THE USE OF COVER CROPS TO INCREASE YIELD AND REDUCE PEST PRESSURE IN A COMMERCIAL AVOCADO ORCHARD AT LEVUBU, LIMPOPO PROVINCE

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ABSTRACT

The study investigated the impact of cover crops (*Medicago sativa*, *Lotus corniculatus*, *Trifolium pratense*, *Melilotus alba* and *Phacelia tanacetifolia*), bare soil and natural ground cover on pest and beneficial arthropods, soil health, crop yield, pest damage and weed suppression in avocado orchards. The trial plots were sited within established commercial avocado orchards with trees of similar cultivar ('Hass'), soil-type and age, located in Levubu, Limpopo, South Africa. Mixtures of cover crops were planted in the alleys of avocado orchards and the effects were compared to that of a control (other half of the orchard). Mechanical clearing of vegetation in half of the alleys of different avocado orchards were compared to the other half that was left undisturbed. Data were collected during the flowering and fruit set stages of the avocado trees in the months of September - November 2019. Results revealed that there was higher abundance and diversity of flowering plants in the orchard alleys of the cover crop treatment compared to the control comprising of natural vegetation. Cover crops had a significantly positive effect on the soil health of the orchard but little or no effect on beneficial arthropods within the orchard nor any positive effect on the pests of avocados. However, the number of thrips scouted on the fruit were significantly less where cover crops were established. Avocado scale infection rates were also significantly lower where cover crops were established. There were significantly less arthropods, and specifically pests, pollinators and herbivores where the topsoil was removed mechanically. The yield resulting from the orchard half where cover crops were established were significantly higher. More research still needs to be done about the use, management and impact of cover cropping on not only commercial avocado orchards but on other fruit crops. This study shows good evidence for the benefits for using cover crops and the negative effects in having no vegetation cover in the orchards.

Key words: avocado; cover crops; biodiversity; pests; pollinators; predators.

DECLARATION

By submitting this dissertation, I declare that the entire work contained therein is my own original work, and that I am the sole author. I have acknowledged the sources that I have used in the entire document. I have not submitted this work in any other institution nor for any another degree.

Signature: Date:

13 August 2020

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1 CHAPTER ONE: INTRODUCTION

1.1 Background Information

For agricultural production to meet the needs of a growing world population, it needs to increase by an estimated 70% globally and by 100% in developing countries by 2050 (Bharucha, 2013). When food demand is exceeding supply, there is enormous pressure on land use for agricultural food production. Pressure may lead to a decline in soil nutrients and an increase in soil degradation (Eberle, 1999). Sustainable farming is one solution to maintaining soil integrity while meeting the global increase in food demand, however, it will involve applying alternative techniques that does not result in environmental degradation or is impinging on human health (Mensah and Castro, 2004).

Evidence has accumulated showing that intensive farming practices such as monoculture have brought a variety of economic, environmental and social problems. According to (Altieri, 2005) monoculture systems in agriculture do not represent ecological diversity, it rather leads to loss of natural habitats that in turn lead to loss of wildlife species. This results in destabilised ecosystems and could lead to their total collapse. The biodiversity of flora and fauna becomes less and less, and loss of beneficial insects within the systems are experienced. Studies show that there is a significant decline in the quality of natural resources due to unsustainable agricultural practices. Monoculture practices that promote the use of pesticides, herbicides and fertilizers in commercial farming for improved yields and profitability lead to some irreversible consequences to the natural environment and can even cause harm to human life. Fertilizers and pesticides contain toxic and unstable compounds which contaminate freshwater systems (Youssef, 2015).

Introduction of cover crops to enhance diversity reduces the risk of crop failure by attracting and improving beneficial insects such as pollinators (Saunders *et al.,* 2013), predators and parasitoids. When there is high diversity in orchards, functions such as nutrient recycling, decomposition, pollination and predation are improved, promoting yield and leading to higher profitability.

When natural enemies are low in numbers in orchards, it leads to an increase in the population of pests (Ashraf *et al.,* 2018). In South Africa, commercial farming that includes fruit and nut production is faced with the challenge of yield decline due to pest infestations, diseases and nutrient deficiencies in orchards. Farmers are relying more and more on synthetic inorganic fertilizers and pesticides and are increasingly minimising labour input due to the lack of productivity and narrow profit margins due to competition in the global market. Mechanization is becoming a trend in the fruit and nut industries. In addition, farmers must produce products of high quality while complying to environmental and food safety standards for export markets, and this puts them under tremendous pressure (Simon *et al.,* 2017).

Although many pesticides may not have been banned, South African farmers are anyway moving away from conventional ways of farming and are slowly converting to more organic systems, by steering away from the application of synthetic pesticides and fertilizers. This is especially true in the avocado industry of South Africa. Farmers are continually testing alternatives that imitate the way of natural ecosystems (Keyes *et al.,* 2015). These techniques will help in optimising recycling of nutrients and organic matter turnover, conserving water and soil nutrients, increase pollinators, reduce pests and most importantly conserve biodiversity (Santos *et al.,* 2007). Crop rotations, cover crops and intercropping are some of the strategies that farmers are relying on in moving away from conventional ways of farming (Altieri and Nicholls, 2005).

Studies have shown that cover crops are an important ecological farming tool that, when implemented correctly will improve soil nutrients, organic matter content, reduce top soil erosion and pest infestations in orchards. Although there are risks and challenges, the proposed strategy should result in the reduction in the application of synthetic pesticides, herbicides and fertilizers (Collins and Qualset,1999; Cheng and Baumgartne, 2004; Gliessman, 2007).

1.2 Problem Statements

1.2.1 Modern commercial practices that result in losses of biodiversity and soil health are unsustainable.

1.2.2 Inorganic pesticides result in the loss of the ecological integrity of orchard ecosystems and adversely affects crops.

1.3 Research Objectives

1.3.1 General objective

a) To investigate the impact of cover crops that are cultivated on bare soil as a result of mechanized ridging on pest, pollinator, predator and parasitoids assemblages in commercial avocado orchards by measuring organism abundance and diversity and coupling it with crop yield and pest damage.

1.3.2 Specific objectives

a) To measure the abundance and diversity of beneficial insects (pollinators, predators and parasitoids) in replicated bare soil or cover crop treatments and compare it to control plots.
b) To measure pest presence and damage during fruit growth and compare results across the treatment and control plots.
c) To quantify pest damage upon harvest and compare results for the treatment and control plots.
d) To assess the changes in soil health as a result of cover crop treatments and compare it with control plots and compare this with measurements of yield and avocado weight
e) To assess the impacts of cover crop treatments on weed suppression.

1.4 Research Questions

1.4.1 Will the application of cover crops in avocado orchards increase the abundance and diversity of beneficial insects (pollinators, predators and parasitoids)?

1.4.2 Did mechanised ridging that resulted in bare soil in avocado orchards decrease the abundance and diversity of beneficial insects (pollinators, predators and parasitoids)?

1.4.3 Will the application of cover crops in avocado orchards reduce pest damage by providing habitat heterogeneity and hence, more natural predators?

1.4.5 Did mechanised ridging that resulted in bare soil in avocado orchards increase pest damage by destroying habitat heterogeneity?

1.4.5 Will the application of cover crops in avocado orchards improve the soil health of the treated plots?

1.4.6 Will the application of cover crops in avocado orchards improve yield and avocado weight through reduced pest pressure, and enhanced predation, pollination and parasitism?

1.4.7 Will the application of cover crops improve the abundance and diversity of flowering plants in the treated plots?

1.5 Thesis Statement

Bare soil in commercial avocado orchards results in reduced numbers of beneficial insects and more pest damage while cover crops that are nitrogen-fixing in character, attracting or repelling pests, pollinator friendly and which contain natural bio-fumigating agents, result in an increased crop yield and reduced insect damage as well as an improvement in soil health in avocado orchards when planted in the orchard alleys.

1.6 Delineations and Limitations

1.6.1 This study was limited to the use of a mixture of cover crops strategically planted in avocado orchard alleys to achieve specific goals related to crop yield, pest damage reduction and soil health improvement.

1.6.2 The major pests of avocado were monitored and recorded throughout the growing season.

1.6.3 Time and funding have prevented a more comprehensive study to include more ecological interactions and other fruit crop systems.

1.7 Underlying Assumptions

All environmental factors other than the treatments which may have had an influence on crop yield, pest damage and soil health in the trial plots were considered to be insignificant for the purpose of the study.

1.8 Significance of the Study

The study is of importance due to the challenges that South Africa and the rest of the agricultural sector face in farming sustainably. The agricultural industry is growing at a phenomenal rate, and studies have shown that many conventional agricultural practises seem to have a tremendous negative impact on the environment. This study will promote alternative sustainable agricultural practices in commercial farming that do not harm the environment and risk human health. This study emphasizes the need for further research on environmentally friendly farming alternatives that will improve yields and reduce pest pressure in the production of avocados. More solutions to cultivate avocados in a more sustainable manner will be highly significant to help commercial farming industries to become more sustainable.

It is of importance to understand and have better knowledge on yield suppression or improvement especially in organic farming systems where effective management requires considerable ecological knowledge. Cover crops have the potential to attract beneficial arthropods (e.g. pollinators, predators and parasitoids) that will result in increasing crop yield and repel and reduce fruit damaging pests. Cover crops can contribute significantly in improving soil health, as many cover crops are good soil builders. Due to high competition in the avocado industry it is of importance that farmers produce fruits that are attractive and marketable

1.9 Terms and Concepts

Biodiversity – “refers to all species of plants, animals and microorganism that are found on the farm” (Altier, 1999; Altieri and Nicholls, 2005).

Biological control – “the direct use of natural enemies that are usually called ‘beneficial insects’ or ‘beneficials’ to reduce, prevent or delay outbreaks of insects, nematodes, weeds or plant diseases” (Altieri and Nicholls, 2005).

Conventional farming – “the mixing of topsoil through tillage, removing plant canopies that protect the soil, adding fertilizers and biocides and removing harvest” (Gliessman, 2007).

Cover crop – “any living ground cover that is planted into or after annual main crops or in permanent orchards” (Hartwig and Ammon, 2002).

Ecological diversity – “the degree of heterogeneity of an ecosystem’s or agroecosystem’s species make up, genetic potential, vertical spatial structure, horizontal spatial structure, strophic structure, ecological functioning, and change over time” (Gliessman, 2000).

Insect parasitoid – “an insect that lives as a parasite in a host organism and ultimately killing it” (Clark, 2007).

Monoculture – “an agricultural practice where labour inputs are minimised and technology-based inputs are maximised in order to increase productive efficiency” (Gliessman, 2007).

Nitrogen fixation – “a microbiological process which converts atmospheric nitrogen into a plant-usable form” (Bohlool *et al*., 1992).

Organic farming – “a system which seeks to avoid the direct and /or routine use of readily soluble chemicals and biocides whether naturally occurring, nature identical or not” (Lampkin, 1990).

Pests – “undesirable insects causing damage that results in downgraded or unmarketable crops” (Peltzer, 2013).

Insect predators – “an important biological control organism that feeds on its prey, they kill and eat another insects” (Clark, 2007).

Insect pollinators – “organisms that transfer pollen grains from anther (male part) to stigma (female part) of the flower which results in seeds and fruit” (Scherr, 2007).

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Today, many agro- scientists agree that modern agriculture confronts an environmental crisis. The agriculture of the future must be both sustainable and highly productive if it is to feed the growing human population. This twin challenge means that we cannot simply abandon conventional practices wholesale and return to traditional or indigenous practices. Although traditional agriculture can provide models and practices valuable in developing sustainable agriculture, it cannot produce the amount of food required to supplement distinct urban centres and global markets because of its focus on meeting small-scale needs. What is called for then, is a new approach to agricultural development that builds on the resource-conserving aspects of traditional farming while at the same time drawing on ecological knowledge and methods (Gliessman, 2007).

