling time. The least weed species diversity was found in week 8 (0.84 species) and the highest weed species was found in week 16 (1.16 species).

Table 3.9: Weed species diversity in Ukulinga

	Time of sampling		
Treatment	week 8	week 12	week 16
Bare plot	1.16 g	1.28 h	1.39 i
Cowpea	1.05 ef	0.93 cd	1.05 ef
Lablab	1.13 fg	0.97 de	0.57 a
Velvet bean	0.99 de	0.75 b	0.54 a
Herbicide	0.84 bc	0.97 de	1.16 g
LSD	0.10		

Means with different letter show significant difference at P<0.05

3.6.6. Weed species richness in Bergville and Ukulinga

There was no significant interaction between treatment and sampling times with weed species richness in Bergville ($F_{(8,120)}$ =1.80, P=0.08) and there was no significance difference of weed species richness within treatments ($F_{(4, 120)}$ = 0.89, P=0.47) (see ANOVA in appendix G).

Weed species richness showed significant difference in sampling times (P< 0.05) (Table 3.10). Week 8 had the lowest species richness (0.30 species) and was significantly different to week 16 (0.58 species).

Table 3.10: Weed species richness in Bergville

Sampling time	Weed species richness
Week 8	0.30 a
Week 12	0.40 ab
Week 16	0.58 b
LSD	0.21

Means with different letter show significant difference at P<0.05

There was significant interaction between treatment and sampling time with weed species richness in Ukulinga ($F_{(8, 120)}$ =4.72, P=.001) (Table 3.11) (see ANOVA in appendix H).

At week 8 in Ukulinga weed species richness did not show significant difference across treatments. The lowest weed species richness was found in cowpea (0.60 species) and the highest weed species richness was found in bare plot (0.90 species). At week 12 velvet bean had the lowest weed species richness (0.41 species) and was not significantly different to cowpea (0.48 species) and lablab (0.64 species). The highest weed species richness was found in bare plot and herbicide (0.97 species). At week 16 lablab and velvet bean had the

lowest weed species richness (0.16 species) and was not significant to cowpea (0.30 species). The highest weed species richness was found in bare plot (1.48 species).

Bare plot in Ukulinga showed significant difference across sampling time. Week 8 had the lowest weed species richness (0.90 species) and the highest was found in week 16 (1.48 species). Cowpea did not show significant difference across sampling times. The lowest weed species richness was found in week 16 (0.30 species) and the highest was found in week 8 (0.60 species). Lablab showed significant difference in weed species richness across sampling time. The lowest weed species was found in week 16 (0.16 species) and the highest weed species richness was found in week 8 (0.98 species). Velvet bean had the least weed species richness in week 16 (0.16 species) which was significantly different to week 8 (0.82 species). Herbicide did not show any significant difference across sampling time. The least weed species richness was found in week 8 (0.61 species) and the highest was found in week 16 (1.05 species).

Table 3.11: Weed species richness in Ukulinga.

	Time of sampling		
Treatment	week 8	week 12	week 16
Bare plot	0.90 def	0.97 ef	1.48 g
Cowpea	0.60 bcde	0.48 abcd	0.30 ab
Lablab	0.98 ef	0.64 bcdef	0.16 a
Velvet bean	0.82 cdef	0.41 abc	0.16 a
Herbicide	0.61 bcde	0.97 ef	1.05 f
LSD	0.42		

Means with different letter show significant difference at P<0.05

3.7. Discussion

All the cover crops did not produce more than 2t/ha of biomass in Bergville. Lablab and velvet bean obtained the highest biomass accumulation. It has been reported that velvet bean is not adapted to acid soils with low availability of phosphorus (Carsky et al., 2001). However, velvet bean obtained the highest above ground biomass accumulation in highly acidic soils in Bergville and this could have been attributed to the robust growth habit it has (Chivenge et al., 2002). This is supported by Malama and Kondowe (2002) who reported that *Mucuna pruriens* L. appears to be ideal for high biomass accumulation in acidic soils.

Velvet bean had the highest biomass accumulation in Ukulinga. It is reported to have a good adaptation in dry hot conditions during warm seasons (Teasdale et al., 2007). Velvet bean was followed by cowpea and this was due to its aggressiveness growth habit. Cowpea is said to be tolerant to hot conditions with low rainfall. Hutchinson and McGiffen (2000) reported a phenomenon such as this, where cowpea produced abundant biomass in the hottest months of the year. However in this study, lablab accumulated the least biomass when compared to the rest of the cover crops.

Lablab performed best in weed suppression in Bergville. Although the soil was acidic, lablab produced a canopy cover more rapidly than the other cover crops that managed to suppress weeds across all sampling times. This agrees with Frageria et al. (2009) who reported that lablab is tolerant to low soil pH and this gives it a chance to outcompete weeds by competing for limited resources required for growth and development. Lablab was followed by cowpea in weed suppression. Cowpea also made a cover that smothered weeds and this was because cowpea managed to grow vigorously with a spreading growth habit. This agrees with Teasdale (2007) who reported that cowpea can grow vigorously and is well adapted to hot climatic conditions. Velvet bean had poor weed suppression in week 8 and week 12 after planting but performed better at week 16. This could have been because most weeds that were growing were annual weeds and had reached their physiological maturity.

Cowpea performed best than all cover crops in weed suppression in Ukulinga. Although it did not produce the highest biomass accumulation, it produced a dense cover that allowed it to be competitive to weeds by depriving sunlight to weeds needed for growth and development. Its effectiveness to suppress weeds was also influenced by its ability to make a cover faster compared to all the other cover crops leaving a considerable reduction of weed biomass. In twelve weeks after planting cowpea reduced weed biomass and due to

observations, the yellow nutsedge had changed its colour to brownish as a result of lack of sufficient light reception. Weed biomass increased in cowpea treatment in week 16 after planting, this was because the cover crop was reaching its physiological maturity stage and there was high leaf scenesense. Herbicide was not effective to weed suppression and this was because it was a post emergence herbicide and was applied once before planting. This herbicide was never applied again throughout the growing season. However, because weeds are known to be aggressive, they recovered aggressively after herbicide application.

Velvet bean had the lowest weed biomass in week 12 after planting at Ukulinga. In 8 weeks after planting velvet bean was not well established due to its slow emergence compared to the rest of the cover crops. In week 12 after planting velvet bean had made a cover that suppressed weeds. However weed biomass increased in the 16th week after planting and this was attributed to the fact that velvet bean was twirling on the maize crops instead of continuing to make a canopy. This was advantageous for weeds to re-generate since they were able to receive light which is important for growth.

Weed species richness in Bergville did not differ significantly between treatments and also did not have an interaction between treatments and sampling times. Lablab had low weed species richness and this might be a result of the rapid growth that it showed. This is also supported by Mhlanga et al. (2015) who found that velvet bean and lablab are most suitable to suppress weed species due to their fast growing habit and high production of biomass. Herbicide treatment also showed low species richness. However there was an increase in weed species richness in week 12. This might have been caused by the aggressive regeneration of weeds.

Weed species richness in Ukulinga was decreased across sampling time in cowpea, lablab and velvet bean. Bare plot and herbicide had high weed species richness. Herbicide had high species richness due to its failure to effectively suppress weeds. Velvet bean might have managed to reduce weed species richness across sampling time due its toxic substance it releases (Eucharia and Edward, 2010). Cowpea had the lowest weed species richness due to its effective weed suppression. The consistent decrease in weed species richness in cowpea and lablab could have been attributed to the failure of weeds to aggressively develop when light reception was insufficient due to a dense canopy cover.

Weed species diversity varied across treatments and weeks in Bergville. Legere et al. (2005) reported that weed diversity can be consistently affected by weed management and this is

supported by the findings on this study. Lablab, velvet bean and cowpea were effective compared to bare plot. Lablab and cowpea reduced weed species diversity by the canopy cover that managed to suppress weeds effectively.

Weed diversity in velvet bean was the lowest in Ukulinga. This indicates the strong ability of velvet bean to suppress a large range of weed species compared to other cover crops. However velvet bean could have managed to reduce weed species diversity due to its allelochemicals. Velvet bean was followed by lablab in reduction of weed species diversity. Hutson, (1997) and Mulder et al. (2001) indicated that weed diversity depends on soil fertility and moisture and the weed species diversity is likely to decrease when there is a limitation of these factors. This could mean that lablab competed with weeds for moisture, resulting in a decrease of weed species diversity.

Herbicide treatment had high weed species diversity in Ukulinga. This was due to aggressive regeneration of weed species after glyphosate was applied. Tuesca and Puricelli (2007) reported that glyphosate herbicide is more effective when applied with other herbicides. Mavunganidze et al. (2014) confirmed the findings of Tuesca by reporting that glyphosate has to be supplemented with pre-emergence herbicides which suppresses weeds before planting.

Weed species in Ukulinga were evenly distributed across the plots. Cowpea reduced the total weed species abundance (counts). Cowpea was effective in reducing all the dominant species (*Oxalis latifolia* H.B.K, *Bidens pilosa* L. and *Commelina benghelansis* L.) and it suppressed *Bidens pilosa* L. to zero abundance and zero biomass. This was because the light interception was reduced for weed development. Lablab was also effective in suppressing *Bidens pilosa* L.

In Bergville herbicide treatment had the lowest weed species abundance. *Leucas martinicensis* L. was not present before the commencement of the study. After soil disturbance it germinated because it is a shallow grower (Grabandt, 1985). *Cleome monophylla* had patchy distribution before the study commenced and thus resulted in high seed banks in some of the plots. *Leucas martinicensis* L. was effectively suppressed by lablab and cowpea. *Acanthospermum australe* (loefl.) Kuntze has a creeping habit and is known to be competitive in crop production systems. However lablab reduced the biomass of *Acanthospermum australe* (loefl.) Kuntze.

Future research needs

- More trials on screening for a wide range of leguminous cover crops should be conducted under various agroecological zones.
- The effect of planting dates on cover crop biomass, yield and weed suppression in maize cropping systems should be evaluated in order to reduce weed competition.
- Conduct soil fertility improvement aspects of cover crops.
- Determine methods of managing cover crop biomass (mulching versus incorporation) in terms of soil fertility improvement and weed dynamics.
- The effect of cover crops and weeds on grain yield should be investigated.

3.8. Conclusion and recommendation

Cowpea and lablab are adaptive to acidic soil and can be highly recommended for weed suppression in conservation agriculture due to their ability of providing a good canopy cover. Velvet bean does produce a high biomass but its canopy is not effective in weed suppression. This shows that high cover crop biomass does not mean that it is effective in weed suppression. Velvet bean and lablab can highly reduce weed species diversity. Cowpea and lablab can reduce weed species richness and hence can be recommended for use as cover crops in conservation agriculture. The effectiveness of cover crops in conservation agriculture is also a function of water availability and soil pH.

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CHAPTER FOUR

Screening for cover crops for soil macrofauna abundance and diversity in conservation agriculture

Abstract

Soil health is important for sustainable crop production. Frequent soil cultivation has a negative impact on soil health, resulting in loss of soil macrofauna. Conservation agriculture can be practiced to improve soil health by improving the abundance of soil macrofauna. Three leguminous cover crops were tested for soil macrofauna abundance *Vigna unguiculata*, (cowpea) *Lablab purpureus* L. (dolichos lablab) and *Mucuna pruriens* (L.) DC (velvet bean). The experiment was done in two contrasting experimental sites of KwaZulu-Natal (Ukulinga and Bergville) in a randomised complete block design replicated three times. Bare plot and herbicide treatments served as controls. Natural fallow was used to make a comparison to all the other treatments. Cowpea and lablab had the highest soil macrofauna abundance in both Bergville and Ukulinga. Cowpea and lablab improved soil macrofauna diversity in Bergville. Natural fallow had the lowest soil macrofauna diversity in Bergville. Lablab and velvet bean had the highest soil macrofauna species diversity in Ukulinga. Bare plot and natural fallow had the lowest soil macrofauna species diversity. It can be concluded that cowpea, lablab and velvet bean can be recommended for improving soil macrofauna abundance in conservation agriculture.