Agricultural fertilization and pesticide use entail significant economic and environmental costs. Certain conventional farming practices and associated chemical inputs have raised many environmental and public health concerns. Among these concerns is the reduction of biodiversity, water contamination, soil erosion and land degradation (Tu *et al*., 2006).

Pest damage on crops and yield decline are a big challenge for commercial farmers including avocado producers in tropical and sub-tropical regions of Southern Africa. Farmers need to know and understand and be able to identify the pests that attack their crop and cause damage. For the sake of the environment and human health, the application of chemical pesticides for control of pests should be limited or completely avoided (van den Berg *et al.,* 2010).

2.2 Population Growth and Farming Production

Agricultural productivity has been increasing rapidly since the middle of the 20th century. Food security remains a challenge for many developing countries around the world and in Africa. Food production will have to expand by 70 % by 2050 to keep up with a global population which is currently at 7.3 billion and is expected to reach 8.5 billion by 2030 and 9.7 billion by 2060. More than half of this population growth is expected to occur in Africa (Agricultural Outlook, 2017).

South Africa is known globally as a producer and exporter of citrus, deciduous and subtropical fruits. The Economic Review of the South African Agriculture (2017) estimated that the value of exports in South Africa increased by 17.4%, from R83 022 million in 2015/16 to R97 429 million in 2016/17. Fruits and nuts produced are among South Africa's top ten most valuable exports valued at 3.4 billion (3.8%) (Workman, 2018).

2.3 An Overview of the Avocado Industry

South Africa is one of the countries in the world with high avocados fruit production. The avocado industry consists of approximately 17 500 ha of commercial avocado orchards. Most orchards are in Limpopo and Mpumalanga and 1000 ha new orchards are planted annually. It has been reported that South Africa produces 125 000 tons of avocadoes, of which about 45% is exported to world markets, 21% is sold in the local fresh produce markets, and the rest is sold informally to retailers across the country. Limpopo contributes ± 60% of the total production. South Africa exports most of its avocado fruit to Europe (South African Avocado Growing Association (SAAGA), 2019; SA Fruit Trade Flow, 2017).

This country is faced with high unemployment and poverty. Commercial avocado production contributes to direct employment of the country's population, employing 1 permanent worker per 2.6 ha and another non-permanent worker during the harvest season. The increase in yield means more exports that lead to more employment and poverty alleviation (SAAGA, 2019).

2.4 Characteristics of a Conventional Cropping Systems

Agricultural fertilisation, pesticide use, and monoculture entail significant economic and environmental costs. Certain conventional farming practices and associated chemical inputs have raised many environmental and public health concerns. Prominent among these is the reduction of biodiversity, environmental pollution and soil degradation (Tu *et al.,* 2006).

The practices of conventional agriculture tend to compromise future productivity in favour of high yield in the present. Therefore, signs that the conditions necessary to sustain production are being eroded should be increasingly visible over time. Many areas where modern practices were instituted for growing grain in the 1960's, yield has begun to level off and have even decreased following the initial spectacular improvement in yield (Gliessman, 2007).

Contamination problems are encountered particularly during rainy seasons and spraying times of the year for farmers in orchards. Water runoff that contains pesticides and fertilizers percolates down to the bedrock moving through the terrain contaminating groundwater systems and surrounding important surface water bodies such as wetlands, which ends up into the food chain affecting both wildlife and human beings (Atucha, 2012; Rodriguez *et al.,* 2018).

2.4.1 Monoculture orchards

Farming with a single crop type across several hectares causes problems. Monoculture depend on farming practices that enrich the soil system to keep it productive. Farmers are worryingly dependent on agrochemicals for fertilization, controlling pests and weeds infestations (Altieri and Nicholls, 2005). Literature studies have revealed that monoculture is associated with a lot of negative environmental implications including land degradation, salinization and pollution of water bodies by agrochemicals contaminations (Altieri and Nicholls, 2001; Gliessman, 2007).

2.4.2 Use of synthetic agrochemicals

The prolonged use of synthetic agrochemicals to improve yield and reduce pest infestations is common in today’s farming activities. The indirect costs of pesticide use to the environment and public health needs to be balanced against the benefits. Prolonged use of agrochemicals has dire environmental consequences including impacting on wildlife, pollinators, natural enemies, fisheries and water. Other consequences include the development of resistance to the pesticides by pests; farmers also need to be concerned when it comes to the use of synthetic agrochemicals (Gliessman, 2007).

2.4.3 Tillage

Tillage as a conventional agricultural practice has significant implications for wild flora and fauna diversity found in the soil. Tillage is categorised as one of the most highly destructive methods on agricultural land that impacts negatively on the biodiversity in and around agricultural land. One of the impacts of soil tillage is that it leaves the topsoil vulnerable to rain runoff and severe erosion leading to loss of fertile soil. Soils that have not been tilled have not been physically disturbed while the crop residues from the previous year's growth will be left untouched at the soil surface to decay and add more nutrients to the soil and reduce runoff (McLaughlin and Mineau, 1995).

2.4.4 Agricultural drainage

Farmers employ artificial drainage methods when the agricultural lands have too much water on the surface, which presumably leads to crop plant damage e.g. fungus infections. Heavy rainfall can lead to water not percolating into the ground. It becomes a challenge when water is not penetrating enough to reach the roots of the crop. Drainage practices have dire environmental consequences such as habitat loss leading to biodiversity loss. Excessive leaching is also one of the impacts drainage activities will have with consequences of surface and subsurface contamination by chemical pollutants (McLaughlin and Mineau, 1995).

2.5 Impacts of Conventional Farming

2.5.1 Loss of biodiversity

Conventional farming is characterised using agrochemicals for improved yield and profitability. The use of fertilizer and pesticides have significant implications on biodiversity. Habitat destruction is the leading cause of loss of biodiversity. Soil fauna are vulnerable to conventional agricultural practices that involve the application of chemical fertilizers and pesticides. The increase in pollutant and sediment load in water bodies such as wetlands impacts on species such as reptiles, amphibians, birds, mammals and fish (Toan *et al.,* 2013). Application and drifting of pesticides on a regular basis affect non-targeted species. Fish that has been contaminated is consumed by another fish-eating species such as birds, leading to a chain of species being affected by the pesticide. (Mclaughlin and Mineau, 1995; Dupont *et al.*, 2018).

There is a reduction and decline of flower-visiting insects like bees that will lead to reduced pollination leading to reduction of fruit yield. The European Union has banned the use of many pesticides over the past decade. Studies have showed that some of these banned pesticides were impacting negatively on honeybees. Honeybee populations were decreasing due to death and reproductive malfunctions triggered by the chemical pesticide actives (Valavanidis, 2018).

Pesticides also affect non-target species of natural enemies such as parasitoids and predators. These beneficial insects play an important role on, for example, reducing damage on avocado by insects such as scale, false codling moth and thrips. The biological diversity and abundance of beneficial insects in orchards tend to be negatively affected by the application of insecticides (Geiger, 2010). Restrictions of pesticide use is done to prevent the effect it might have on non-targeted species such as these beneficial predators and parasitoids (Altieri and Nicholls, 2004).

2.5.2 Impact on water bodies

During the rainy season, runo is a major mechanism for transporting pesticides from orchards and other cropping fields into nearby rivers and other water bodies. Schulz (2001) conducted a study in the Western Cape province of South Africa on the inputs of pesticides and sediments from orchards into the nearby river during heavy rainfalls. The study showed that runo events led to increases in total suspended sediment levels exceeding the target water quality range. Pesticide levels detectable during runo were found to be above legislative threshold values. It reached levels that were acutely toxic to the aquatic fauna. The study has revealed that a single heavy rainfall event can lead to considerable input of pesticides into the nearby river each rainy season (Tharme *et al.*, 2007).

2.5.3 Impact on human health

According to (Lammogli *et al.*, 2017) human beings get exposed to chemical pesticides during the manufacturing, mixing & loading, spraying in the fields, harvesting, and during consumption of the treated crops, derived products or consumption of contaminated water. The contamination from chemicals leads to health problems that include poisoning causing fatal illnesses and disabilities (Lai, 2017). A study conducted in Malawi by Donga and Eklo, (2018) showed that pesticides, entering the human body through the skin, nose and mouth lead to skin rash & irritation, headache, coughing, running nose, fever, dizziness, chest pain and diarrhoea.

2.6 Major insect pests of avocado

Commercial avocado farmers are faced with the challenge of pest infestations. Going back as late as 1952, the avocado industry has been experiencing the problem of pest infestations (Ebeling and Pence, 1952). However, Alberts (2004) revealed that many insects visiting the avocado trees during the flowering season to feed on nectar and pollen promotes pollination. Some insect pests that visit avocados feed on the flower and young fruit causing damages leading to fruits dropping before they reach maturity, or damage to the extent that it cannot be exported or is downgraded and achieve lower prices on the market.

Controlling and preventing the outrage of pests includes making use of the methods such as natural control that involve increasing predatory and parasitic insects in the field. Although chemical control that involve making use of pesticides is not highly recommended due to the negative impact it has on beneficial insects like the predators and parasitoids (van den Berg *et al.,* 2010). The major avocado damage causing insects include coconut bug, avocado bug, thrips, scale insects, false codling moth and fruit flies (Picker *et al*., 2002; van den Berg *et al.,* 2010).

2.7 Impacts of pests on commercial productions

2.7.1 Reduction of fruit yield

The increasing demand for sustainable, environmentally friendly cropping is bringing challenges that are hindering the achievements of optimum yields, especially in subtropical fruit orchards. Pest damage on crops is a major challenge for fruit growers in South Africa. Pest infestations in orchards lead to decline in fruit due to damages that are caused throughout the season. Farmers must employ economically sound management strategies that promote maximum yields and at the same time preserving the orchard environment for the long term (Clark, 2007; Campbell, 2014). Campbell (2014) recommended the use of cover crops as an alternative to improve yield by enhancing soil health by relieving compaction and adding organic matter that boosts soil microbes, increase pollination and reduce pest insects.

When there are pest infestations in commercial orchards, fruit damages may not be avoidable. Insects such as thrips, fruit flies, coconut bug and other sucking bugs can cause extensive damage to the fruit. Sucking bugs will leave a lesion that is recognisable on the skin of the fruit. The marks, holes and spots that are left after feeding by the insects become visible during the fruit maturity stage. Damaged fruits may not be very appealing for exportation markets and are either downgraded or rejected (van den Berg *et al.,* 2010). Pack houses are used for the survey of avocado fruit damages after harvest, giving figures that indicate crop losses due to insect damages that are recognised as lesions on the fruit surface or dents in the skin of a matured avocado (van den Berg *et al.,* 2010).

2.8 The sustainable development concept

Cassim and Jackson (2003) defined sustainable development as "development that meets the needs of the present, without compromising the ability of future generations to meet their own needs". Sustainability in the agricultural sector means the use of resources without degrading and/or depleting them. Studies show that land devoted to agricultural purposes has been expanding at a slower pace. Arable land is expected to shrink globally by about 200 million hectares by 2050 (Taylor, 2002).

Sustainable development is threatened by rapid population growth and uncontrolled urban expansions exerting an enormous pressure on the natural environment causing ecosystem destructions and malfunctions (Martinez *et al.*, 2018). According to Nwonwu (2007), sustainable development is achievable when the three pillars of development, which are economic development, social development and environmental protection, are strategically positioned to maximise their interdependent and mutually supportive services.

Agricultural production in South Africa has been equally resource intensive and environmentally degrading. There is a high dependence on harmful chemicals and pesticides that impact negatively on the environment and human health. The environmental impacts include soil degradation, the pollution of freshwater bodies & underground water sources and the loss of biodiversity (United Nations Development Programme, 2003; Atucha, 2012). Government needs to urgently invest in agricultural approaches that address poverty, food security and conservation of natural resources. Agricultural land should be managed in ways that are productive while it delivers ecosystem services. Sustainable agriculture practices are economically, environmentally and socially viable and positively contribute to the economy and livelihoods (Altieri and Nicholls, 2005).

2.9 Sustainable agricultural policy framework

Governments must work with field experts in the design of policies that will favour and lead to better sustainable agricultural practices (Valavanidis, 2018). Most countries are facing the challenge of designing policies that will drive agriculture toward environmentally friendly practices that will not involve the use of agrochemicals (Zhengfei *et al.,* 2005). These policies should be developed to promote sustainable cropping in both commercial and traditional agriculture either through incentives or tax relief. The objectives for the policies should be to protect beneficial insect pollinators and parasitoids and the protection of soil health. Limitation of soil tillage and application of synthetic fertilizers is important. Agricultural land should be rehabilitated and farmers should be encouraged to use environmental friendly practices that protect the environment (Giliomee, 2006).

South Africa’s concern over the environmental impacts that are caused by agricultural practices led to the passing of legislation geared towards the conservation of biodiversity, policies that should lead the country to produce more food and at the same time protecting the environment (Table 1 : There is always a need for policy revision to encourage newly researched alternatives to save the environment (Khwidzhili and Worth, 2017).

Table 1 : South African Agricultural Sustainable Policy and legislation

Policy	Objective
National Climate Change Response White Paper.	To support conservation efforts and improve agricultural production.
Agricultural Pest Act of 1983.	To limit the destruction of pests on agriculture.
National Biodiversity Framework (2017-2022).	To promote biodiversity conservation efforts.
Conservation of Agricultural Resource Act of 1983.	To improve agricultural practise & promote soil, water & vegetation conservation.
Strategic plan 2012/13-2016/17 for the department of agriculture, forestry and fisheries.	To promote climate smart agricultural practices.
National strategy for sustainable Development and Action plan 2011-2014.	To promote improved agricultural techniques.
Policy on Agriculture in sustainable development & Fertilizers, farm feeds, agricultural remedies and stock remedies Act of 1947.	To promote sustainable agricultural practices and register fertilizers, farm feeds, pests control operators.
Plant Improvement Act of 1976	To ensure the availability of high-quality propagating material to all users.

Adopted from the National Government of South Africa Policy and Legislation (www.gov.za).

2.10 Sustainable agricultural systems

Most farmers, especially in the developing counties, are forced to switch to organic sustainable farming. This is mainly due to the rising cost of agrochemicals such as pesticides and inorganic fertilizer and the fact that there is low supply of these products in the farming industries (Connor, 2008).

Sustainable organic farming is recommended for farmers to overcome the damage caused by insects and improve their crop yields. Lansink *et al.,* (2002) defined organic farming as "a farming system which comprises fewer or less detrimental effects to the environment and to resources use than conventional farming systems". Instead of using inorganic fertilizers for soil nutrient improvements, farmers should rely on organic and green manure. Instead of using synthetic agrochemicals for pest, weed, and pathogen control, farmers should rely on alternative methods such as uprooting of weeds and biological control that involves the introduction of parasitoids or predatory species for controlling pests (Drinkwater *et al.,* 1995).

There are many alternative organic practices to consider for yield improvement and pest repelling techniques that are environmentally friendly. These alternatives include cover cropping, no tillage and alley cropping. Studies have shown that these practices help meet the farmers' objectives of sustainable farming with improved yield and reduced pest damage on orchard trees and fruits.

2.10.1 No tillage system

Tillage causes severe damage to the soil structure. Farmers are opting for no till planting to sow seeds of the main crop and/or establish cover crops. With the use of no tillage especially for establishment of a cover crop, the soil is protected from exposure to direct sun and erosion which improves the organic content of the soil. Conventional tillage makes it difficult to build-up organic matter as it leaves the soil bare, susceptible to erosion and degradation (United State Department of Agriculture, 1999; Clark, 2007).

2.10.2 Flowering weeds system

Studies have shown that floristically diverse crop fields tend to have much higher numbers of arthropod pests than in monocultures. Crop lands with dense weed cover and high diversity also tend to have greater numbers of predacious arthropods. Weed diversified systems provide nectar and pollen that are normally unavailable in monoculture systems for insects to feed on and continue their life stages or rather than feeding on the main crop (Sork, 1997).

Weed density may be related to the number of pests and pest damage in crop fields. When the density of plants in the weed community increases, the damage by pests also seems to decrease. This was demonstrated in a study of army worms in corn fields that yielded positive results. The study showed there was an increased number of predators in comparison to a monoculture system (Altieri and Whitcomb, 1980).

The negative aspects of flowering weeds may be that, when it comes to orchard sanitation and clearing of the weeds, farmers are likely to use herbicides. The larvae of some pests feed on weeds, and, if the weeds are removed, the larvae will alternatively have to feed on the main crop which then poses a challenge (Altieri and Whitcomb, 1980; Capinera, 2005). The other negative aspects of the floral weeds may be that, they become too attractive for pollinators and instead of them aiding crop pollination for the main crop, pollinators reside in the weeds (Capinera, 2005).

2.10.3 Alley cropping systems

Alley cropping practice integrate the main crop with an alternative for improvement in flora and fauna diversity. Arthropods are found to be highly diverse where the system is complex, and this brings positive effects to the main crop compared to monoculture cropping. This land use management system also increases the biological interaction between flora and fauna leading to an improvement on biodiversity protection and conservation (Akbulut *et al.,* 2003).

Studies have shown that alley cropping can have a positive effect on crop yield. It leads to plant diversity that influences the abundance of arthropods. Mixtures of plants that are to be incorporated between the alleys of the main crop depends on the objective of the grower. The objective might be to reduce and/ or eliminate completely the destructive insect pests such as herbivores that feed on leaves and flowers of the main crop. Growers will plant in the alley of the main crop; the crops will increase the conducive environment for more predatory species to prey on destructive pests. Increased diversity means an increase in natural enemies (Song *et al.,* 2014; Ashraf, 2018; Buchanan *et al.,* 2018).

2.10.4 Cover cropping system

Cover crops are not only planted by farmers for harvest or for cash sales. They are also used for the improvement of growing conditions for the main crop (Sundermeier, 2009). Most research on cover crops has focused on their role in cereal crop and there is little information available on their role in organic fruit production (Macdonald *et al.,* 2005). Farmers make use of pure or mixed stands of legumes or other annual plant species among fruit trees for improving soil fertility, enhancing biological control of pests, and modifying the orchard microclimate.

When leguminous plants are used as cover crops, either alone or in combination with non-legume species, the quality and quantity of the biomass can be greatly improved. The resultant biomass can be incorporated into the soil or left on the surface as a protective mulch until it decomposes. Research done at the University of California Santa Cruz, showed that a local variety of fava bean called bell bean, grown as a cover crop in combination with either cereal rye or barley during the winter wet season fallow period, showed improved results on the crop (Altieri and Rosset, 1996; Gliessman, 2000).

The primary benefits of cover crops include the improvement of soil health. Cover crops that are nitrogen fixing act as green manures and can increase the nitrogen required for the main crop (Smil, 1997). Soil is susceptible to erosion when there is no vegetative ground cover on the surface (Hartwig, 2002). Ground covers reduce water runoff and soil erosion leading to improved soil conservation (Evanylo *et al*., 2008).

Weeds are suppressed by cover crops that take up space and sunlight preventing weeds from sprouting (Campbell, 2014; Pardini *et al.,* 2002). There is an addition of organic matter which increases soil health and productivity leading to the reduction of environmental pollution from fertilizers (Altieri, 1995).

Cover crops are vital for the protection of the health status of water ecosystems that are found near the orchards. When cover crops are planted in the alleys of the orchard trees it helps to trap water, improve infiltration and reduce runoff. Higher amounts of water percolates into the ground providing more water for the main crop (King and Berry, 2005).

Examples of cover crops:

a) Sunnhemp (*Crotalaria juncea*)

Sunnhemp seedlings are tender and susceptible to mechanical damage. This may restrict their use as a relay intercrop. The plant grows to be a tall herbaceous shrub of one to three meters tall with vegetative parts covered with short, downy hair. The taproot is long and strong with many well-developed lateral shoots. Stems are up to 2cm in diameter. It grows in warm and moderate humidity climates from 8.4 to 27.5°C with the mean of 29°C. The plant is susceptible to frost and tolerates soil pH from 5.0 to 8.4. Seedlings of sunnhemp can be broadcasted or drilled, in drilling they can be close, as with small grains, or wide, as with corn and sorghum. Alleys can be wide when availability of seed is limited, or if it is desired to control weeds by cultivation. Sunnhemp can produce between 12.5 and 14 mf/ha of dry above ground biomass. An experiment was conducted in India and there, sunnhemp yielded more nitrogen than five other legumes, including cowpea, which was second highest. It has a nitrogen content of 1.7 % (Sullivan, 2003).

b) Hairy vetch (*Vicia villosa*)

Hairy vetch is an annual crop species that grows in temperatures ranging from 4.3 to 21.1°C and can tolerate severe winter conditions. It grows where the mean annual rainfall is between 3.1 and 16.6 mm It is a drought resistant crop. Hairy vetch is best known for fixing nitrogen and supplementing phosphorous. Studies showed that the introduction of hairy vetch as a cover crop increased profitability of crops. Some of the positive effects of this cover in orchards is that it prevents soil erosion (Hartwig, 2002), suppresses weeds and retains moisture (Clark, 2007).

c) Cowpea (*Vigna unguiculata*)

Cowpea seeds germinate on the soil surface. This is an annual herb that grows up to 80 cm in height. It tolerates annual mean temperatures from 12.5 to 27.8°C. It does not tolerate cold or frost. Cowpea grows under rainfed rather than irrigated conditions and is drought resistant with a taproot that can penetrate the soil deeply for moisture. It is tolerant to high and low pH levels, aluminium and poor soil. It grows well on different types of soil from low fertility soil to sandy loams. Cowpea is sensitive to excess amount of boron. It can tolerate moderate shade (Sullivan, 2003).

d) Forage sorghum (Sorghum x Sudan grass hybrid)

Forage sorghum grows well in warm conditions, it requires high temperatures to germinate and grow. It produces a natural nematicide when cut and incorporated into the soil. It does not tolerate temperatures below freezing point. Forage sorghum grows on shallow soil with high clay content and poor growth is seen on soil with a sandy texture. It is grown directly from the seed and will regrow if mowed down and can grow to a height of 1.5 - 2 m. Forage sorghum grows well when mixed with sunnhemp as a natural summer windbreak in younger orchards (Campbell, 2014).

2.11 Impacts of cover crops in orchards

2.11.1 Increase in beneficial arthropods

Not all insects found in the orchards are bad for commercial farming purposes. Beneficial insects include pollinators such as honeybees, predators such as predatory mites and parasitoids; their presence is favoured in orchards with ground covers (van den Berg *et al.,* 2010). In agro-ecosystems, cover crops are used to enhance the natural control of insect pests, to bring an improvement in the abundance of beneficial insects of predatory, pollinator and parasitoids species and prevent the outbreak of unwanted pests compared to the conventional way of farming (Sanchez *et al.,* 2007). Predatory insects help in controlling the pest infestations that may cause damage to fruit. Predatory arthropods such as spiders, predatory mites, and predacious thrips are most common in orchards occurring naturally (van den Berg *et al.,* 2010).