Keywords: soil macrofauna abundance, soil macrofauna diversity, cover crops, conservation agriculture.

4.1. Introduction

Soil health is essential for plant life and for promoting plant health as a whole. The greatest threat to soil health begins when frequent soil tillage is practiced. Frequent soil tillage results in land degradation, soil compaction and soil erosion (Hamza and Aderson, 2005), thus resulting in a decrease of organic matter and a decrease in soil biodiversity (Kosewska et al., 2014). Soil macrofauna are living organism that reside in the soil and are essential for improving soil health, improving crop production significantly (Doran, 2002). Soil macrofauna improves soil health by improving soil structure, organic matter decomposition and also nutrient cycling (Doran, 2002). Soil macrofauna such as termites and earthworms are considered to be the major soil engineers and are essential for sustainable crop production. However, their contribution to soil quality and crop performance in conservation agriculture is not well understood.

Conservation agriculture is the use of agricultural practices that result in less disturbance of the soil. However it is also being promoted to reduce land degradation and to safeguard soil properties including soil macrofauna (Mutema et al., 2013). Conservation agriculture which has three pillars: minimum tillage, use of mulch and crop rotation is economically friendly because it conserves natural resources (Giller et al., 2009) and could be practiced in order to restore better conditions for soil organisms. Conservation agriculture is known to improve soil fauna activities and improvement on soil biological properties than conventional practices (Busari et al., 2015).

Soil macrofauna such as the beetles of the carabidae family are important arthropods and are known to be sensitive to frequent soil disturbance as a result of cultivation. Kosewska et al. (2014) reported that ploughing has a negative impact to the composition of species and their abundance, thus resulting in a reduction of the carabidae beetles. Earthworms are also known to be very sensitive to soil cultivation as it decreases their counts significantly. This means that soil health should be maintained by reducing frequent tillage in order to reduce the loss of soil fauna biodiversity that will help to improve soil health.

Cover crops being one of conservation agriculture pillars are known to have an impact in the diversity of soil fauna. Cover crops such as *Mucuna pruriens* L. have been found to increase the abundance of earthworms, centipedes, millipedes and the beetle adults, thus improving the soil structure and the availability of nutrients (Lai, 2003). The use of cover crops to improve soil macrofauna has not been well understood in the African continent. The

objective of this study was to evaluate the effect of legume cover crops on soil macrofauna abundance.

4.2. Materials and methods

The study was carried out in two contrasting experimental sites of KwaZulu-Natal Province (Ukulinga and Bergville). The two sites were different in soil properties. Annual rainfall of Bergville was 643 mm and the temperature ranged from 19.3º C to 27.9º C. The monthly rainfall and temperature data in Bergville could not be found. Monthly rainfall and temperature records are shown in Table 4.1 while soil chemical and properties are shown in Table 4.2.

Table 4.1: Monthly rainfall and temperature in Ukulinga 2015.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Min temp º C	16.03	15.60	15.68	12.02	11.88	8.93	8.94	10.92
Max temp º C	27.66	26.47	27.04	23.90	25.96	22.20	21.13	24.51
Rainfall mm	132.80	143.00	82.20	0	5.02	2.02	32.99	3.04

Table 4.2: Soil fertility in Bergville and Ukulinga before planting.

Site	sand %	silt %	clay %	pH (KCI)	Total N%	Org C %	P (mg/kg)	K (mg/kg)
Bergville	26	17	59	3.83	0.23	2.2	7.9	165
Ukulinga	38	26	36	9.61	0.23	2.5	13.59	133

4.3. Experimental design

Three legume cover crops were evaluated for weed suppression and biomass accumulation. The cover crops were cowpea (V*igna unguiculata* (L.) Walp), velvet bean (*Mucuna pruriens* (L.) DC) and dolichous (*Lablab purpureus* (L.)).The treatments were laid in a randomised complete block design, replicated three times. Bare plot and herbicide treatments served as control were no cover crops were grown. Natural fallow was used for comparison to all the other treatments. The difference between natural fallow and all the treatments is that no fertiliser was applied and no herbicide was applied. Each plot size was 10 m x 5 m.

Glyphosate was applied once in the herbicide treatment before planting at a rate of 1.5% per 10 L. The area was slashed prior to planting. The maize and cover crops were planted during the same time in holes opened up by a hand hoe. Planting was done during the second week of January 2015. All cover crops were planted at a spacing of 15 cm x 30 cm to create a dense cover. Superphosphate fertiliser was applied during planting at 20 kg/ha in Ukulinga and 55 kg/ha in Bergville. Weeding was done once using a hand hoe after 4 weeks of planting. Urea (46% N) was applied two days after weeding at a recommendation of 120 kg/ha.

4.4. Sampling

Soil samples were taken before planting. Soil monoliths were taken from each plot using metallic monoliths. The soil monoliths were taken three times randomly within each plot at least 2 m apart. The soil monolith was driven into the soil using a metallic hammer. The size of the monolith was 20 cm x 20 cm x 20 cm. The soil was removed from the monolith and the soil macrofauna was hand-sorted from each sample. Soil macrofauna found was placed in bottles with 70% alcohol (Dangerfield, 1993).

4.5. Data analysis

Soil macrofauna diversity was calculated by Shannon-Wiener diversity index. Species richness was calculated by Margalef Index (Margalef, 1958). Data was then subjected to Genstat 14th edition for analysis of variance (ANOVA). The formula used for Margalef Index is: d= (S-1) In N. Where:

S = number of species

N = total number of individuals in the sample

Poisson distribution with log link function and likelihood type iii test was used to analyse soil macrofauna abundance using Generalised linear models (GLM) in SPSS version 23.

4.6. Results

4.6.1 Cover crop biomass accumulation in Bergville and Ukulinga

There was no significant interaction between treatments and sampling time in Bergville ($F_{(4,16)}$ =2.86, P= >0.05) (see ANOVA in appendix A). Cover crop biomass showed significant difference across treatment (P< 0.05) (Table 4.3). Velvet bean (0.72 t/ha) had the greatest biomass and was significantly different to Cowpea (0.59 t/ha) and Lablab (0.65 t/ha).

There was no significant interaction between treatments and sampling times in Ukulinga ($F_{(4,16)}$ = 1.48, P=0.25) (see ANOVA in appendix B). Treatments showed significant difference in cover crop biomass (P<0.05) (Table 4.3). Velvet bean had the highest biomass (1.59 t/ha) and was significantly different to cowpea (0.98 t/ha) and lablab (0.88 t/ha) which showed no significant difference.

Table 4.3: Cover crop biomass accumulation in Bergville and Ukulinga

	Biomass in t/ha	
Treatment	Bergville	Ukulinga
Cowpea	0.59 a	0.98 a
Lablab	0.65 b	0.88 a
Velvet bean	0.72 c	1.59 b
LSD	0.05	0.39

Means with different letters show significant difference at P<0.05.

4.6.2 Soil macrofauna species abundance in Bergville and Ukulinga

In Ukulinga the lowest total count of soil macrofauna species abundance was found in the natural fallow (15). The highest total count of soil macrofauna species abundance was found in lablab (57). In Bergville the lowest total count of soil macrofauna species abundance was found in the natural fallow (9). The highest total count of soil macrofauna species abundance was found in cowpea treatment (39). (See appendix K).

There was a significant difference within soil macrofauna species abundance in Ukulinga (P<0.05). Ants were significantly different to beetles, millipedes, and woodlice species. Beetles were significantly different to woodlice. Centipedes and termites were not significantly different to all the species. Earthworms showed significant difference to ants. Millipedes were significantly different to woodlice.

In Bergville there was significant difference with soil macrofauna species abundance across sampling time (P< 0.05). Week 8 and week 12 were significantly different to week 16.

There was significant difference with soil macrofauna species abundance across treatments in Bergville (P < 0.05) (Table 4.4) (see appendix L). The natural fallow and bare plot were not significantly different to all the treatments. Cowpea was significantly different to velvet bean and herbicide but was not significantly different to the rest of the treatments. There was significant difference with soil macrofauna species abundance when comparison was done amongst the species in Bergville (P <0.05). Ants were significantly different to beetles but was not significantly different to the rest of the species

Table 4.4: Soil macrofauna species abundance in Bergville and Ukulinga (Total counts per 50 m^2)

Treatment	Bergville	Ukulinga
Bare plot	30	42
Cowpea	39	51
Lablab	36	57
Velvet bean	30	54
Herbicide	33	54
Natural fallow	9	15

The proportion of soil macrofauna species abundance in Ukulinga (Table 4.5) had high occurrence of woodlice (29.7%). Woodlice were followed by ants (25.3%) and beetles (18.7 %). The absence of occurrence of soil macrofauna species richness accounted for 6.6 %. Centipedes, earthworms and termites had a low occurrence throughout the season. (See appendix page K).

In Bergville (Table 4.5) beetles had the highest percentage of occurrence throughout the season (37%). Beetles were followed by ants which occurred 25.4% throughout the season. The absence of occurrence of soil macrofauna in Bergville was high (27.1%). Centipedes, earthworms, termites and millipedes had a low occurrence throughout the season. (See appendix L).

Table 4.5: Proportion of soil marofauna species abundance occurrence in Bergville and Ukulinga

Species	Bergville	Ukulinga
Ants	25.4%	25.3%
Beetle	37.3%	18.7%
Centipede	1.7 %	1.1%
Earthworm	3.4 %	3.3%
Millipedes	1.7 %	13.2%
Termites	3.4 %	2.2%
No species	27.1%	6.6%
Woodlice		29.7%

4.6.3 Soil macrofauna diversity in Bergville and Ukulinga

There was a significant interaction of soil macrofauna diversity in Bergville ($F_{(10, 126)}$ =21.18, P= .001) (Table 4.6) (see ANOVA in appendix M).

At week 8 in Bergville, soil macrofauna diversity showed significant difference across treatments (P< 0.05). Velvet bean had the lowest diversity of soil macrofauna (0 species) and was significantly different to the rest of the treatments. The highest soil macrofauna diversity was found in bare plot (0.90 species) which was not significantly different to cowpea (0.81 species) and lablab (0.79 species). At week 12 the treatments showed significant difference in soil macrofauna diversity. Herbicide had the lowest soil macrofauna diversity (0.23 species) and was not significantly different to lablab treatment (0.38 species). Cowpea had the highest soil macrofauna abundance (0.96 species) and was not significantly different to bare plot (0.86 species), velvet bean (0.79 species) and natural fallow (0.69 species). At week 16 velvet bean, bare plot and natural fallow had the lowest soil macrofauna diversity of 0 species. The highest diversity was found in lablab (0.67 species).

Bare plot was significantly different over sampling times with the highest soil macrofauna diversity found in week 8 (0.90 species) and the lowest found in week 16 (0 species). Cowpea showed significant difference over sampling times. The highest soil macrofauna diversity was found in week 12 (0.96 species) and the lowest was found in week 16 (0.49 species). Lablab had the lowest soil macrofauna diversity at week 12 (0.38 species) and was significantly different to week 8 and week 16 which did not show significant difference in them. Velvet bean had the highest soil macrofauna diversity at week 12 (0.79 species). Week 8 and week

16 had no significant difference (0 species). Herbicide showed significant difference over sampling times. The highest soil macrofauna diversity was found in week 8 (0.76 species) followed by week 12 (0.23 species) then week 16 (0.10 species). The natural fallow showed significant difference. Week 16 had 0 soil macrofauna diversity. Week 8 and week 12 had the highest soil marofauna diversity (0.69 species).