Pollinators are of essential importance in commercial orchards. Some insects act as active agents that transfer pollen by visiting flowers of fruit trees. The honeybee is one of the insects in South Africa significantly needed to assist in transfer of pollen from one fruit tree to another. The more visits to the flowers the higher are the chances on increased fruit set, quality and yield (van den Berg *et al.,* 2010; Saunders, 2013).

Parasitoids are normally introduced to orchards for biological control of pests. The presence of parasitoids in orchards increases the general mortality of problematic insect pests. They attack the pests from egg to adult stage leading to a decrease in the pest number (van den Berg *et al.,* 2010)

2.11.2 Improves soil health

Inorganic chemical uses such as the use of inorganic fertilizers bring with them different negative effects on the soil and impact negatively on water bodies through pollution. Cover cropping as a soil management treatment may be substituted for improved soil health. Heavily mechanised alleys that leave the surface bare and exposed impact negatively on the health of the soil leading to degradation (Sanchez *et al.*, 2007; Sofi *et al.,* 2018).

Nitrogen fixing cover cropping systems when applied to orchard alleys protect the soil from heavy rainfall drop impact and erosion of the top layer. They improve water percolation and soil aggregation, hence soil protection. They increase soil organic matter and stimulate soil microbial activities and at the same time supply the soil with enough nitrogen to improve tree growth, yield and fruit quality (Cruz *et al.,* 2014; Sharifi, et al., 2016).

The bacterial community has been recognised as one of the most important factors in the maintenance of soil quality for agro-ecosystem functions. Management systems such as the application of cover crops play an important role in influencing the abundance and diversity of bacterial community through the modification of soil properties (Nacker *et al.*, 2011).

2.12 Conclusion & aims

From this review it is concluded that conventional agricultural practices have severe consequences which negatively affect the natural environment and human health. The review also suggests a transition to sustainable farming methods and the conversion from unsustainable conventional crop production. Agro-ecology as a study provides the knowledge and methodology necessary for developing an agriculture that is on one hand environmentally sound and on the other hand highly productive and economically viable (Gliessman, 2000). Cover crops are used to bring life into orchards, restore soil health, reduce pest damage on fruit and improve yield. There is a great need for information on the effect of conventional farming practices, which includes tillage, leaving soil exposed to radiation, and conservation farming practices such as the incorporation of ground covers in orchard alleys.

We first aim to compare the effects of mixtures of cover crops planted in between each alternate row of an avocado orchard to a control with no established cover crop but only natural vegetation that is left undisturbed. Secondly, we aim to compare the effects of cleared soil (established through 'ridging' the soil in-between the orchard alleys toward the tree row) to undisturbed ground cover in avocado orchards.

3 CHAPTER THREE: ECOLOGICAL SETTING OF STUDY AREA

3.1 Location of the study area

The study was conducted on a commercial avocado farm, located in Levubu in the Limpopo Province of South Africa. The farm is located at 23□02'33.44"S and 30□15'13.92"E, 600 m above sea level. It is 30 km west of Thohoyandou and 49 km east of Louis Trichardt (Figure 1). Levubu is a subtropical fruit growing area that is dominated by extensive monoculture of avocado, macadamia, banana and guava orchards. The trial blocks consisted of commercially farmed avocado orchards (Figure 2).

3.2 Climate

The general study area has a summer rainfall with dry winters. Mean annual precipitation varies from about 550 mm on the lower slopes of the escarpment of the general study area in the east to about 1000 mm where it borders grassland at higher altitudes. Mean monthly maximum and minimum temperatures are 36.4ºC and 5.7ºC respectively.

3.3 Geology and Soils

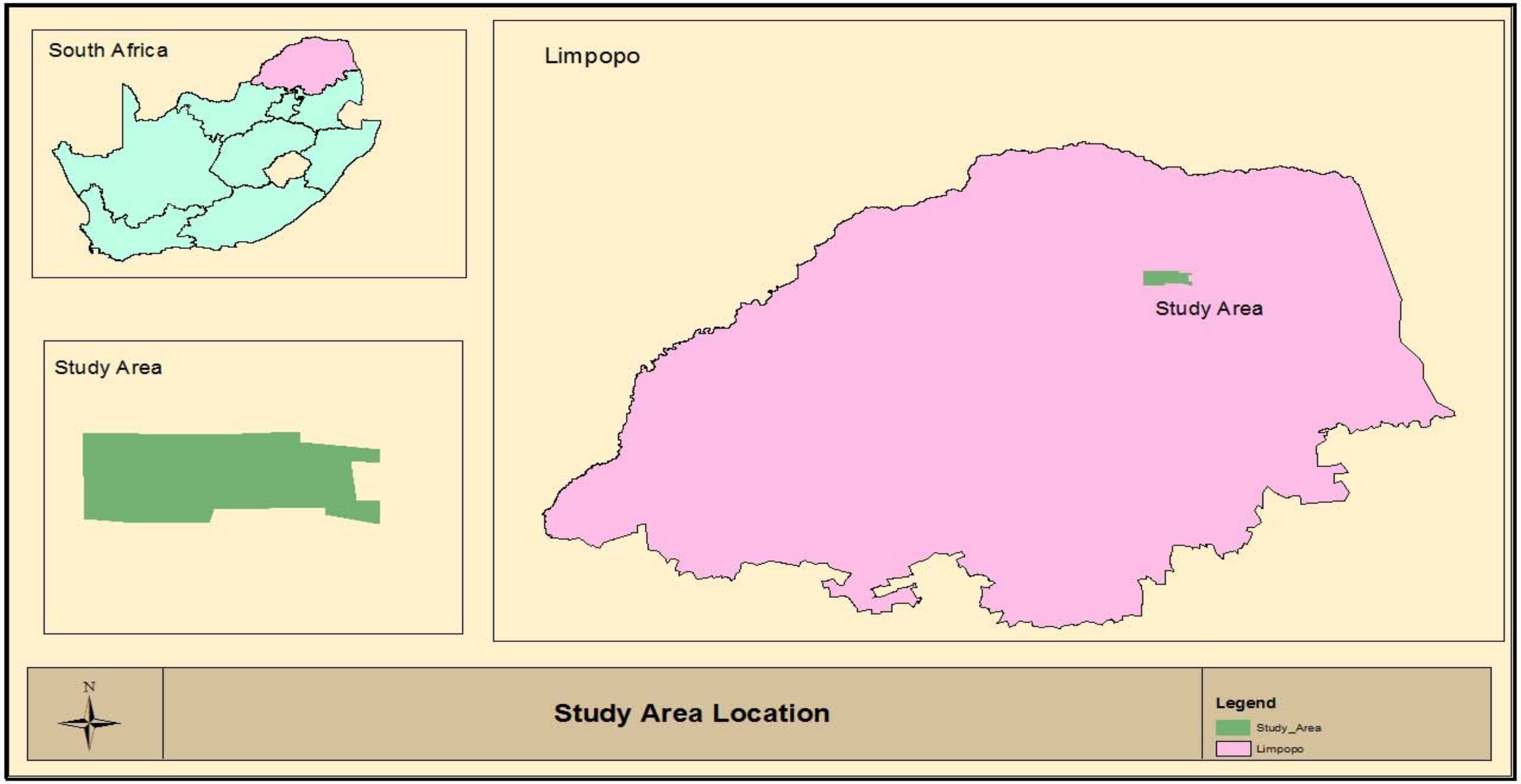
The potassium poor gneisses of the Goudplaats Gneiss (Swazian Erathem) and an Archaean granite dyke underlie most of the surrounding area within which the study area is located. Shale and Quartzite of the Wolkberg group are present, but not common. Soils are the Hutton form, deep with a clay content of about 24 %.

3.4 Vegetation and Landscape Features

The vegetation of the general surrounding area consists of a deciduous, tall open bushveld (parkland) with well developed, tall grassland. It has been classified by Mucina and Rutherford (2006) as Soutpansberg Mountain Bushveld.

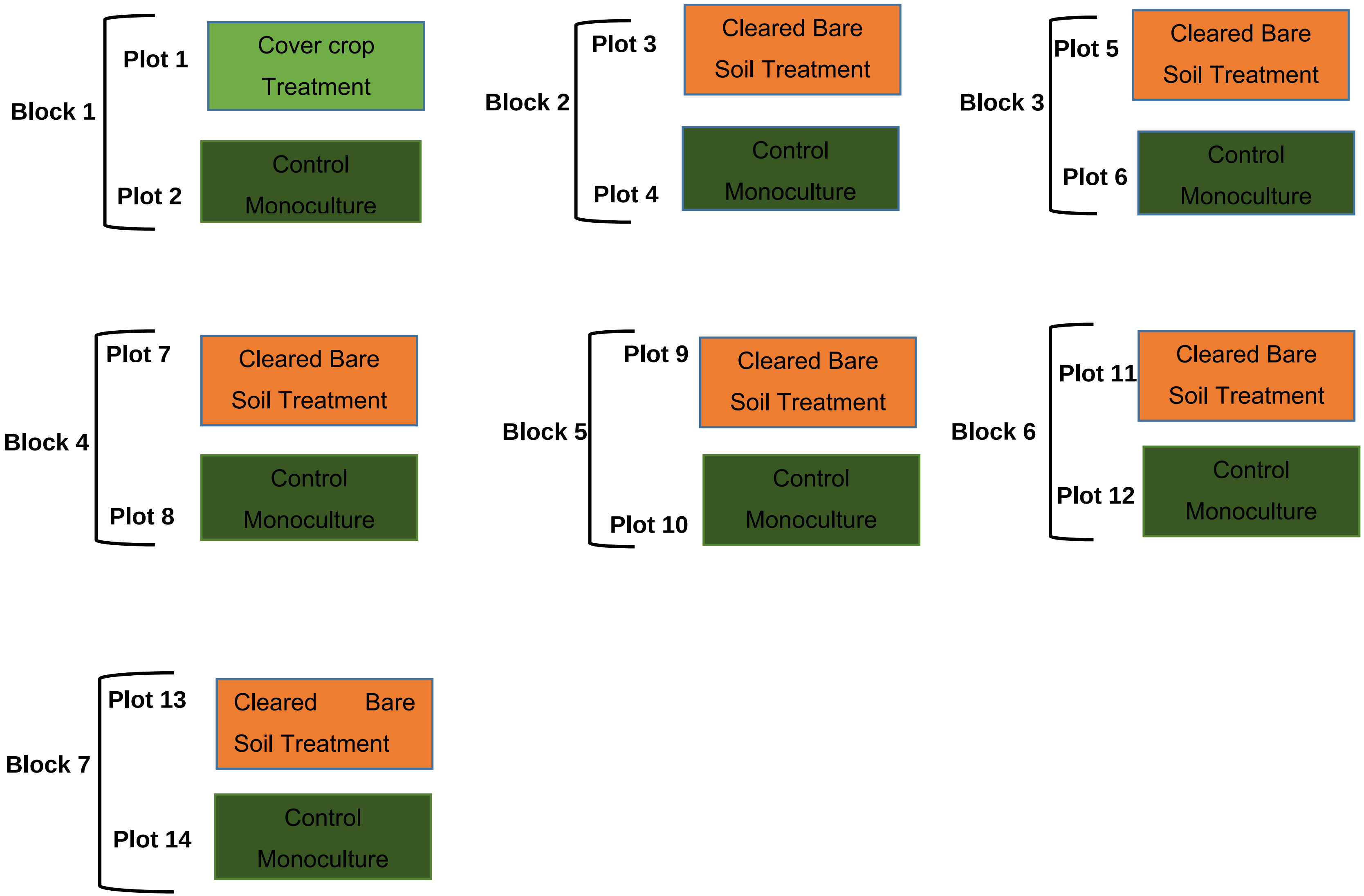
3.5 Location Map

Figure 1. Location map of Levubu in Limpopo Province



3.6 Field Layout

Figure 2. Field layout showing the 7 blocks each split into 2 plots of the treatments and control monoculture



4 CHAPTER FOUR: RESEARCH METHODOLOGY

4.1 Introduction

This chapter provides information on how data was collected to determine the effects of cover and mechanised ridging (tilling, leaving bare soil between tree rows) on the abundance and diversity of flora, damage causing insect pests, beneficial insects and the extent of damage on fruit by pests in an avocado orchard. It provides the methodologies that were used in the collection of data and the statistical tools for analysing and interpreting the raw data for purposes of the study.