Table 4.6: Soil macrofauna species diversity in Bergville

	Time of sampling		
Treatment	week 8	week 12	week 16
Bare plot	0.90 ij	0.86 ij	0.00 abc
Cowpea	0.81 hij	0.96 j	0.49 fg
Lablab	0.79 hij	0.38 ef	0.67 h
Velvet bean	0.00 a	0.79 hij	0.00 abc
Herbicide	0.76 hi	0.23 bde	0.10 abcd
Natural fallow	0.69 ghi	0.69 ghi	0.00 abc
LSD	0.31		

Means of different letters show significant difference at P<0.05.

There was significant interaction of soil macrofauna diversity between treatments and sampling times in Ukulinga ($F_{(10, 126)}$ =13.16, P= .001) (Table 4.7) (see ANOVA in appendix N).

At week 8 bare plot had 0 soil macofauna diversity and was significantly different to the rest of the treatments. The highest soil macrofauna diversity was found in velvet bean (1.00 species). At week 12 in natural fallow soil macrofauna diversity was 0 and was significantly different to the rest of the treatments. The highest soil macrofauna diversity was found in herbicide treatment (1.08 species). At week 12 bare plot had the lowest soil macrofauna abundance (0.13 species) and was significantly different to the rest of the treatments. The highest soil macrofauna was found in cowpea (0.72 species).

Bare plot in Ukulinga had the lowest soil macrofauna abundance in week 8 (0 species) and was not significantly different to week 16 (0.13 species). Week 12 had the highest soil macrofauna diversity (0.77 species). Cowpea had the lowest soil macrofauna diversity in week 8 (0.41 species) and was not significantly different to week 12 (0.43 species). Week 12 had the highest soil macrofauna diversity (0.72 species). Lablab had no significant difference over sampling time. The highest soil macrofauna diversity was found in week 12 (0.66 species) and the lowest soil macrofauna diversity was found in week 16 (0.47 species). Velvet bean showed significant difference over sampling times. Week 12 had the lowest soil

macrofauna diversity (0.59 species) and was not significantly different to week 16 (0.65 species). Week 8 had the highest soil macrofauna diversity (1.00 species). Herbicide had the lowest soil macrofauna diversity in week 16 (0.64 species) and was not significant to week 8 (0.75 species). Week 12 had the highest soil macrofauna diversity (1.08 species). The natural fallow had the lowest soil macrofauna diversity in week 12 (0 species). Week 8 and week 16 were not significantly different.

Table 4.7: Soil macrofauna species diversity in Ukulinga

	Time of sampling		
Treatment	week 8	week 12	week 16
Bare plot	0.00 a	0.77 f	0.13 a
Cowpea	0.41 b	0.43 b	0.72 ef
Lablab	0.55 bcde	0.66 def	0.47 bcd
Velvet bean	1.00 g	0.59 bcdef	0.65 def
Herbicide	0.75 f	1.08 g	0.64 def
Natural fallow	0.69 cdef	0.00 a	0.44 bcd
LSD	0.33		

Means of different letters show significant difference at P<0.05.

4.6.4 Soil macrofauna species richness in Bergville and Ukulinga

There was no significant interaction in Bergville with soil macrofauna species richness between treatments and sampling time ($F_{(10, 126)} = 0.50$, P= 0.88) (see ANOVA in appendix O). There was significant difference with soil macrofauna across treatments P< 0.05 (Table 4.8). Velvet bean had the lowest soil macrofauna species richness (0.02 species) and was significantly different to herbicide (0.79 species). The highest soil macrofauna species richness was found in herbicide (0.79 species).

Table 4.8: Soil macrofauna species richness in Bergville

Treatment	Species richness
Bare plot	0.10 a
Cowpea	0.48 ab
Lablab	0.42 ab
Velvet bean	0.02 a
Herbicide	0.79 b
Natural fallow	0.06 a
LSD	0.36

Means of different letters show significant difference at P<0.05

There was no significant interaction with soil macrofauna species richness between treatment and sampling time in Ukulinga ($F_{(10,\ 126)}$ =1.42, P=0.18). There was also no significant difference with soil macrofauna species richness across treatments.

Sampling time showed significant difference with soil macrofauna species richness at P< 0.05 (Table 4.9) (see ANOVA in appendix P). Week 16 had the lowest soil macrofauna species richness (0.02 species) and was significantly different to week 8 and week 12 which did not show significant difference. The highest soil macrofauna species richness was found in week 8 (0.20 species).

Table 4.9: Soil macrofauna species richness in Ukulinga

Sampling time	Species Richness
Week 8	0.20 b
Week 12	0.19 b
Week 16	0.02 a
LSD	0.15

Means of different letters show significant difference at P<0.05

4.7. Discussion

Cowpea and lablab had the highest soil macrofauna species abundance in Bergville and were followed by velvet bean. The environment created by these cover crops influenced the survival and abundance of the soil macrofauna. The natural fallow was dominated by grass species and these resulted in low soil macrofauna species abundance due to poor cover. Beetles were evenly distributed across all treatments. Lablab and velvet bean had the highest abundance of ants. This is similar to the study that was done by Silva et al. (2007) who found that there was high abundance of the ants in velvet bean cover crop.

Lablab had the highest soil macrofauna species abundance in Ukulinga. The cover it formed was spreading and dense and therefore improved soil macrofauna abundance. The natural fallow had the lowest soil macrofauna species abundance. *Tagetes minuta* was dominant in the natural fallow and it did not make a good cover that would create a good environment for soil macrofauna survival. Ants respond well to legumes that make a dense cover creating a moist environment. Laossi et al. (2007) reported an increase in ant abundance under herbaceous legume *Arachi pintoi* due to the dense leaf cover it formed. Lablab had the highest ant abundance and this might have been due to the canopy it formed as supported by Laossi et al. (2007).

Cowpea is known for a dense cover that it produces. In Bergville cowpea had an increasing species diversity of soil macrofauna over sampling time. This was because cowpea produced a favourable condition with less temperature fluctuation (Santos et al., 2008). However in week 16, cowpea had a reduction of soil macrofauna species diversity and this was caused by the maturity stage it had reached with a reduced cover due to leaf senescence. In Ukulinga velvet bean had high soil macrofauna diversity in week 8 then reduced in week 12. The reason of the reduction could have been caused by the lack of cover due to the twirling of the velvet bean on the maize crop. And by this, soil macrofauna did not have a conducive environment where they could survive. Cowpea had an increase in soil macrofauna species diversity over time. The soil macrofauna species diversity increased with an increase in the cover that was formed by cowpea, creating a good environmental condition for soil invertebrates.

Cowpea had the highest soil macrofauna species richness compared to the other two cover crops in Bergville. Although it did not produce the highest biomass, the cover it produced influenced the survival of soil macrofauna and this led to the highest species richness. Velvet

bean has been found to increase soil macrofauna (Silva et al., 2007). Contrary to this finding, velvet bean had the lowest soil macrofauna species richness and this might be because of the poor cover it formed. Earthworms, termites, centipedes and millipedes had a very low occurrence throughout the season and this could have been caused by the low soil pH. Some soil macrofauna such as earthworms and termites are known to be sensitive to low soil pH thus reducing their survival (Lavelle et al., 1995).

All treatments in Ukulinga did not have a significant effect on soil macrofauna species richness. However the herbicide treatment had the highest species richness. Herbicide was applied once before planting, this caused weeds to be aggressive and to have a massive growth and development which gave a high weed biomass. The high weed biomass was constituted by high abundance of broadleaf weed species. This could lead to a good environment for soil macrofauna to survive. The lack of occurrence of centipedes and earthworms could have been caused by the soil type in Ukulinga. The soil type had a hard pan and was compact, reducing the better movements of earthworms and centipedes in the soil.

Future research needs

- More trials on screening for a wide range of leguminous cover crops should be conducted under various agro-ecological zones for soil macrofauna abundance.
- Evaluate soil macrofauna for improvement of soil fertility under conservation agriculture
- Evaluate soil macrofauna for improvement of soil physical properties

4.8. Conclusion

High legume cover crop biomass can influence the abundance and diversity of soil macrofauna. However, the growth habit can have a significant effect on the abundance of soil macrofauna. Velvet bean had the highest biomass accumulation but its twirling growth habit did not have a positive effect in soil macrofauna abundance compared to other cover crops. Cowpea cover crop helps to improve soil macrofauna species diversity and richness and can be recommended to be used in conservation agricultural systems. High low soil pH and low soil moisture have a negative effect on the soil macrofauna survival.

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CHAPTER FIVE

General discussion

The practice of conservation agriculture can be efficient for sustainable crop production. Frequent soil tillage causes land degradation as a result of soil erosion and this may result in loss of soil nutrients. It also results in soil compaction and this is not good for crop production. In conservation agriculture, the main purpose is to reduce land degradation by reducing soil disturbance. Conservation agriculture is being promoted world-wide because it improves soil physical and soil chemical properties. It also reduces labour costs, soil erosion and it improves soil moisture. Conservation agriculture is composed of three components namely: no- till, crop rotation and mulch.

Weeds being known as plants growing in unwanted places are problematic because they compete for limited resources with the crops. Most studies have compared the use of conventional tillage and conservation tillage practices on weed management. The findings in these studies show that conventional agriculture is effective in weed suppression. However this practice is not sustainable to the soil. There are many studies that have been done to show the effect of cover crops on weed suppression. However their comparison was done under conventional tillage practices. Very few studies have been done under conservation agriculture using legume cover crops. Other studies have focused on the comparison of cereal cover crops for weed suppression. Other studies focused on using legume crops as intercrops and rotations for weed suppression. There is lack of studies that compare legume cover crops effect on soil macrofauna abundance. Most studies focus on leguminous trees, evaluating the effect of litter on soil macrofauna abundance. In other studies, *Mucuna pruriens* (L.) DC alone has been assessed for soil macrofauna abundance. However this study has focused on the effect legume cover crops on both weed suppression and soil macrofauna abundance and diversity. Legume cover crops provide significant nitrogen levels in managed and natural ecosystems. The benefit of using legume cover crops is that it reduces the need of nitrogen fertiliser application.

Although conservation agriculture is being promoted over conventional tillage practice, weed management remains one of the greatest problems that smallholder farmers in Bergville are facing. The problem of weed management in conservation agriculture in Bergville resulted when farmers relied on herbicide for weed suppression. The farmers in Bergville often apply a wrong dosage of herbicide, moreover, applying the same herbicide repeatedly.

This resulted in some weeds developing resistance thus making the herbicide to be less effective in weed suppression. Cover crops can be used as an alternative to herbicide application to suppress weeds by their growth mechanisms and ability to create a cover that may form unfavourable conditions for weed development. Therefore, the use of cover crops promotes sustainable agricultural production, as a result of reduced or no herbicide use.

The main aim of the study was to evaluate the use of different legume cover crops on weed suppression and soil macrofauna abundance and diversity in two contrasting sites due to their soil properties. The first research chapter assessed the effect of three leguminous cover crops (*Vigna unguiculata* (L.) Walp*, Lablab purpureus* L. and *Mucuna pruriens* (L.) DC) on weed suppression. Weed suppression was quantified in terms of biomass, abundance and diversity. Cover crop biomass was also compared. Velvet bean produced the greatest biomass compared to the other two cover crops in both experimental sites. Its robust growth form resulted in the highest biomass.

In terms if weed suppression, results showed that lablab performed best in Bergville and was followed by cowpea. In Ukulinga, results showed that cowpea performed best in weed suppression. This means that these two cover crops managed to create an environment whereby light was restricted for weeds and that reduced the growth and development of weed species. Results also showed that lablab reduced weed species richness in Bergville and cowpea reduced weed species richness in Ukulinga. In terms of diversity, lablab and velvet bean showed to be effective in reducing weed species diversity in Bergville. In Ukulinga velvet bean had the lowest weed species diversity. Lablab showed to be effective in reducing the abundance of weed species in Bergville whereas in Ukulinga cowpea was effective in reducing weed species abundance.

The second research chapter assessed three legume cover crops on soil macrofauna abundance and diversity. A relationship between cover crop biomass production and soil macrofauna abundance was assessed. The results showed that cowpea improved the abundance of soil macrofauna species in Bergville. In Ukulinga lablab performed best in improving soil macrofauna species abundance. These cover crops created a good environment for soil macrofauna survival.

Results also showed that cowpea has the ability to improve the diversity of soil macrofauna species abundance in Bergville. In Ukulinga, results showed that velvet bean increased soil

macrofauna species diversity. In Ukulinga all the treatments did not show any significant difference in improving soil macrofauna species richness.

Conclusions and recommendations

According to the results it can be concluded that there is a relationship in cover crops that suppress weeds and cover crops that improve soil macrofauna species abundance. Cowpea and lablab have the ability to suppress weeds and also have the ability to improve soil macrofauna abundance. According to the findings cowpea and lablab can be recommended to be used in conservation agriculture to suppress weeds and improve soil macrofauna abundance. The use of cowpea and lablab could benefit farmers and the environment. Farmers would have more profit due to reduced herbicide use for weed control. Their profit will also be improved due to reduced fertiliser applications because legumes supply nitrogen needed for crop growth.

Future research needs to look at the following:

- More trials on screening for a wide range of leguminous cover crops should be conducted under various agro-ecological zones.
- The effect of planting dates on cover crop biomass, yield and weed suppression in maize cropping systems should be evaluated in order to reduce weed competition.
- Conduct soil fertility improvement aspects of cover crops.
- Determine methods of managing cover crop biomass (mulching versus incorporation) in terms of soil fertility improvement and weed dynamics
- More trials on screening for a wide range of leguminous cover crops should be conducted under various agro-ecological zones for soil macrofauna abundance.
- Evaluate soil macrofauna for improvement of soil fertility under conservation agriculture
- Evaluate soil macrofauna for improvement of soil physical properties
- The effect of cover crop on crop yield through competition for water should be investigated

Appendix

Appendix A

Bergville cover crop biomass

GenStat Release 17.1 (PC/Windows 8) 01 August 2015 20:43:56
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GenStat Seventeenth Edition
GenStat Procedure Library Release PL25.1

Analysis of variance

Variate: Biomass_sqrt

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.069039	0.034520	13.50	
Block.*Units* stratum					
Treatment	2	0.076215	0.038107	14.91	<.001
Sampling time	2	0.926955	0.463477	181.30	<.001
Treatment.sampling time	4	0.029285	0.007321	2.86	0.058
Residual	16	0.040903	0.002556		
Total	26	1.142396			

Message: the following units have large residuals.

Block 1 *units* 6 -0.1075 s.e. 0.0389

Tables of means

Variate: Biomass_sqrt

Grand mean 0.6553

Treatment	2	3	4
	0.5912	0.6533	0.7213

Sampling time	8	12	16
	0.4098	0.6987	0.8573

Treatment	sampling time	8	12	16
2		0.3183	0.6352	0.8200
3		0.4546	0.7125	0.7927
4		0.4564	0.7483	0.9592

Standard errors of differences of means

Table	Treatment	sampling time	Treatment Sampling time
rep.	9	9	3
d.f.	16	16	16
s.e.d.	0.02383	0.02383	0.04128

Least significant differences of means (5% level)

Table	Treatment	sampling time	Treatment Sampling time
rep.	9	9	3
d.f.	16	16	16
l.s.d.	0.05053	0.05053	0.08752

Stratum standard errors and coefficients of variation

Variate: Biomass_sqrt

Stratum	d.f.	s.e.	cv%
Block	2	0.06193	9.5
Block.*Units*	16	0.05056	7.7

Fisher's protected least significant difference test

Treatment

	Mean	
2	0.5912	a
3	0.6533	b
4	0.7213	c

Fisher's protected least significant difference test
Sampling time

	Mean	
8	0.4098	a
12	0.6987	b
16	0.8573	c

Appendix B

Ukulinga cover crop biomass

Analysis of variance

Variate: Biomass_sqrt

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.3557	0.1779	1.17	
Block.*Units* stratum					
Treatment	2	2.6272	1.3136	8.63	0.003
Sampling time	2	6.3179	3.1589	20.75	<.001
Treatment.sampling time	4	0.9040	0.2260	1.48	0.253
Residual	16	2.4364	0.1523		
Total	26	12.6413			

Message: the following units have large residuals.

Block 3 *units* 2 0.946 s.e. 0.300

Tables of means

Variate: Biomass_sqrt

Grand mean 1.153

Treatment	2	3	4
	0.980	1.591	0.887

Sampling time	8	12	16
	0.766	0.857	1.835

Treatment	sampling time	8	12	16
2		0.571	0.843	1.526
3		1.105	1.048	2.619
4		0.622	0.680	1.360

Standard errors of differences of means

Table	Treatment	sampling time	Treatment sampling time
rep.	9	9	3
d.f.	16	16	16
s.e.d.	0.1840	0.1840	0.3186

Least significant differences of means (5% level)

Table	Treatment	sampling time	Treatment

			sampling time
rep.	9	9	3
d.f.	16	16	16
l.s.d.	0.3900	0.3900	0.6754

Stratum standard errors and coefficients of variation

Variate: Biomass_sqrt

Stratum	d.f.	s.e.	cv%
Block	2	0.1406	12.2
Block.*Units*	16	0.3902	33.9

Fisher's protected least significant difference test

Treatment

	Mean	
4	0.887	a
2	0.980	a
3	1.591	b

Fisher's protected least significant difference test

Sampling time

	Mean	
8	0.766	a
12	0.857	a
16	1.835	b

Appendix C

Bergville weed biomass

Analysis of variance

Variate: sqrt_biomass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.15089	0.07544	2.42	
Block.*Units* stratum					
Treatment	4	3.13748	0.78437	25.14	<.001
sampling_time	2	0.61137	0.30568	9.80	<.001
Treatment.sampling_time	8	0.99677	0.12460	3.99	0.003
Residual	28	0.87360	0.03120		
Total	44	5.77010			

Message: the following units have large residuals.

Block 1 *units* 6	0.312	s.e. 0.139
Block 1 *units* 10	-0.366	s.e. 0.139
Block 3 *units* 14	-0.302	s.e. 0.139

Tables of means

Variate: sqrt_biomass

Grand mean 0.819

Treatment	1	2	3	4	5
	1.198	0.640	0.461	0.771	1.025

sampling_time	8	12	16
	0.675	0.960	0.821

Treatment	sampling_time	8	12	16
1		0.897	1.296	1.401
2		0.631	0.804	0.484
3		0.478	0.583	0.322
4		0.748	0.949	0.614
5		0.621	1.169	1.285

Standard errors of differences of means

Table	Treatment	sampling_time	Treatment sampling_time
rep.	9	15	3
d.f.	28	28	28
s.e.d.	0.0833	0.0645	0.1442

Least significant differences of means (5% level)

Table	Treatment	sampling_time	Treatment sampling_time
rep.	9	15	3
d.f.	28	28	28
l.s.d.	0.1706	0.1321	0.2954

Stratum standard errors and coefficients of variation

Variate: sqrt_biomass

Stratum	d.f.	s.e.	cv%
Block	2	0.0709	8.7
Block.*Units*	28	0.1766	21.6

Fisher's protected least significant difference test

Treatment.sampling_time

	Mean	
3 16	0.3218	a
3 8	0.4781	ab
2 16	0.4844	ab
3 12	0.5834	abc
4 16	0.6143	abcd
5 8	0.6208	bcd
2 8	0.6308	bcd
4 8	0.7482	bcde
2 12	0.8042	cde
1 8	0.8969	def
4 12	0.9494	ef
5 12	1.1695	fg
5 16	1.2847	g
1 12	1.2958	g
1 16	1.4013	g

Appendix D

Ukulinga weed biomass

Analysis of variance

Variate: SQrt_biomass

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.10819	0.05410	0.89	
Block.*Units* stratum					
Treatment	4	0.99150	0.24788	4.07	0.010
sampling_time	2	0.20030	0.10015	1.65	0.211
Treatment.sampling_time	8	0.98509	0.12314	2.02	0.080
Residual	28	1.70403	0.06086		
Total	44	3.98911			

Message: the following units have large residuals.

Block 1 *units* 8	0.448	s.e.	0.195
Block 2 *units* 12	-0.415	s.e.	0.195

Tables of means

Variate: SQrt_biomass

Grand mean 0.710

Treatment	1	2	3	4	5
	0.841	0.533	0.601	0.651	0.925

sampling_time	8	12	16
	0.678	0.803	0.649

Treatment	sampling_time	8	12	16
1		0.652	1.125	0.747
2		0.633	0.330	0.634
3		0.626	0.751	0.424
4		0.748	0.582	0.624
5		0.734	1.226	0.815

Standard errors of differences of means

Table	Treatment	sampling_time	Treatment sampling_time
rep.	9	15	3
d.f.	28	28	28
s.e.d.	0.1163	0.0901	0.2014

Least significant differences of means (5% level)

Table	Treatment	sampling_time	Treatment sampling_time
rep.	9	15	3
d.f.	28	28	28
l.s.d.	0.2382	0.1845	0.4126

Stratum standard errors and coefficients of variation

Variate: SQrt_biomass

Stratum	d.f.	s.e.	cv%
Block	2	0.0601	8.5
Block.*Units*	28	0.2467	34.7

Fisher's protected least significant difference test

Treatment

	Mean	
2	0.5325	a
3	0.6006	a
4	0.6514	ab
1	0.8410	bc
5	0.9247	c

Appendix E

Bergville weeds abundance

Analysis of variance

Variate: Sqrt_abundance

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	4	3.0099	0.7525	1.94	0.130
Samping time	2	1.4203	0.7102	1.83	0.178
Treatment. Sampling time	8	4.2650	0.5331	1.37	0.248
Residual	30	11.6434	0.3881		
Total	44	20.3386			

Message: the following units have large residuals.

units 2	1.101	s.e.	0.509

Tables of means

Variate: Sqrt_abundance

Grand mean 2.015

Treatment	1	2	3	4	5
	2.343	1.970	1.728	2.283	1.750

Sampling time	8	12	16
	2.015	2.232	1.797

Treatment	sampling time	8	12	16
1		2.008	2.757	2.264
2		2.136	2.172	1.602
3		2.117	1.636	1.430
4		2.684	2.491	1.674
5		1.131	2.105	2.014

Standard errors of differences of means

Table	Treatment	Sampling time	Treatment Sampling time
rep.	9	15	3
d.f.	30	30	30
s.e.d.	0.2937	0.2275	0.5087

Least significant differences of means (5% level)