4.2 Experimental design

To compare the effect of ground cover *vs*. a control with no cover, cover crops were planted in a form of strip-cropping in every alternate row of the treatment plots within the avocado orchards (Figure 3A & B). These were *Medicago sativa* @ 4kg/ha, *Lotus corniculatus* @ 3kg/ha, *Trifolium pratense* @ 3kg/ha, *Melilotus alba* @ 2kg/ha and *Phacelia tanacetifolia* @1kg/ha. A no-till planter was used for planting the cover crops to minimise disturbances to the orchard floor. Each treatment was replicated five times, represented by 5 rows (30m each). The distance between the treatment and the control plots was at least 300m apart.

To compare the effect of bare soil after ridging mechanically to a control of no ridging (i.e., no bare soil in orchard alleys) (Figure 3C), replicated trial blocks were used in which half of every block was ridged mechanically (treatment) and half was left undisturbed.

Each treatment was compared to a monoculture control plot (Figure 3D) comprised of natural grass and flowering weeds in the tree alleys. The trees in each trial block was of similar cultivar (‘Hass’), age, soil type and plant health status.

Figure 3. Photos of treatments and the control where A) shows the cover crops sprouting after no-till planting, B) shows the grown cover crops, C) shows the bare soil as a result of mechanized ridging and D) shows a typical control alley with undisturbed natural tree alleys.

4.3 Cover Crop Selection

A list of cover crops to be planted in the alleys of avocado trees was compiled with reference to the relevant literature particularly cover crops which are nitrogen fixers and those that influence the diversity and abundance of arthropods positively. It should have created more opportunities for increased numbers of pollinators, parasitoids and predatory species. It should also have provided nectar, pollen and increased the abundance of natural enemies, decreasing pest pressure.

Table 2: Cover crops considered for establishment on the orchard floors. Bold entries are the cover crops that were used in the avocado field trials.

Family	Genus and species	Common name	Characteristics	References
Fabaceae	*Medicago sativa*	**Lucerne**	Perennial summer legume which grows well in all parts of the country. It is planted by sowing the seed in soils that are being irrigated.	Gang *et al.,* 2004; Altieri and Nicholls, 2005; Sullivan, 2003
Fabaceae	*Lotus corniculatus*	**Birdsfoot trefoil**	Perennial plant that adapts well in soils with poor drainage and low pH. The living mulch on a slope reduces water runoff and soil loss.	Sampson, 1928; Clark, 2007
Fabaceae	*Trifolium pratense*	**Red clover**	Annual legume that improves topsoil. It can easily be over-seeded into a standing crop. It can be planted during winter and it provides pollen to beneficial insects after winter.	Bone *et al.,* 2009; Sullivan, 2003
Fabaceaae	*Melilotus alba*	**Sweet clover**	Annual legume that has benefits that most cover crops do not seem to have. It seems to have a bigger capability to extract potassium, phosphorus and other soil nutrients from otherwise insoluble minerals.	Sullivan, 2003; Ogle *et al.,* 2008
Boraginaceae	*Phacelia tanacetifolia*	**Phacelia**	Annual crop that can be planted in strips within crops to enhance the availability of pollen and nectar, necessary for optimal	Altieri and Nicholls, 2005

			reproduction, fertility and longevity of many natural enemies of pests. It enhances the abundance of aphidophagous predators.	
Asteraceae	*Cosmos bipinnatus*	Cosmos	It is both annual and perennial and can be used to attract beneficial organisms such as spiders and nematode parasites of insect pests.	Altieri and Nicholls, 2005
Asteraceae	*Achillea millefolium*	Common yarrow	Perennial plant that requires little or no irrigation as a winter cover, it provides abundant organic matter and is an excellent weed suppressor. It attracts beneficial insects and can also be a mulch.	Altieri and Nicholls, 2005
Fabaceae	*Lens esculenta*	Lentil	Annual leguminous plant that grows well in the soil with a pH of 6.0 to 8.0. It can tolerate frost and it is drought tolerant.	Altieri and Nicholls, 2005
Asteraceae	*Tagetes patula*	Marigold	Annual plant. It grows in well drained soils. The seed is directly sowed in. It possess rich nectar, and can help support populations of bees and other pollinating insects	Hooks *et al.,* 2010
Apiaceae	*Coriandrum sativum*	Coriander	Annual herb that does not grow well in cold conditions or extreme heart. It grows well in warm weather conditions.	Altieri and Nicholls, 2005

4.4 Sampling Design

Sampling was done following a systematic sampling design which guaranteed randomisation. Randomisation is of importance as it addresses the problems of field variability, reduces experimental errors and determines the true effect of the treatments being compared. Random sampling points were established at a location in each replicated tree row and sampling points were systematically distanced from the starting point (following Ashraf *et al.,* 2018). For measurements and samples from the cover crop treatment block, samples were taken from the centre of the inter-rows in order to avoid any edge effects. From comparison between the mechanically cleared surface plots, sampling was conducted underneath the avocado trees and sampling points established in the same way as described for the cover crop measurements. Randomized sampling was performed weekly during the following avocado phenological stages: flower bud development, flowering and fruit set, fruit expansion and fruit maturity. Pest monitoring and collection of damage data were done in line with each vegetation sampling point. Figure 4 provides the layout of the study. Note which variable measurements in the grey blocks were conducted for which experiment between the cover cropped treated alley and bare soil alleys.

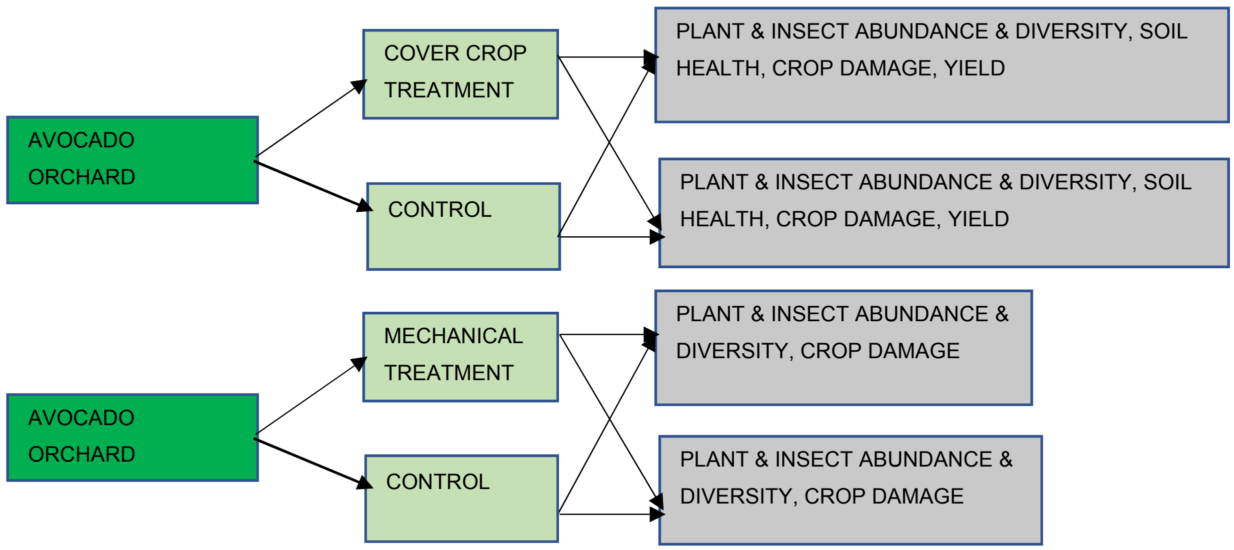


Figure 4. Study design.

4.5 Research Instruments

The following instruments where used when collecting data in both the experiment and control field plots: A sweep net was used for sampling insects (Akbulut *et al.,* 2003; Campbell, 2016) and a hula hoop (Whigham, 1999; Casteel, 2016) for identifying shrub stands at random. Plastic bags were used for holding the collected insects and plants, a clipboard for notetaking; a tray for tapping flowers and fruits for insect counting and collection; magnifying glasses for ease of insect identification both in the field and laboratory; containers for larger specimens; tablets device containing an app for survey data entering and storage, measuring tape and reference materials.

4.6 Flowering Plants Identification

Flowering plant identification was done during the flowering and fruit set of the avocado trees in September to October 2019. Flowering plant species compositions in the experimental fields were assessed by casting a 0.5 square meter hula hoop randomly. Rooted flowering plants species within the quadrat (hoop circle) were counted and identified. Flowering weed abundance was determined by counting and recording the weed species within the hula hoop at each replicated plot. For ease of flower identification, a reference collection and photos were taken of each flowering plant including cover crops and avocado.

4.7 Arthropod sampling

Arthropod sampling was conducted weekly from September to October 2018 with the aid of a sweep net, sweeping ten times in each of the five rows at the treatment plots. Between each sweep, three big steps were taken to result in a 30m transect. The same transect was scouted for arthropod movement and these arthropods were collected by hand or with a net. Five avocado flowers from five randomly selected trees along the transect were shaken over a sampling bag to record the presence of pest insects.

Collected insects were put in a plastic bag with an insect killing agent (ethanol) and taken into the lab for counting and identification. Collected arthropods were counted and identified to family and genus level, using several identification guides (van den Berg *et al.,* 2010; Picker *et al.,* 2002; Schoeman 2013; Schoeman *et al.,* 2013). Arthropods were further categorised according to feeding guilds: pests, predators, pollinators, parasitoids and herbivores.

4.8 Scale insects sampling

Five trees were randomly selected from five rows in the treatment and control plots. Ten leaves of the 5 trees each were randomly collected and put into a bag and taken to the laboratory for sorting and counting the number of leaves with heart-shaped scale and those with avocado scale present or absent.

4.9 Thrips sampling

Thrips sampling was also conducted during the September to October months in 2018, during flowering and initial stages of fruit set of the avocado trees. Sampling was done in the treatment and control plots from 5 fruits randomly selected on 5 randomly selected trees in 5 replicated rows per treatment. Avocado fruits were tapped 5 times onto a tray to shake off thrips on the fruit which were counted.

4.10 Fruit damage assessments

Quantification of fruit damage was conducted on the treatment and control plots at the stages of fruit set. To quantify fruit damages, 5 trees per plot were randomly selected for damage assessment. Damage assessment was done on the fruit and leaves. Sucking bug damage, thrips damage and other mechanical damage to fruits were recorded per replicated treatment and control plot.

4.11 Soil sampling from cover crop experiments

Soil samples were taken from the treatment and control plots using a soil auger (Figure 5). From each replicated point located randomly in the treatment and control plots, soil samples were combined and put inside a plastic bag to have three samples each per treatment and per control. The soil samples were then sent to NviroTek Laboratories and Sporatec for soil health assessments which included the assessment of bacterial community, fungal community and Urease & Phosphatase enzymatic analysis.