Table	Treatment	Sampling time	Treatment Sampling time
rep.	9	15	3
d.f.	30	30	30
l.s.d.	0.5998	0.4646	1.0388

Stratum standard errors and coefficients of variation

Variate: Sqrt_abundance

d.f.	s.e.	cv%
30	0.6230	30.9

Fisher's protected least significant difference test

Appendix F
Ukulinga weed abundance

Analysis of variance

Variate: Sqrt

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	4	57.016	14.254	5.25	0.002
Time	2	428.768	214.384	79.00	<.001
Treatment.Time	8	15.062	1.883	0.69	0.694
Residual	30	81.409	2.714		
Total	44	582.255			

Tables of means

Variate: Sqrt

Grand mean 6.10

Treatment	1	2	3	4	5
	6.13	4.63	5.43	6.31	8.02

Time	8	12	16
	9.15	7.29	1.87

Treatment	Time	8	12	16
1		8.69	7.25	2.45
2		7.46	5.20	1.23
3		8.69	6.32	1.28
4		9.09	7.79	2.05
5		11.83	9.87	2.36

Standard errors of differences of means

Table	Treatment	Time	Treatment Time
rep.	9	15	3
d.f.	30	30	30
s.e.d.	0.777	0.602	1.345

Least significant differences of means (5% level)

Table	Treatment	Time	Treatment Time
rep.	9	15	3
d.f.	30	30	30
l.s.d.	1.586	1.228	2.747

Stratum standard errors and coefficients of variation

Variate: Sqrt

d.f.	s.e.	cv%
30	1.647	27.0

Fisher's protected least significant difference test

Treatment

	Mean	
2	4.630	a
3	5.432	ab
1	6.132	ab
4	6.308	b
5	8.019	c

Fisher's protected least significant difference test

Sampling time

	Mean	
16	1.874	a
12	7.286	b
8	9.153	c

Appendix G

Weed species richness Bergville

Analysis of variance

Variate: Richness

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
treatment	4	0.9253	0.2313	0.89	0.474
sampling time	2	1.8282	0.9141	3.50	0.033
treatment.sampling time	8	3.7675	0.4709	1.80	0.083
Residual	120	31.3099	0.2609		
Total	134	37.8308			

Tables of means

Variate: Richness

Grand mean 0.430

treatment	1	2	3	4	5
	0.524	0.509	0.295	0.402	0.422

Sampling time	8	12	16
	0.304	0.585	0.401

Treatment	sampling time	8	12	16
1		0.592	0.596	0.383
2		0.038	0.773	0.717
3		0.175	0.549	0.160
4		0.503	0.542	0.160
5		0.214	0.465	0.587

Standard errors of differences of means

Table	treatment	sampling time	treatment Sampling time
rep.	27	45	9
d.f.	120	120	120
s.e.d.	0.1390	0.1077	0.2408

Least significant differences of means (5% level)

Table	treatment	sampling time	treatment Sampling time
rep.	27	45	9
d.f.	120	120	120
l.s.d.	0.2753	0.2132	0.4768

Stratum standard errors and coefficients of variation

Variate: Richness

d.f.	s.e.	cv%
120	0.5108	118.7

Fisher's protected least significant difference test

Sampling time

	Mean	
8	0.3044	a
16	0.4013	ab
12	0.5850	b

Appendix H

Weed species richness Ukulinga

Analysis of variance

Variate: richness

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
treatment	4	8.9098	2.2274	10.84	<.001
sampling time	2	0.5614	0.2807	1.37	0.259
treatment.sampling time	8	7.7557	0.9695	4.72	<.001
Residual	120	24.6690	0.2056		
Total	134	41.8959			

Tables of means

Variate: richness

Grand mean 0.705

treatment	1	2	3	4	5
	1.120	0.464	0.598	0.465	0.88

Sampling time	8	12	16
	0.788	0.697	0.631

Treatment	sampling time	8	12	16
1		0.904	0.974	1.481
2		0.609	0.482	0.301
3		0.990	0.643	0.160
4		0.823	0.413	0.160
5		0.617	0.973	1.053

Standard errors of differences of means

Table	treatment	sampling time	treatment Sampling time
rep.	27	45	9
d.f.	120	120	120
s.e.d.	0.1234	0.0956	0.2137

Least significant differences of means (5% level)

Table	treatment	sampling time	treatment Sampling time
rep.	27	45	9
d.f.	120	120	120
l.s.d.	0.2443	0.1893	0.4232

Stratum standard errors and coefficients of variation

Variate: richness

d.f.	s.e.	cv%
120	0.4534	64.3

Fisher's protected least significant difference test

Treatment

	Mean	
2	0.4638	a
4	0.4653	a
3	0.5975	a
5	0.8810	b
1	1.1196	b

Fisher's protected least significant difference test

Treatment.sampling time

	Mean			
4 16	0.1603	a		
3 16	0.1603	a		
2 16	0.3012	ab		
4 12	0.4130	abc2 12	0.4815	abcd
2 8	0.6088	bcde		
5 8	0.6167	bcde		
3 12	0.6428	bcdef		
4 8	0.8227	cdef		
1 8	0.9043	def		
5 12	0.9729	ef		
1 12	0.9738	ef		
3 8	0.9896	ef		
5 16	1.0534	f		
1 16	1.4806	g		

Appendix I

Ukulinga weed diversity
Analysis of variance

Variate: diversity_sqrt

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
treatment	4	3.88012	0.97003	77.76	<.001
sampling time	2	0.21228	0.10614	8.51	<.001
treatment.sampling time	8	3.01733	0.37717	30.23	<.001
Residual	120	1.49695	0.01247		
Total	134	8.60669			

Message: the following units have large residuals.

units 91	-0.2795	s.e.	0.1053
units 127	-0.7362	s.e.	0.1053

Tables of means

Variate: diversity_sqrt

Grand mean 0.9893

treatment	1	2	3	4	5
	1.2791	1.0129	0.8945	0.7654	0.9948

Sampling time	8	12	16
	1.0400	0.9848	0.9432

treatment	sampling time	8	12	16
1		1.1630	1.2813	1.3930
2		1.0529	0.9355	1.0504
3		1.1386	0.9728	0.5721
4		0.9971	0.7589	0.5401
5		0.8485	0.9753	1.1605

Standard errors of differences of means

Table	treatment	sampling time	treatment Sampling time
rep.	27	45	9
d.f.	120	120	120
s.e.d.	0.03040	0.02355	0.05265

Least significant differences of means (5% level)

Table	treatment	sampling time	treatment Sampling time
rep.	27	45	9
d.f.	120	120	120
l.s.d.	0.06019	0.04662	0.10425

Stratum standard errors and coefficients of variation

Variate: diversity_sqrt

d.f.	s.e.	cv%
120	0.11169	11.3

Fisher's protected least significant difference test

Treatment

	Mean	
4	0.7654	a
3	0.8945	b
5	0.9948	c
2	1.0129	c
1	1.2791	d

Fisher's protected least significant difference test

Treatment.sampling time

	Mean	
4 16	0.5401	a
3 16	0.5721	a
4 12	0.7589	b
5 8	0.8485	bc
2 12	0.9355	cd
3 12	0.9728	de
5 12	0.9753	de
4 8	0.9971	de
2 16	1.0504	ef
2 8	1.0529	ef
3 8	1.1386	fg
5 16	1.1605	g
1 8	1.1630	g
1 12	1.2813	h
1 16	1.3930	i

Appendix J
Bergville weed diversity

Analysis of variance

Variate: Sqrt

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
treatment	4	0.73054	0.18264	11.09	<.001
sampling time	2	0.54441	0.27220	16.52	<.001
treatment.sampling time	8	1.32543	0.16568	10.06	<.001
Residual	120	1.97688	0.01647		
Total	134	4.57726			

Tables of means

Variate: Sqrt

Grand mean 0.941

Treatment	1	2	3	4	5
	1.031	0.979	0.835	0.874	0.983

Sampling time	8	12	16
	0.917	1.027	0.877

Treatment	sampling time	8	12	16
1		1.026	1.019	1.047
2		0.874	1.070	0.995
3		0.807	1.047	0.653
4		0.950	1.047	0.624
5		0.928	0.955	1.067

Standard errors of differences of means

Table	treatment	sampling time	treatment Sampling time

rep.	27	45	9
d.f.	120	120	120
s.e.d.	0.0349	0.0271	0.0605

Least significant differences of means (5% level)

Table	treatment	sampling time	treatment Sampling time
rep.	27	45	9
d.f.	120	120	120
l.s.d.	0.0692	0.0536	0.1198

Stratum standard errors and coefficients of variation
Variate: Sqrt

d.f.	s.e.	cv%
120	0.1284	13.6

Fisher's protected least significant difference test

Treatment

	Mean	
3	0.8354	a
4	0.8736	a
2	0.9795	b
5	0.9834	b
1	1.0308	

Fisher's protected least significant difference test
Treatment.sampling time

	Mean	
4 16	0.6239	a
3 16	0.6529	a
3 8	0.8066	b
2 8	0.8742	bc
5 8	0.9283	cd
4 8	0.9503	cde
5 12	0.9546	cde
2 16	0.9945	de
1 12	1.0192	de
1 8	1.0261	de
4 12	1.0466	de
3 12	1.0466	de
1 16	1.0472	de
5 16	1.0675	e
2 12	1.0698	e

Appendix K

Generalised Linear Models. Ukulinga

Notes

Output Created		18-NOV-2015 11:36:49
Comments		
Input	Active Dataset	DataSet1
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	273
Missing Value Handling	Definition of Missing	User-defined missing values for factor, subject and within-subject variables are treated as missing.
	Cases Used	Statistics are based on cases with valid data for all variables in the model.
Weight Handling		not applicable
Syntax		GENLIN Count BY Time Treatment Species (ORDER=ASCENDING) /MODEL Time Treatment Species INTERCEPT=YES DISTRIBUTION=POISSON LINK=LOG /CRITERIA METHOD=FISHER(1) SCALE=1 COVB=MODEL MAXITERATIONS=100 MAXSTEPHALVING=5 PCONVERGE=1E-006(ABSOLUTE) SINGULAR=1E-012 ANALYSISTYPE=3(WALD) CILEVEL=95 CITYPE=WALD LIKELIHOOD=FULL /EMMEANS TABLES=Time SCALE=TRANSFORMED COMPARE=Time CONTRAST=PAIRWISE PADJUST=SEQSIDAK /EMMEANS TABLES=Treatment SCALE=TRANSFORMED COMPARE=Treatment CONTRAST=PAIRWISE PADJUST=SEQSIDAK /EMMEANS TABLES=Species SCALE=TRANSFORMED COMPARE=Species CONTRAST=PAIRWISE PADJUST=SEQSIDAK /MISSING CLASSMISSING=EXCLUDE /PRINT CPS DESCRIPTIVES MODELINFO FIT SUMMARY SOLUTION.
Resources	Processor Time	00:00:00.11
	Elapsed Time	00:00:00.11

Dependent Variable	Count
Probability Distribution	Poisson
Link Function	Log

Case Processing Summary

	N	Percent
Included	273	100.0%
Excluded	0	0.0%
Total	273	100.0%

Categorical Variable Information

			N	Percent
Factor	Time	8	108	39.6%
		12	93	34.1%
		16	72	26.4%
		Total	273	100.0%
	Treatment	0	15	5.5%
		1	42	15.4%
		2	51	18.7%
		3	57	20.9%
		4	54	19.8%
		5	54	19.8%
		Total	273	100.0%
	Species	ants	69	25.3%
		Beet	51	18.7%
		Centi	3	1.1%
		EW	9	3.3%
		mill	36	13.2%
		no species	18	6.6%
		term	6	2.2%
		wood	81	29.7%
		Total	273	100.0%

Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	Count	273	0	36	1.41	3.606

Goodness of Fit[a]

	Value	df	Value/df
Deviance	835.971	258	3.240
Scaled Deviance	835.971	258	
Pearson Chi-Square	1166.892	258	4.523
Scaled Pearson Chi-Square	1166.892	258	
Log Likelihood[b]	-571.700		
Akaike's Information Criterion (AIC)	1173.399		
Finite Sample Corrected AIC (AICC)	1175.267		
Bayesian Information Criterion (BIC)	1227.541		
Consistent AIC (CAIC)	1242.541		

Dependent Variable: Count

Model: (Intercept), Time, Treatment, Species

a. Information criteria are in smaller-is-better form.

b. The full log likelihood function is displayed and used in computing information criteria.

Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
285.067	14	.000

Dependent Variable: Count

Model: (Intercept), Time, Treatment, Species

a. Compares the fitted model against the intercept-only model.

Tests of Model Effects

	Type III		
Source	Wald Chi-Square	df	Sig.
(Intercept)	5.157	1	.023
Time	3.506	2	.173
Treatment	28.259	5	.000
Species	159.241	6	.000

Dependent Variable: Count

Model: (Intercept), Time, Treatment, Species

Parameter	B	Std. Error	95% Wald Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	-.353	.2040	-.753	.047	2.998	1	.083
[Time=8]	.248	.1324	-.012	.507	3.501	1	.061
[Time=12]	.150	.1429	-.130	.430	1.103	1	.294
[Time=16]	0[a]	.	.	.	.	.	.
[Treatment=0]	.126	.2752	-.413	.666	.211	1	.646
[Treatment=1]	.622	.1962	.237	1.006	10.041	1	.002
[Treatment=2]	.794	.1961	.410	1.179	16.396	1	.000
[Treatment=3]	.834	.1800	.481	1.187	21.484	1	.000
[Treatment=4]	.689	.1860	.325	1.054	13.726	1	.000
[Treatment=5]	0[a]	.	.	.	.	.	.
[Species=ants]	.778	.1172	.549	1.008	44.109	1	.000
[Species=Beet]	-1.189	.2325	-1.645	-.733	26.150	1	.000
[Species=Centi]	-1.540	1.0145	-3.528	.449	2.303	1	.129
[Species=EW]	-1.316	.5896	-2.471	-.160	4.979	1	.026
[Species=mill]	-1.363	.2689	-1.890	-.836	25.681	1	.000
[Species=no species]	-31.724[b]	.	.	.	.	.	.
[Species=term]	-.382	.4670	-1.297	.533	.669	1	.413
[Species=wood]	0[a]	.	.	.	.	.	.
(Scale)	1[c]						

Dependent Variable: Count

Model: (Intercept), Time, Treatment, Species

a. Set to zero because this parameter is redundant.

b. Hessian matrix singularity is caused by this parameter. The parameter estimate at the last iteration is displayed.

c. Fixed at the displayed value.

Estimated Marginal Means 1: Time

Estimates

Time	Mean	Std. Error	95% Wald Confidence Interval	
			Lower	Upper
8	-4.186	.181	-4.540	-3.833
12	-4.284	.179	-4.634	-3.934
16	-4.434	.190	-4.806	-4.063

Pairwise Comparisons

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	df	Sequential Sidak Sig.	95% Wald Confidence Interval for Difference[a]	
						Lower	Upper
8	12	.098	.125	1	.501	-.157	.352
	16	.248	.132	1	.173	-.068	.564
12	8	-.098	.125	1	.501	-.352	.157
	16	.150	.143	1	.501	-.169	.470
16	8	-.248	.132	1	.173	-.564	.068
	12	-.150	.143	1	.501	-.470	.169

Pairwise comparisons of estimated marginal means based on the linear predictor of dependent variable Count

a. Confidence interval bounds are approximate.

Overall Test Results

Wald Chi-Square	df	Sig.
3.506	2	.173

The Wald chi-square tests the effect of Time. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Estimated Marginal Means 2: Treatment

Estimates

Treatment	Mean	Std. Error	95% Wald Confidence Interval	
			Lower	Upper
0	-4.686	.279	-5.232	-4.140
1	-4.191	.206	-4.595	-3.786
2	-4.018	.187	-4.385	-3.652
3	-3.978	.189	-4.349	-3.608
4	-4.123	.190	-4.496	-3.751
5	-4.812	.215	-5.234	-4.390

Pairwise Comparisons

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	df	Sequential Sidak Sig.	95% Wald Confidence Interval for Difference[a]	
						Lower	Upper
0	1	-.495	.265	1	.400	-1.218	.228
	2	-.668	.262	1	.103	-1.402	.066
	3	-.708	.252	1	.053	-1.420	.005
	4	-.563	.257	1	.231	-1.274	.149
	5	.126	.275	1	.956	-.531	.783

1	0	.495	.265	1	.400	-.228	1.218
	2	-.173	.179	1	.906	-.642	.297
	3	-.213	.161	1	.766	-.645	.220
	4	-.067	.170	1	.956	-.466	.332
	5	.622[b]	.196	1	.018	.061	1.182
2	0	.668	.262	1	.103	-.066	1.402
	1	.173	.179	1	.906	-.297	.642
	3	-.040	.158	1	.956	-.391	.311
	4	.105	.166	1	.949	-.307	.518
	5	.794[b]	.196	1	.001	.224	1.364
3	0	.708	.252	1	.053	-.005	1.420
	1	.213	.161	1	.766	-.220	.645
	2	.040	.158	1	.956	-.311	.391
	4	.145	.148	1	.906	-.243	.534
	5	.834[b]	.180	1	.000	.307	1.361
4	0	.563	.257	1	.231	-.149	1.274
	1	.067	.170	1	.956	-.332	.466
	2	-.105	.166	1	.949	-.518	.307
	3	-.145	.148	1	.906	-.534	.243
	5	.689[b]	.186	1	.003	.153	1.225
5	0	-.126	.275	1	.956	-.783	.531
	1	-.622[b]	.196	1	.018	-1.182	-.061
	2	-.794[b]	.196	1	.001	-1.364	-.224
	3	-.834[b]	.180	1	.000	-1.361	-.307
	4	-.689[b]	.186	1	.003	-1.225	-.153

Pairwise comparisons of estimated marginal means based on the linear predictor of dependent variable Count

a. Confidence interval bounds are approximate.

b. The mean difference is significant at the .05 level.

Overall Test Results

Wald Chi-Square	df	Sig.
28.259	5	.000

The Wald chi-square tests the effect of Treatment. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Estimated Marginal Means 3: Species

Estimates

Species	Mean	Std. Error	95% Wald Confidence Interval	
			Lower	Upper
ants	1.069	.077	.919	1.219
Beet	-.899	.217	-1.325	-.473
Centi	-1.249	1.010	-3.230	.731
EW	-1.025	.581	-2.165	.114
mill	-1.072	.258	-1.579	-.566
no species	-31.434	.098	-31.626	-31.241
term	-.092	.461	-.996	.812
wood	.290	.098	.098	.483

Pairwise Comparisons

(I) Species	(J) Species	Mean Difference (I-J)	Std. Error	df	Sequential Sidak Sig.	95% Wald Confidence Interval for Difference[b]	
						Lower	Upper
ants	Beet	1.967[a]	.226	1	.000	.	.
	Centi	2.318	1.014	1	.287	-.651	5.287
	EW	2.094[a]	.588	1	.006	.350	3.838
	mill	2.141[a]	.262	1	.000	1.346	2.936
	no species	32.502[a]	.117	1	.000	32.137	32.867
	term	1.160	.467	1	.188	-.216	2.536
	wood	.778[a]	.117	1	.000	.425	1.132
Beet	ants	-1.967[a]	.226	1	.000	1.798E+308	1.798E+308
	Centi	.351	1.032	1	1.000	-2.364	3.066
	EW	.127	.622	1	1.000	-1.471	1.724
	mill	.174	.333	1	.998	-.720	1.067
	no species	30.535[a]	.233	1	.000	29.813	31.257
	term	-.807	.505	1	.753	-2.251	.636
	wood	-1.189[a]	.233	1	.000	-1.887	-.491
Centi	ants	-2.318	1.014	1	.287	-5.287	.651
	Beet	-.351	1.032	1	1.000	-3.066	2.364
	EW	-.224	1.165	1	1.000	-3.213	2.765
	mill	-.177	1.043	1	1.000	-2.830	2.476
	no species	30.184[a]	1.014	1	.000	27.045	33.324
	term	-1.158	1.115	1	.959	-4.242	1.927
	wood	-1.540	1.014	1	.781	-4.411	1.332
EW	ants	-2.094[a]	.588	1	.006	-3.838	-.350
	Beet	-.127	.622	1	1.000	-1.724	1.471
	Centi	.224	1.165	1	1.000	-2.765	3.213
	mill	.047	.636	1	1.000	-1.492	1.586
	no species	30.408[a]	.590	1	.000	28.590	32.226

	term	-.934	.742	1	.903	-3.011	1.144
	wood	-1.316	.590	1	.305	-3.029	.398
mill	ants	-2.141[a]	.262	1	.000	-2.936	-1.346
	Beet	-.174	.333	1	.998	-1.067	.720
	Centi	.177	1.043	1	1.000	-2.476	2.830
	EW	-.047	.636	1	1.000	-1.586	1.492
	no species	30.361[a]	.269	1	.000	29.536	31.187
	term	-.981	.529	1	.575	-2.505	.544
	wood	-1.363[a]	.269	1	.000	-2.165	-.560
no species	ants	-32.502[a]	.117	1	.000	-32.867	-32.137
	Beet	-30.535[a]	.233	1	.000	-31.257	-29.813
	Centi	-30.184[a]	1.014	1	.000	-33.324	-27.045
	EW	-30.408[a]	.590	1	.000	-32.226	-28.590
	mill	-30.361[a]	.269	1	.000	-31.187	-29.536
	term	-31.342[a]	.467	1	.000	-32.770	-29.914
	wood	-31.724	.000	1	.	-31.724	-31.724
term	ants	-1.160	.467	1	.188	-2.536	.216
	Beet	.807	.505	1	.753	-.636	2.251
	Centi	1.158	1.115	1	.959	-1.927	4.242
	EW	.934	.742	1	.903	-1.144	3.011
	mill	.981	.529	1	.575	-.544	2.505
	no species	31.342[a]	.467	1	.000	29.914	32.770
	wood	-.382	.467	1	.986	-1.656	.892
wood	ants	-.778[a]	.117	1	.000	-1.132	-.425
	Beet	1.189[a]	.233	1	.000	.491	1.887
	Centi	1.540	1.014	1	.781	-1.332	4.411
	EW	1.316	.590	1	.305	-.398	3.029
	mill	1.363[a]	.269	1	.000	.560	2.165
	no species	31.724	.000	1	.	31.724	31.724
	term	.382	.467	1	.986	-.892	1.656

Pairwise comparisons of estimated marginal means based on the linear predictor of dependent variable Count

a. The mean difference is significant at the .05 level.

b. Confidence interval bounds are approximate.