4.12 Fruit yield

During harvesting, fruit yield and avocado weighing was recorded by means of replicated deliveries to the pack house from the treatment and control plots of the cover crop experiment.

Figure 5. Soil sampling in random placed hula-hoop.

4.13 Soil health and nutrient status

Bacterial community, fungal community and urease and phosphate enzyme analyses were performed on replicated samples by Sporatek Laboratories. The rest of the analyses were performed for replicated samples by Nvirotek Laboratories (Pty) Ltd. Solvita CO_2-burst soil respiration analyses, Solvita N-mineralization potential analyses and Solvita Biomass analyses were performed per treatment. Soil carbon analyses were done using the WB method and soil organic matter (SOM) were measured as a percentage. Soil nutrient status were measured by specifically analysing soil pH, phosphate, density, calcium, magnesium, potassium, sodium, iron, manganese, copper, zinc, boron, sulphur, aluminium contents using the MelichIII method of analyses.

5 CHAPTER FIVE: DATA ANALYSES

Analysis was done separately on the following response variables to get to the results and draw conclusions. We assessed the diversity and abundance of beneficial arthropods, insect pests, scale insects and thrips and measured soil health indexes, sucking bug damage and yield. Data were collected on at least three replicated dates. Treatment comparisons between the bare soil (mechanically cleared alleys) *vs.* the control (natural vegetation in the alleys) or the cover crop alley treatment *vs.* a control was made using the Shapiro-Wilk normality test to detect deviation from normality in the data, F-test for treatment variances and Welch Two Sample t-test to test the true difference in treatment means. If the data did not meet the assumption of normality, Levene's test for homogeneity of variance and Kruskal-Wallis Rank Sum Tests were used for comparison between treatment medians. For diversity analyses the Margalef Richness Index was calculated per treatment and Shannon index calculations were also performed.

All statistical analyses were done in R (v. 3.4.3, R Foundation for Statistical Computing, 2008, Vienna, Austria) applying Packages 'car' (Fox and Weisberg, 2019), 'psych' (Ravelle, 2019) and 'ggplot2' (Wickham, 2016). Means and standard error of the mean were reported and graphed in all cases.

Soil health data were analysed using the Shannon index to observe the richness and evenness of the microbial community within the samples. The Simpson index was used along with the Shannon index to describe the microbial evenness within the samples. For species richness, the number of Operational Taxonomic Units (OTUs) was used to show how many similar grouped microorganisms exist within the sample.

6 CHAPTER SIX: RESULTS AND DISCUSSION

6.1 Flowering plant abundance and diversity

6.1.1 Flowering plant abundance

The results showed that there were significant differences between the cover crop treated alleys and control in terms of the abundance of flowering plants (Welch Two Sample t-test: t = -3.7009, df = 5.0927, p-value = 0.01353). There was a higher abundance of flowering plants in the cover crop treated plots (32.40 ± 4.35 plants/m^2) than in the control (15.20 ± 1.62 plants/m^2) (Figure 6A). A summary of the flowering plants identified per treatment is given in Table 3. There were no flowering cover crops identified in the control plots.

Flowering weeds were significantly more abundant in the control (natural vegetation) in comparison to the cleared bare soil treatment (Kruskal-Wallis rank sum test: Kruskal-Wallis chi-squared = 7.3052, df = 1, p-value = 0.006876). The data is plotted in Figure 6B and the findings are summarized in Table 4.

6.1.2 Flowering plant diversity

Both the Margalef and Shannon indexes' results revealed that there were significantly higher species richness and evenness in the cover crop treatment alleys compared to the control (natural vegetation). Table 4 contains a list of the weed flowering plants including climbing weeds, friendly creepers, invasive and noxious weeds.

Flowering plants play a role of enhancing ecosystem services due to higher abundance in both flora and fauna. Bennet and Gratton (2013) suggested that flowering plant abundance is a determining factor in arthropod diversity. An increase in biodiversity usually brings about a positive effect on ecosystem functions within the orchard environment. Natural plants, weed species and cover crops help in the restoration of orchard floors, soils are protected from further degradation due to runoff and there is higher water infiltration, and this may not be the case in cleared exposed bare soil. Important forest species are also lost due to loss of habitat as conversion to monoculture occurs. Cover cropping in alleys of avocado trees aid in the prevention of biodiversity loss, and at the same time protects the main crop from pests by mimicking forest biodiversity (Foster *et al,* 2011).

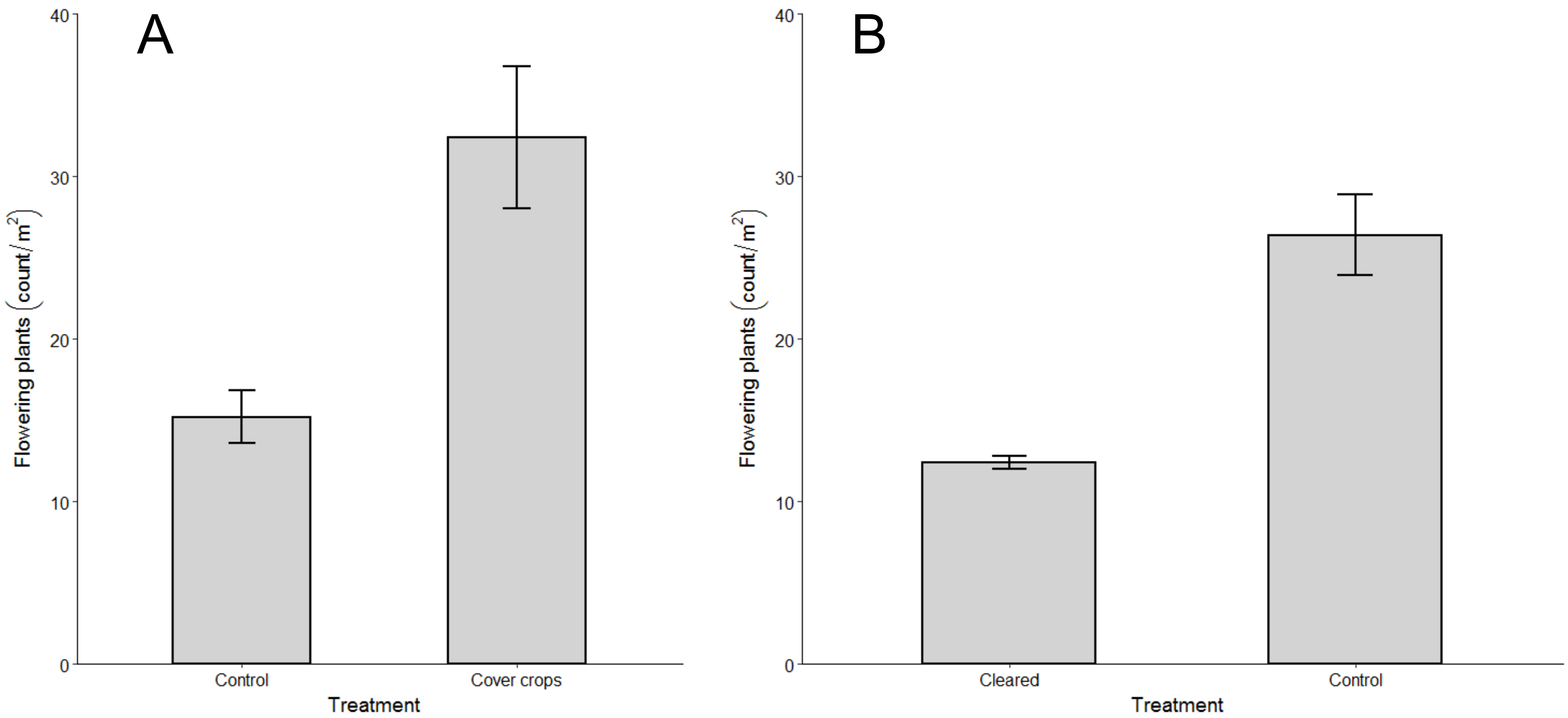


Figure 6. Flowering plants counted on the (A) treatments of cover crop and control and (B) treatments of the cleared soil and control.

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Table 3: Flowering plants species identified in planted (cover crop) and control (monoculture) treatments.

CLASSIFICATION	INDENTIFICATION	COMMON NAME	DESCRIPTION OF PLANT	TREATMENT	
				Control	Cover crop
AVOCADO PLANT	*Persea americana*	Avocado tree	Cultivated	✓	✓
CLIMBING WEEDS	*Momordica balsamina*	Balsam pear	Native to South Africa	✓	
	Lagenaria abyssinica	Bottlegourd	Annual, herbaceous climber	✓	✓
INVASIVE WEEDS	*Ageratum conyzoides*	Chick weed	Moth repellent in agricultural fields	✓	✓
	Bidens pilosa	Black jack	Attract aphids	✓	✓
	Sonchus oleraceus	Sowthistle	A host plant of many viral diseases	✓	
	Galinsoga quadriradiata	Shaggy soldier	Annual herb	✓	
	Ipomoea indica	Blue morning glory	Perennial climber	✓	✓
OTHER WEEDS	*Lantana rugosa*	Bird's brandy	Indigenous to South Africa	✓	
	Argemone ochroleuca	White-flowered Mexican poppy	Noxious, harmful to the environment	✓	✓
	Oxalis corniculata	sleeping beauty	Native to South Africa	✓	
	Taraxacum officinale	Dandelion	Pioneer species that grow on poor soils	✓	✓
	Commelina eckloniana	Dayflower	Not endemic to South Africa	✓	
	Richardia brasiliensis	Mexican clover	Susceptible weed		✓
INDIGENOUS WEEDS	*Commelina benghalensis*	Benghal wandering Jew	Medicinal use plant		✓
COVER CROPS	*Lotus corniculatus*	Bird's foot trefoil	Perennial summer legume		✓
	Medicago sativa	Lucerne	Perennial pasture legume		✓
	Melilotus albus	White sweet clover	Biennial plant		✓
	Phacelia tanacetifolia	Phacelia	Annual herb, source of pollen and nectar		✓
	Trifolium pratense	Red clover	Winter crop, source of pollen and nectar		✓
INDIENEOUS WEED	*Solanum delagoense*	Bitter apple	Alien plant, not invasive	✓	

Table 4: Flowering plant species counted and identified in the (cleared bare soil) and control (monoculture) treatments.

CLASSIFICATION	INDENTIFICATION	COMMON NAME	DESCRIPTION OF PLANT	TREATMENT	
				Control	**Cleared area**
AVOCADO PLANT	*Persea americana*	Avocado tree	Cultivated	6	6
FRIENDLY CREEPER	*Thunbergia alata*	Black-eyed susan	Potentially weedy plant	4	
INVASIVE WEEDS	*Ageratum conyzoides*	Chick weed	Moth repellent in agricultural fields	6	6
	Bidens pilosa	Black Jack	Attract aphids	6	6
	Sonchus oleraceus	Sowthistle	Host plant of many viral diseases	3	
	Argemone ochroleuca	White-flowered Mexican poppy	Noxious, harmful to the environment	6	6
OTHER WEEDS	*Crotalaria laburnifolia*	Bird flower	Indigenous to South Africa, perennial plant	1	
	Dicerocaryum senecioides	Devil Thorn	Not endemic to South Africa	1	
	Galinsoga parviflora	Gallant Soldier	Indicator of high soil fertility	1	
	Lantana rugosa	Bird's brandy	Indigenous to South Africa	6	2
	Lycium schizocalyx	Savana honey-thorn	Native to South Africa	1	
	Oxalis corniculata	sleeping beauty	Native to South Africa	2	1
	Seddera capensis	Cape honeysuckle	Alien plant, but not invasive	2	
	Solanum delagoense	Black nightshade	Alien plant, but not invasive	6	
	Solanum nigrum	Black nightshade	Alien plant, but not invasive	6	
	Taraxacum officinale	Dandelion	Pioneer species that grow on poor soils	6	6
	Momordica balsamina	Balsam pear	Climbing weed, native to South Africa	6	
			Margalef Richness index	**3.8**	**1.7**
			Shannon Index	**3.0**	**6.2**

6.2 Arthropod abundance and diversity

A study conducted by Fernandez *et al*., (2008) revealed a positive effect of cover crop mixtures on an organic apple orchard. That study showed an increase in number and diversity of predacious insect species in the cover crop treated alleys compared to the bare exposed soil in the orchard. A survey was conducted on insect arthropods diversity and richness on the cover crop treated alleys (Table 5) and the cleared bare soil alleys (Table 6), both in comparison to an untreated control (natural vegetation).

The cover crop treated alley had three parasitoids (family Tachinidae, *Gonia* spp.). There were no significant differences between the number of arthropods in general between the treatments (Kruskal-Wallis rank sum test: Kruskal-Wallis chi-squared = 0.43508, df = 1, p-value = 0.5095). However, the Shannon- and Margalef richness indexes showed a higher biodiversity of arthropods in the cover crop treated alleys than in the control (natural vegetation). Cover crop treatment (Margalef richness index = 7.1; Shannon index = 1.8) vs the control monoculture (Margalef richness index = 6.0; Shannon index = 2.0). There was a higher number of arthropods in the cover crop treatment than the control in general (cover crops: 4.00 ± 0.59 insects; control: 3.24 ± 0.46 insects). The results revealed the effect of cover crops in affecting species biodiversity positively within the avocado orchard alleys, however not significant. There were no significant difference within the guilds: pests, predators, pollinators and herbivores found between the treatments (Figure 7A).

There were significantly less arthropods in the cleared *vs.* control alleys (Kruskal-Wallis rank sum test: Kruskal-Wallis chi-squared = 21.614, df = 1, p-value < 0.0001). The pests, pollinators and herbivores were significantly more in the control alley than in the cleared alley (Figure 7B). There were 39.95 ± 16.22 pests counted in the cleared alleys on average and 4.96 ± 1.25 pests counted in the control treatment on average (Kruskal-Wallis rank sum test: Kruskal-Wallis chi-squared = 4.3552, df = 1, p-value = 0.0369). There were 2.19 ± 0.19 predators counted in the cleared alleys on average and 60.97 ± 19.47 predators counted in the control treatment on average (Kruskal-Wallis rank sum test: Kruskal-Wallis chi-squared = 3.228, df = 1, p-value = 0.07239). There were 1 pollinator counted in the cleared alleys and 12.14 ± 7.10 pollinators counted in the control treatment on average (Kruskal-Wallis rank sum test: Kruskal-Wallis chi-squared = 6.0567, df = 1, p-value = 0.01385). There was only one instance with parasitoid observations in the cleared alleys (no standard error could be calculated). In comparison to the numbers found in the control, there was no significant difference between the number of parasitoids found (Kruskal-Wallis rank sum test: Kruskal-Wallis chi-squared = 2, df = 1, p-value = 0.1573). The number of herbivores were significantly higher in the control alleys (27.20 ± 12.47 herbivores) than in the cleared alleys (2.27 ± 0.28 herbivores) (Figure 7B).

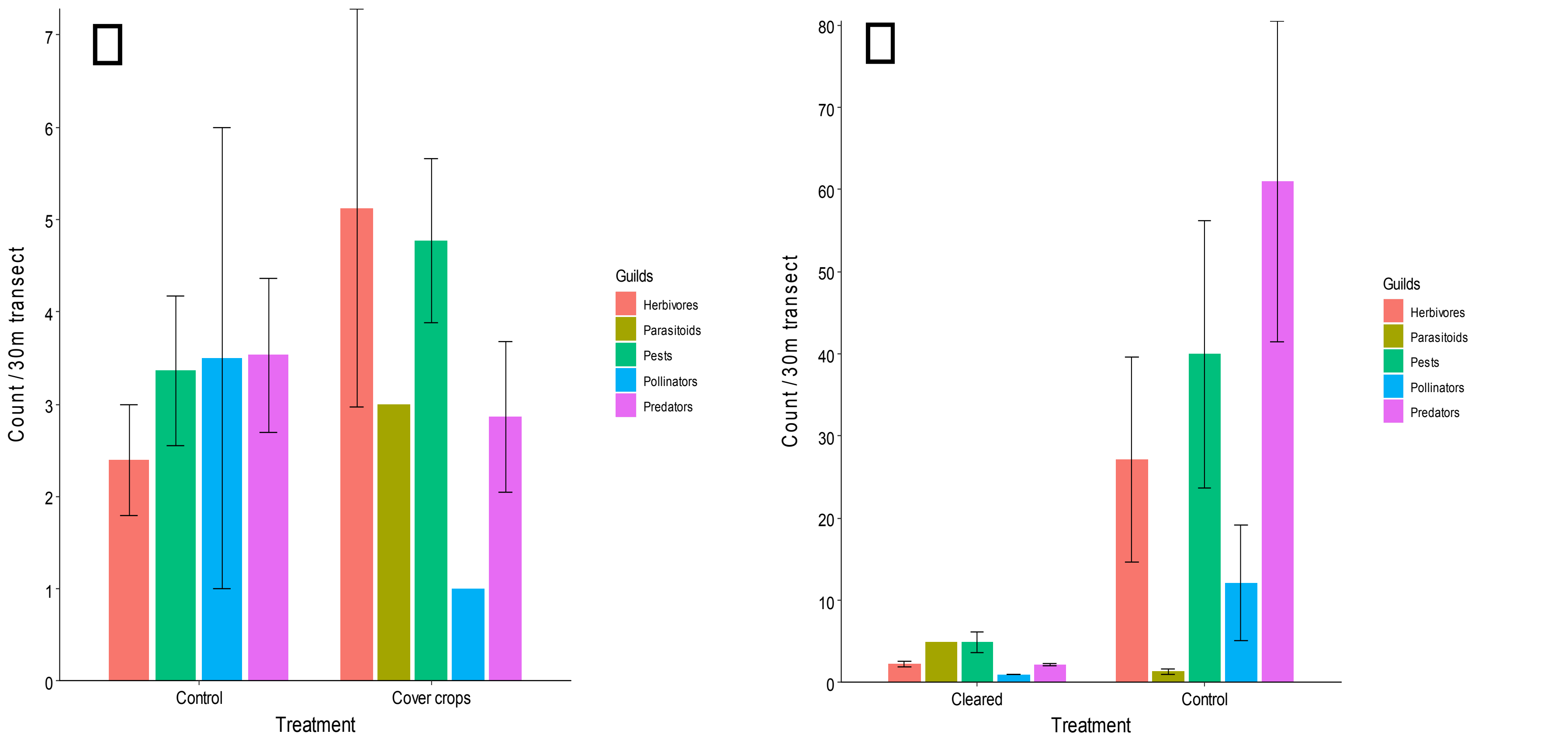

Figure 7. A comparison of arthropods on (A) treatment of cover crops & control and (B) treatment of cleared soil and control in orchard alleys.

Table 5: Identification and counts of arthropods found in the control alleys and in the cover cropped treatments.

GUILD	FAMILY	GENUS	COUNT IN CONTROL	COUNT IN COVER CROPS
HERBIVORES	**Acrididae**	*Abisares*	12	32
		Acanthacris	4	2
		Nomadacris	1	
		Tylotropidius		1
	Anostostomatidae	*Onosandrus*		2
	Gryllotalpidae	*Trigonidiinae*	1	3
	Pamphagidae	*Hoplolopha*	6	1
PARASITOIDS	**Tachinidae**	*Gonia*		3
PESTS	**Alydidae**	*Hypselopus*	1	
	Aphididae	*Uroleucon*	14	13
		Uroleucon	5	
	Apionidae	*Apionidae*	1	2
	Cercopidae	*Cordia*	2	2
	Coreidae	*Pseudotheraptus*	3	22
	Curculionidae	*Ellimenistes*	1	1
	Formicidae	*Camponotus*	8	2
		Monomorium	2	2
	Miridae	*Deraeocoris*	3	26
		Taylorilygus	25	31
	Noctuidae	*Trichoplusia*	4	10
	Pentatomidae	*Atelocera*		1
		Coenomorpha	3	2
		Veterna		1
		Bagrada		6
	Tessaratomidae	*Encosternum*	2	3
POLLINATORS	**Bombyliidae**	*Exoprosopa*		1
	Scarabaeidae	*Aphodius*	6	
	Tiphiidae	*Tiphiidae*	1	
PREDATORS	**Anthicidae**	*Anthicidae*		2
	Berytidae	*Berytidae*		2
	Coccinellidae	*Cheilomenes*	3	3
		Cryptolaemus		1
		Exochomus	9	3
	Erotylidae	*unidentified*		1
		Erotylidae		2
	Hymenopodidae	*Galinthias*	1	3
	Mantidae	*Miomantis*	4	2
	Muscidae	*Lispe*	12	11
	Reduviidae	*Rhinocoris*	4	4
	Salticidae	*Menemerus*	5	4

		Pseudicius		1
		Thyenula	19	21
	Sparassidae	*Palystes*	1	1
	Thespidae	*Hoplocorypha*	1	1
	Thomisidae	*Thomisus*	1	
		Xysticus		1

Table 6: Identification and counts of arthropods found in the cleared alleys and in the control treatments.

GUILD	FAMILY	GENUS	COUNT IN CLEARED	COUNT IN CONTROL
HERBIVORES	**Acrididae**	*Abisares*	19	1059
		Acanthacris	7	1012
		Acrotylus		4
		Arthoctha		20
		Leptacris	12	56
		Nomadacris	1	
		Nomadacris		1
		Oedaleus	1	2
		Truxalis	3	
		Tylotropidius		1
		Truxalis		1
	Alydidae	*Hypselopus*	2	7
	Anostostomatidae	*Libanasa*	1	1
		Libanasidus	1	82
		Nasidius	3	364
	Anostostomatidae	*Onosandrus*	19	149
	Aphididae	*Aphis*	34	16
		Uroleucon	19	51
		Uroleucon	15	
	Apionidae	*unidentified*	21	9
	Cercopidae	*Cordia*	4	26
	Curculionidae	*Ellimenistes*	16	121
	Gryllidae	*Brachytrupes*	3	
	Gryllotalpidae	*Cophogryllus*	1	1
		Trigonidiinae	9	18
	Lentulidae	*Paralentula*	2	
	Pamphagidae	*Hoplolopha*		2
	Pseudophyllodromiidae	*Supella*		134
	Tessaratomidae	*Encosternum*	2	18
PARASITOIDS	**Sarcophagidae**	*unidentified*		1
	Tachinidae	*Gonia*	5	3
PESTS	**Anthribidae**	*Chirotenon*	1	
	Bruchidae	*unidentified*	3	2
	Chrysomelidea	*Monolepta*	1	158
		Platycorynus	6	10
	Coreidae	*Anoplocnemis*	1	
		Holopterna	1	