Overall Test Results

Wald Chi-Square	df	Sig.
81959.834	6	.000

Appendix L
Generalized Linear Models Wald

Notes

Output Created		17-NOV-2015 12:55:13
Comments		
Input	Data	C:\Users\User\Downloads\Priyanka\phophi\Bergville.sav
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	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	177
Missing Value Handling	Definition of Missing	User-defined missing values for factor, subject and within-subject variables are treated as missing.
	Cases Used	Statistics are based on cases with valid data for all variables in the model.
Weight Handling		not applicable
Syntax		GENLIN Count BY Time Treatment Species (ORDER=ASCENDING) /MODEL Time Treatment Species INTERCEPT=YES DISTRIBUTION=POISSON LINK=LOG /CRITERIA METHOD=FISHER(1) SCALE=1 COVB=MODEL MAXITERATIONS=100 MAXSTEPHALVING=5 PCONVERGE=1E-006(ABSOLUTE) SINGULAR=1E-012 ANALYSISTYPE=3(WALD) CILEVEL=95 CITYPE=WALD LIKELIHOOD=FULL /EMMEANS TABLES=Time SCALE=TRANSFORMED COMPARE=Time CONTRAST=PAIRWISE PADJUST=SEQSIDAK /EMMEANS TABLES=Treatment SCALE=TRANSFORMED COMPARE=Treatment CONTRAST=PAIRWISE PADJUST=SEQSIDAK /EMMEANS TABLES=Species SCALE=TRANSFORMED COMPARE=Species CONTRAST=PAIRWISE PADJUST=SEQSIDAK /MISSING CLASSMISSING=EXCLUDE /PRINT CPS DESCRIPTIVES MODELINFO FIT SUMMARY SOLUTION.
Resources	Processor Time	00:00:00.11
	Elapsed Time	00:00:00.11

Model Information

Dependent Variable	Count
Probability Distribution	Poisson
Link Function	Log

Case Processing Summary

	N	Percent
Included	177	100.0%
Excluded	0	0.0%
Total	177	100.0%

Categorical Variable Information

			N	Percent
Factor	Time	8	60	33.9%
		12	63	35.6%
		16	54	30.5%
		Total	177	100.0%
	Treatment	0	9	5.1%
		1	30	16.9%
		2	39	22.0%
		3	36	20.3%
		4	30	16.9%
		5	33	18.6%
		Total	177	100.0%
	Species	Ants	45	25.4%
		Beetle	66	37.3%
		centipede	3	1.7%
		earthworm	6	3.4%
		Millepede	3	1.7%
		No species	39	22.0%
		none	9	5.1%
		Termites	6	3.4%
		Total	177	100.0%

Continuous Variable Information

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	Count	177	0	32	.96	3.225

Goodness of Fit[a]

	Value	df	Value/df

Deviance	377.482	162	2.330
Scaled Deviance	377.482	162	
Pearson Chi-Square	448.498	162	2.769
Scaled Pearson Chi-Square	448.498	162	
Log Likelihood[b]	-261.037		
Akaike's Information Criterion (AIC)	552.074		
Finite Sample Corrected AIC (AICC)	555.055		
Bayesian Information Criterion (BIC)	599.716		
Consistent AIC (CAIC)	614.716		

Dependent Variable: Count

Model: (Intercept), Time, Treatment, Species[a]

a. Information criteria are in smaller-is-better form.

b. The full log likelihood function is displayed and used in computing information criteria.

Omnibus Test[a]

Likelihood Ratio Chi-Square	df	Sig.
239.251	14	.000

Dependent Variable: Count

Model: (Intercept), Time, Treatment, Species[a]

a. Compares the fitted model against the intercept-only model.

Tests of Model Effects

	Type III		
Source	Wald Chi-Square	df	Sig.
(Intercept)	3.296	1	.069
Time	28.323	2	.000
Treatment	31.219	5	.000
Species	41.972	5	.000

Dependent Variable: Count

Model: (Intercept), Time, Treatment, Species

Parameter Estimates

Parameter	B	Std. Error	95% Wald Confidence Interval	Hypothesis Test

			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	.430	.6173	-.780	1.640	.485	1	.486
[Time=8]	-.778	.2314	-1.232	-.325	11.305	1	.001
[Time=12]	-.931	.1840	-1.291	-.570	25.598	1	.000
[Time=16]	0[a]	.	.	.	.	.	.
[Treatment=0]	-1.059	1.0231	-3.065	.946	1.072	1	.300
[Treatment=1]	-1.014	.4189	-1.835	-.193	5.859	1	.015
[Treatment=2]	-.820	.2216	-1.254	-.386	13.698	1	.000
[Treatment=3]	-.740	.2457	-1.222	-.259	9.076	1	.003
[Treatment=4]	.167	.2042	-.233	.568	.671	1	.413
[Treatment=5]	0[a]	.	.	.	.	.	.
[Species=Ants]	1.351	.6019	.171	2.530	5.035	1	.025
[Species=Beetle]	.309	.6176	-.901	1.520	.251	1	.617
[Species=centipede]	-.072	.9468	-1.927	1.784	.006	1	.940
[Species=earthworm]	.118	.9533	-1.751	1.986	.015	1	.902
[Species=Millepede]	-.788	1.1579	-3.058	1.481	.463	1	.496
[Species=No species]	-30.236	744662.9372	-1459542.773	1459482.302	.000	1	1.000
[Species=none]	-30.252[b]	.	.	.	.	.	.
[Species=Termites]	0[a]	.	.	.	.	.	.
(Scale)	1[c]						

Dependent Variable: Count

Model: (Intercept), Time, Treatment, Species

a. Set to zero because this parameter is redundant.

b. Hessian matrix singularity is caused by this parameter. The parameter estimate at the last iteration is displayed.

c. Fixed at the displayed value.

Estimated Marginal Means 1: Time

Estimates

Time	Mean	Std. Error	95% Wald Confidence Interval	
			Lower	Upper
8	-8.372	93082.867	-182447.440	182430.695
12	-8.525	93082.867	-182447.592	182430.542
16	-7.594	93082.867	-182446.661	182431.473

Pairwise Comparisons

(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	df	Sequential Sidak Sig.	95% Wald Confidence Interval for Difference[a]

						Lower	Upper
8	12	.153	.238	1	.522	-.314	.619
	16	-.778[b]	.231	1	.002	-1.296	-.261
12	8	-.153	.238	1	.522	-.619	.314
	16	-.931[b]	.184	1	.000	-1.370	-.492
16	8	.778[b]	.231	1	.002	.261	1.296
	12	.931[b]	.184	1	.000	.492	1.370

Pairwise comparisons of estimated marginal means based on the linear predictor of dependent variable Count

a. Confidence interval bounds are approximate.

b. The mean difference is significant at the .05 level.

Overall Test Results

Wald Chi-Square	df	Sig.
28.323	2	.000

The Wald chi-square tests the effect of Time. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Estimated Marginal Means 2: Treatment

Estimates

			95% Wald Confidence Interval	
Treatment	Mean	Std. Error	Lower	Upper
0	-8.646	93082.867	-182447.713	182430.422
1	-8.600	93082.867	-182447.667	182430.467
2	-8.406	93082.867	-182447.473	182430.661
3	-8.326	93082.867	-182447.393	182430.741
4	-7.419	93082.867	-182446.486	182431.648
5	-7.586	93082.867	-182446.653	182431.481

Pairwise Comparisons

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	df	Sequential Sidak Sig.	95% Wald Confidence Interval for Difference[a]	
						Lower	Upper
0	1	-.045	1.094	1	.997	-2.417	2.327
	2	-.239	1.033	1	.997	-2.753	2.274
	3	-.319	1.034	1	.997	-2.895	2.256

	4	-1.227	1.028	1	.908	-4.070	1.617
	5	-1.059	1.023	1	.943	-3.849	1.730
1	0	.045	1.094	1	.997	-2.327	2.417
	2	-.194	.439	1	.995	-1.321	.933
	3	-.274	.445	1	.990	-1.446	.898
	4	-1.181	.428	1	.061	-2.392	.029
	5	-1.014	.419	1	.145	-2.187	.159
2	0	.239	1.033	1	.997	-2.274	2.753
	1	.194	.439	1	.995	-.933	1.321
	3	-.080	.269	1	.997	-.750	.590
	4	-.987[b]	.233	1	.000	-1.668	-.306
	5	-.820[b]	.222	1	.003	-1.464	-.176
3	0	.319	1.034	1	.997	-2.256	2.895
	1	.274	.445	1	.990	-.898	1.446
	2	.080	.269	1	.997	-.590	.750
	4	-.907[b]	.259	1	.006	-1.654	-.161
	5	-.740[b]	.246	1	.031	-1.442	-.038
4	0	1.227	1.028	1	.908	-1.617	4.070
	1	1.181	.428	1	.061	-.029	2.392
	2	.987[b]	.233	1	.000	.306	1.668
	3	.907[b]	.259	1	.006	.161	1.654
	5	.167	.204	1	.976	-.381	.715
5	0	1.059	1.023	1	.943	-1.730	3.849
	1	1.014	.419	1	.145	-.159	2.187
	2	.820[b]	.222	1	.003	.176	1.464
	3	.740[b]	.246	1	.031	.038	1.442
	4	-.167	.204	1	.976	-.715	.381

Pairwise comparisons of estimated marginal means based on the linear predictor of dependent variable Count

a. Confidence interval bounds are approximate.

b. The mean difference is significant at the .05 level.

Overall Test Results

Wald Chi-Square	df	Sig.
31.219	5	.000

The Wald chi-square tests the effect of Treatment. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Estimated Marginal Means 3: Species

Estimates

Species	Mean	Std. Error	95% Wald Confidence Interval	
			Lower	Upper
Ants	.633	.202	.236	1.030
Beetle	-.408	.217	-.834	.017
centipede	-.789	.751	-2.261	.683
earthworm	-.600	.757	-2.083	.883
Millepede	-1.506	1.035	-3.535	.523
No species	-30.953	744662.937	-1459543.491	1459481.584
none	-30.969	.619	-32.183	-29.756
Termites	-.718	.619	-1.931	.496

Pairwise Comparisons

(I) Species	(J) Species	Mean Difference (I-J)	Std. Error	df	Sequential Sidak Sig.	95% Wald Confidence Interval for Difference[b]	
						Lower	Upper
Ants	Beetle	1.041[a]	.184	1	.000	.480	1.603
	centipede	1.422	.735	1	.663	-.794	3.639
	earthworm	1.233	.760	1	.878	-1.047	3.513
	Millepede	2.139	1.024	1	.545	-.966	5.244
	No species	31.586	744662.937	1	1.000	-2030670.124	2030733.296
	none	31.602[a]	.602	1	.000	29.726	33.478
	Termites	1.351	.602	1	.425	-.482	3.183
Beetle	Ants	-1.041[a]	.184	1	.000	-1.603	-.480
	centipede	.381	.744	1	1.000	-1.780	2.542
	earthworm	.192	.758	1	1.000	-1.976	2.359
	Millepede	1.097	1.036	1	.998	-1.993	4.188
	No species	30.545	744662.937	1	1.000	-1997752.266	1997813.356
	none	30.561[a]	.618	1	.000	28.643	32.479
	Termites	.309	.618	1	1.000	-1.486	2.104
centipede	Ants	-1.422	.735	1	.663	-3.639	.794
	Beetle	-.381	.744	1	1.000	-2.542	1.780
	earthworm	-.189	1.059	1	1.000	-3.187	2.809
	Millepede	.717	1.263	1	1.000	-2.981	4.414
	No species	30.164	744662.937	1	1.000	-1854862.014	1854922.342
	none	30.180[a]	.947	1	.000	27.250	33.110
	Termites	-.072	.947	1	1.000	-2.690	2.547
earthworm	Ants	-1.233	.760	1	.878	-3.513	1.047
	Beetle	-.192	.758	1	1.000	-2.359	1.976

	centipede	.189	1.059	1	1.000	-2.809	3.187
	Millepede	.906	1.259	1	1.000	-2.830	4.642
	No species	30.353	744662.937	1	1.000	-1959206.344	1959267.050
	none	30.369[a]	.953	1	.000	27.430	33.308
	Termites	.118	.953	1	1.000	-2.551	2.786
Millepede	Ants	-2.139	1.024	1	.545	-5.244	.966
	Beetle	-1.097	1.036	1	.998	-4.188	1.993
	centipede	-.717	1.263	1	1.000	-4.414	2.981
	earthworm	-.906	1.259	1	1.000	-4.642	2.830
	No species	29.447	744662.937	1	1.000	-1778030.461	1778089.356
	none	29.464[a]	1.158	1	.000	25.908	33.019
	Termites	-.788	1.158	1	1.000	-4.202	2.625
No species	Ants	-31.586	744662.937	1	1.000	-2030733.296	2030670.124
	Beetle	-30.545	744662.937	1	1.000	-1997813.356	1997752.266
	centipede	-30.164	744662.937	1	1.000	-1854922.342	1854862.014
	earthworm	-30.353	744662.937	1	1.000	-1959267.050	1959206.344
	Millepede	-29.447	744662.937	1	1.000	-1778089.356	1778030.461
	none	.016	744662.937	1	1.000	-1665421.251	1665421.283
	Termites	-30.236	744662.937	1	1.000	-1912892.961	1912832.490
none	Ants	-31.602[a]	.602	1	.000	-33.478	-29.726
	Beetle	-30.561[a]	.618	1	.000	-32.479	-28.643
	centipede	-30.180[a]	.947	1	.000	-33.110	-27.250
	earthworm	-30.369[a]	.953	1	.000	-33.308	-27.430
	Millepede	-29.464[a]	1.158	1	.000	-33.019	-25.908
	No species	-.016	744662.937	1	1.000	-1665421.283	1665421.251
	Termites	-30.252	.000	1	.	-30.252	-30.252
Termites	Ants	-1.351	.602	1	.425	-3.183	.482
	Beetle	-.309	.618	1	1.000	-2.104	1.486
	centipede	.072	.947	1	1.000	-2.547	2.690
	earthworm	-.118	.953	1	1.000	-2.786	2.551
	Millepede	.788	1.158	1	1.000	-2.625	4.202
	No species	30.236	744662.937	1	1.000	-1912832.490	1912892.961
	none	30.252	.000	1	.	30.252	30.252

Pairwise comparisons of estimated marginal means based on the linear predictor of dependent variable Count

a. The mean difference is significant at the .05 level.

b. Confidence interval bounds are approximate.

Overall Test Results

Wald Chi-Square	df	Sig.

2764.847	6	.000

Appendix M

Bergville soil macrofauna species diversity

Analysis of variance

Variate: Diversity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	4.30535	0.86107	22.87	<.001
Time	2	5.48451	2.74225	72.82	<.001
Treatment.Time	10	7.97668	0.79767	21.18	<.001
Residual	126	4.74473	0.03766		
Total	143	22.51126			

Tables of means

Variate: Diversity

Grand mean 0.516

Treatment	1	2	3	4	5	outside
	0.587	0.758	0.619	0.266	0.367	0.464
rep.	27	27	27	27	27	9

Time	8	12	16
	0.657	0.651	0.240

Treatment	Time	8	12	16
1		0.900	0.860	0.000
	rep.	9	9	9
2		0.816	0.964	0.494
	rep.	9	9	9
3		0.797	0.382	0.677
	rep.	9	9	9
4		0.000	0.799	0.000
	rep.	9	9	9
5		0.760	0.233	0.109
	rep.	9	9	9
outside		0.697	0.697	0.000
	rep.	3	3	3

Standard errors of differences of means

Table	Treatment	Time	Treatment Time	
rep.	unequal	48	unequal	
d.f.	126	126	126	
s.e.d.	0.0915X		0.1584	min.rep

	0.0747	0.0396	0.1294	max-min
	0.0528		0.0915	max.rep

(No comparisons in categories where s.e.d. marked with an

Least significant differences of means (5% level)

Table	Treatment	Time	Treatment Time	
rep.	unequal	48	unequal	
d.f.	126	126	126	
l.s.d.	0.1810X		0.3136	min.rep
	0.1478	0.0784	0.2560	max-min
	0.1045		0.1810	max.rep

(No comparisons in categories where l.s.d. marked with an X)

Stratum standard errors and coefficients of variation

Variate: Diversity

d.f.	s.e.	cv%
126	0.1941	37.6

Fisher's protected least significant difference test

Treatment.Time

	Mean	
4 8	0.0000	a
outside 16	0.0000	ab
1 16	0.0000	abc
4 16	0.0000	abc
5 16	0.1089	abcd
5 12	0.2333	bde
3 12	0.3822	ef
2 16	0.4944	fg
3 16	0.6767	h
outside 8	0.6967	ghi
outside 12	0.6967	ghi
5 8	0.7600	hi
3 8	0.7967	hij
4 12	0.7989	hij
2 8	0.8156	hij
1 12	0.8600	ij
1 8	0.9000	ij
2 12	0.9644	j

Appendix N

Ukulinga soil macrofauna species Diversity

Analysis of variance

Variate: Diversity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	4.97531	0.99506	22.62	<.001
Time	2	0.56123	0.28061	6.38	0.002
Treatment.Time	10	5.78788	0.57879	13.16	<.001
Residual	126	5.54344	0.04400		
Total	143	16.86786			

Tables of means

Variate: Diversity

Grand mean 0.581

Treatment	1	2	3	4	5	outside
	0.304	0.524	0.565	0.752	0.828	0.379
rep.	27	27	27	27	27	9

Time	8	12	16
	0.555	0.667	0.521

Treatment	Time	8	12	16
1		0.000	0.779	0.132
	rep.	9	9	9
2		0.412	0.439	0.720
	rep.	9	9	9
3		0.554	0.662	0.478
	rep.	9	9	9
4		1.003	0.596	0.658
	rep.	9	9	9
5		0.757	1.082	0.644
	rep.	9	9	9
outside		0.697	0.000	0.440
	rep.	3	3	3

Standard errors of differences of means

Table	Treatment	Time	Treatment Time	
rep.	unequal	48	unequal	
d.f.	126	126	126	
s.e.d.	0.0989X		0.1713	min.rep
	0.0807	0.0428	0.1398	max-min
	0.0571		0.0989	max.rep

(No comparisons in categories where s.e.d. marked with an X)

Least significant differences of means (5% level)

Table	Treatment	Time	Treatment Time	
rep.	unequal	48	unequal	
d.f.	126	126	126	
l.s.d.	0.1957X		0.3389	min.rep
	0.1598	0.0847	0.2767	max-min

0.1130 0.1957 max.rep

(No comparisons in categories where l.s.d. marked with an X)

Stratum standard errors and coefficients of variation

Variate: Diversity

d.f.	s.e.	cv%
126	0.2098	36.1

Fisher's protected least significant difference test

Treatment.Time

	Mean	
1 8	0.0000	a
outside 12	0.0000	a
1 16	0.1322	a
2 8	0.4122	b
2 12	0.4389	bc
Natural fallow 16	0.4400	bcd
3 16	0.4778	bcd
3 8	0.5544	bcde
4 12	0.5956	bcdef
5 16	0.6444	def
4 16	0.6578	def
3 12	0.6622	def
Natural fallow 8	0.6967	cdef
2 16	0.7200	ef
5 8	0.7567	f
1 12	0.7789	f
4 8	1.0033	g
5 12	1.0822	g

Appendix O

Bergville soil macrofauna species richness

Analysis of variance

Variate: Richness

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	11.2168	2.2434	2.50	0.034
Time	2	0.0486	0.0243	0.03	0.973
Treatment.Time	10	4.5268	0.4527	0.50	0.884
Residual	126	113.0801	0.8975		
Total	143	128.8722			

Tables of means

Variate: Richness

Grand mean 0.347

Treatment	1	2	3	4	5	outside
	0.107	0.483	0.423	0.023	0.796	0.062
rep.	27	27	27	27	27	9

Time	8	12	16
	0.323	0.367	0.352

Treatment	Time	8	12	16
1		0.160	0.160	0.000
	rep.	9	9	9
2		0.202	0.523	0.725
	rep.	9	9	9
3		0.799	0.160	0.310
	rep.	9	9	9
4		0.000	0.069	0.000
	rep.	9	9	9
5		0.561	1.046	0.780
	rep.	9	9	9
outside		0.000	0.000	0.186
	rep.	3	3	3

Standard errors of differences of means

Table	Treatment	Time	Treatment Time	
rep.	unequal	48	unequal	
d.f.	126	126	126	
s.e.d.	0.4466X		0.7735	min.rep
	0.3646	0.1934	0.6316	max-min
	0.2578		0.4466	max.rep

(No comparisons in categories where s.e.d. marked with an X)

Least significant differences of means (5% level)

Table	Treatment	Time	Treatment Time	
rep.	unequal	48	unequal	
d.f.	126	126	126	
l.s.d.	0.8838X		1.5307	min.rep
	0.7216	0.3827	1.2498	max-min
	0.5102		0.8838	max.rep

(No comparisons in categories where l.s.d. marked with an X)

Stratum standard errors and coefficients of variation

Variate: Richness

d.f.	s.e.	cv%

126	0.9473	272.7

Fisher's protected least significant difference test

Treatment

	Mean	
4	0.0230	a
outside	0.0620	a
1	0.1069	a
3	0.4231	ab
2	0.4834	ab
5	0.7957	b

Appendix P

Ukulinga soil macrofauna species richness

Analysis of variance

Variate: Richness

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatment	5	0.6318	0.1264	0.90	0.481
Time	2	0.9584	0.4792	3.42	0.036
Treatment.Time	10	1.9805	0.1980	1.42	0.181
Residual	126	17.6313	0.1399		
Total	143	21.2019			

Tables of means

Variate: Richness

Grand mean 0.140

Treatment	1	2	3	4	5	outside
	0.110	0.101	0.080	0.152	0.269	0.101
rep.	27	27	27	27	27	9

Time	8	12	16
	0.202	0.193	0.025

Treatment	Time	8	12	16
1		0.101	0.229	0.000
	rep.	9	9	9
2		0.144	0.158	0.000
	rep.	9	9	9
3		0.202	0.038	0.000
	rep.	9	9	9
4		0.324	0.000	0.131
	rep.	9	9	9
5		0.205	0.603	0.000
	rep.	9	9	9

outside		0.303	0.000	0.000
	rep.	3	3	3

Standard errors of differences of means

Table	Treatment	Time	Treatment Time	
rep.	unequal	48	unequal	
d.f.	126	126	126	
s.e.d.	0.1763X		0.3054	min.rep
	0.1440	0.0764	0.2494	max-min
	0.1018		0.1763	max.rep

(No comparisons in categories where s.e.d. marked with an X)

Least significant differences of means (5% level)

Table	Treatment	Time	Treatment Time	
rep.	unequal	48	unequal	
d.f.	126	126	126	
l.s.d.	0.3490X		0.6044	min.rep
	0.2849	0.1511	0.4935	max-min
	0.2015		0.3490	max.rep

(No comparisons in categories where l.s.d. marked with an X)

Stratum standard errors and coefficients of variation

Variate: Richness

d.f.	s.e.	cv%
126	0.3741	267.5

Fisher's protected least significant difference test

Treatment

Fisher's protected least significant difference test

Time

	Mean	
16	0.0246	a
12	0.1928	b
8	0.2021	b