		Pseudotheraptus	10	37
	Formicidae	*Camponotus*	30	1034
		Messor	31	31
		Monomorium	15	4
		Monomorium	160	27
	Fulgoridae	*Zanna*	1	6
	Lygaedae	*Spilostethus*	2	
	Miridae	*Deraeocoris*	3	52
		Taylorilygus	66	1720
	Noctuidae	*Trichoplusia*	17	750
	Pentatomidae	*Atelocera*	3	9
		Coenomorpha	7	33
		Veterna	2	2
	Tephritidae	*Ceratitis*	2	40
POLLINATORS	**Apidae**	*Apis*	2	2
	Bombyliidae	*Exoprosopa*		89
	Chrysididae	*unidentified*	1	
	Colletidae	*unidentified*	1	8
	Scarabaeidae	*Adoretus*	1	68
		Aphodius	1	3
PREDATORS	**Anthicidae**	*unidentified*	13	6
	Asilidae	*Daspletis*		3
	Berytidae	*unidentified*		1
	Berytidae	*Berytinus*	4	4
	Coccinellidae	*Cheilomenes*	23	80
		Cryptolaemus		1
		Exochomus	16	201
		Henosepilachna	1	
	Dolichopidae	*unidentified*		1
	Erotylidae	*unidentified*	3	10
	Hemerobiidae	*unidentified*	1	
	Hymenopodidae	*Galinthias*	14	1031
	Mantidae	*Miomantis*	10	5
		Popa		1
		Sphodromantis		3
	Muscidae	*Lispe*	20	1050
	Myrmeleontidae	*Creoleon*		1
	Philodromidae	*Tibellus*		1
	Reduviidae	*Platychiria*	1	
		Rhinocoris	4	7
	Salticidae	*Menemerus*	15	1014
		Myrmarachne	4	2
		Nigorella	2	3
		Pseudicius	2	1005
		Saitis	1	516
		Thyenula	63	1127
		Urena	4	7
	Sparassidae	*Palystella*	4	1000
		Palystes	2	73
	Tettigoniidae	*Conocephalus*	1	2
	Thespidae	*Hoplocorypha*	8	5

	Thomisidae	*Thomisus*	5	259
		Xysticus	7	263

The Margalef richness index and the Shannon index revealed a lower species diversity in the cleared treatment when compared to the control. Cleared bare treatment (Margalef richness index =9.8; Shannon index = 1.6) *vs.* the control monoculture (Margalef richness index = 4.9; Shannon index = 1.2). The high number of pests abundant in the control alley may have been due to the vegetation that was prevalent. In the cleared bare soil alleys, there were no vegetation to feed on. The results show that the mechanically cleared land treatment had significantly less pollinators than the control. This may be due to the lack of vegetation in the bare soil alley. The control had a higher number of pollinators, this may have been due to the flowering of weed species that attracted the pollinators (Figure 7B).

The parasitoid numbers were low for both the mechanically cleared land and the control alleys comprising of weeds and grass (Figure 7B). The small number of parasitoids may have been due to the technique used for collecting the arthropods, in this case the use of sweep nets may not have been ideal.

6.3 Heart shaped scale

The comparison of scale insect infestations between cover crop alleys and control alleys and cleared alleys and control alleys were done on the leaves. The results show that there was no significant difference between the number of leaves infested with heart shaped scales in the bare soil treatment (cleared) and the control plots (natural vegetation) (Kruskal-Wallis chi-squared = 0.030306, df = 1, p-value = 0.8618, Figure 8). The Welch two-sample t-test did not result in a significantly higher number of heart shaped scale in the control plots compared to the cover crop treatment either (t = 1.589, df = 2.1344, p-value = 0.2453, Figure 8).

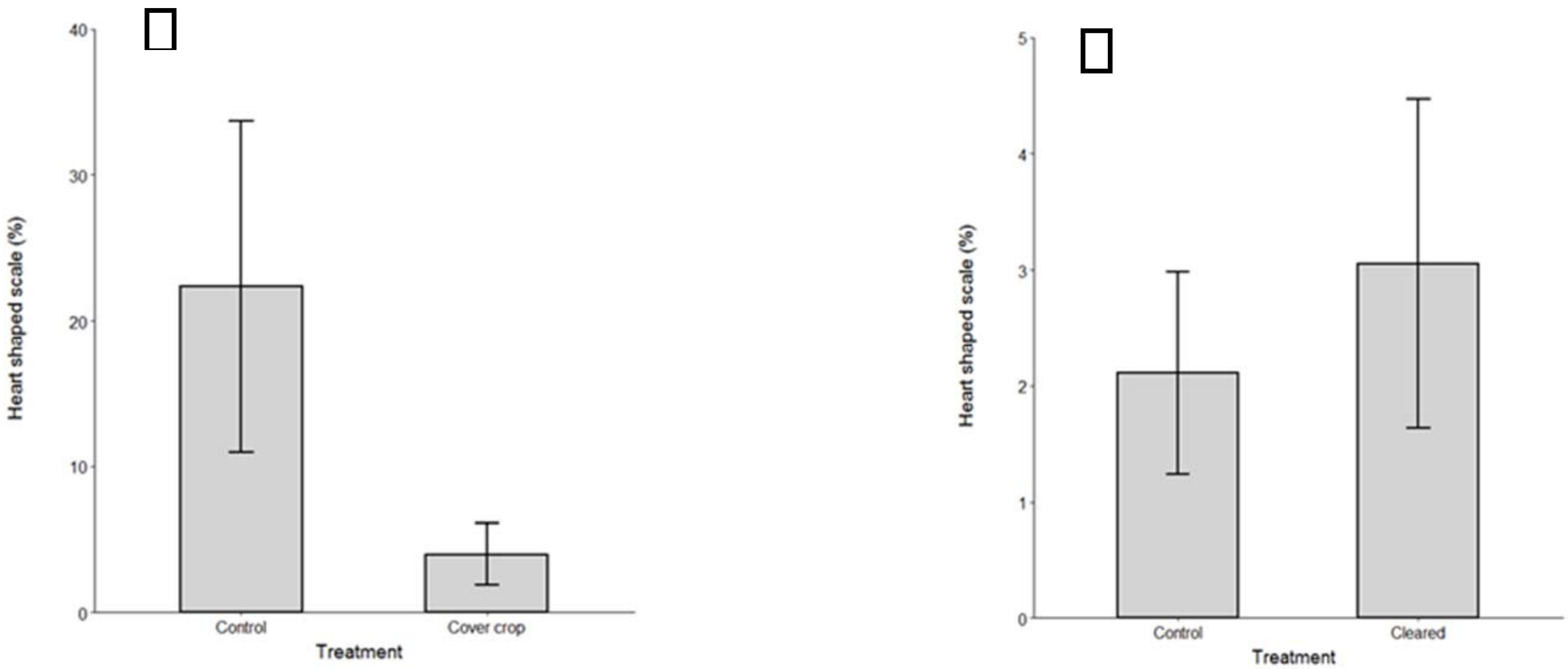

Figure 8. A comparison of the heart-shaped scale on the (A) treatment of cover crop & control and (B) treatment of cleared soil & control.

6.4 Avocado scale

The bare soil treatment did not show a significantly higher number of leaves with scales than the control alleys (Kruskal-Wallis chi-squared = 0.047337, df = 1, p-value = 0.8278, Figure 9B). The results in the cover cropped alleys showed that there were significantly less leaves with avocado scales than in the control plots (Kruskal-Wallis chi-squared = 4.3548, df = 1, p-value = 0.0369, Figure 9A).

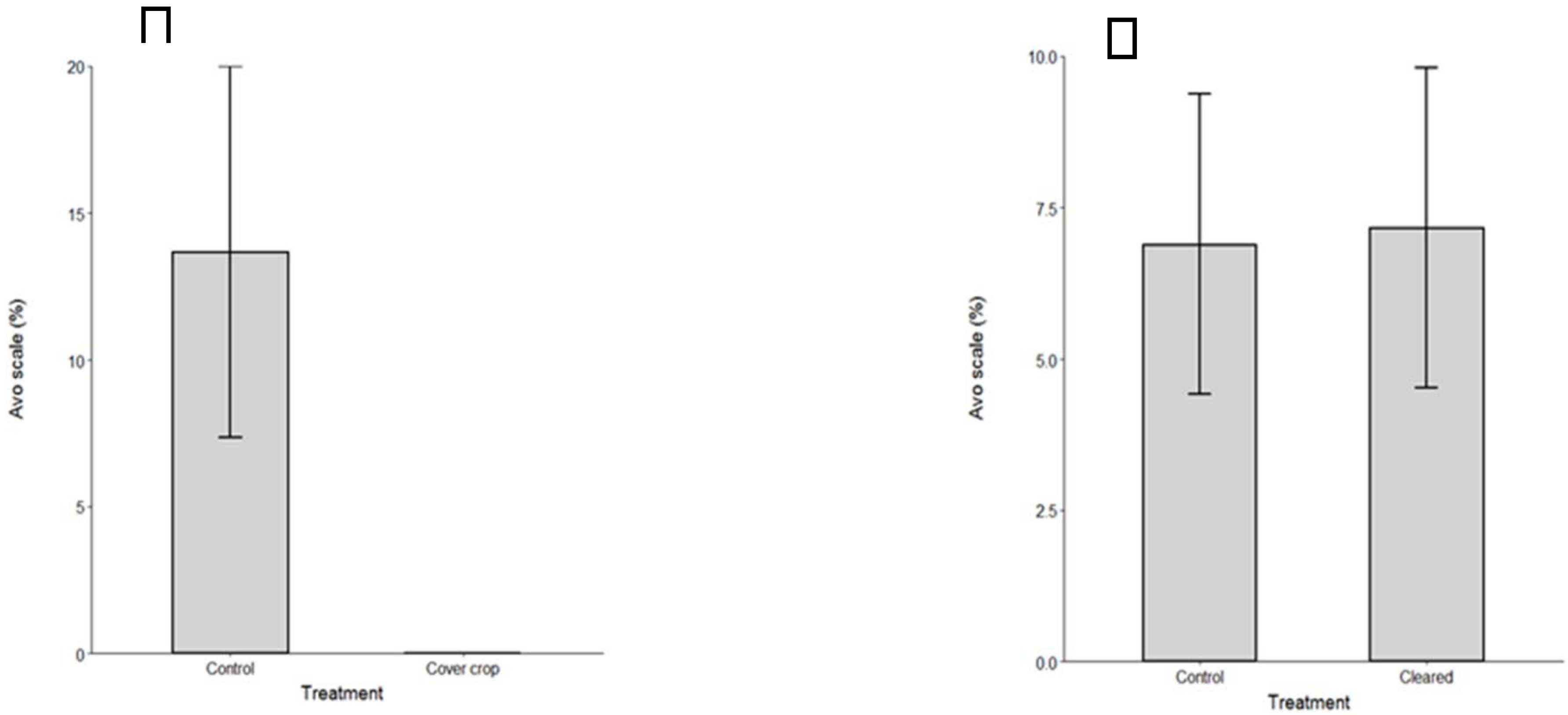

Figure 9. A comparison of avocado scale infestation on the (A) treatment of cover crops & control and (B) treatment of cleared alleys.

6.5 Thrips count and damage

A comparison of thrips infestation was conducted between the cover cropped alleys and control alleys and the bare soil (cleared) alleys and control alleys. The data showed a significantly higher number of thrips (0.66 ± 0.09 thrips per fruit in the control) where there were no cover crops in comparison to 0.38 ± 0.07 thrips per fruit where cover crops were established (Kruskal-Wallis chi-squared = 7.4151, df = 1, p-value = 0.006468, Figure 10A). The damage observed by thrips were however not significantly different between the treatments (Kruskal-Wallis chi-squared = 2.0776, df = 1, p-value = 0.1495).

There were no significant differences in the number of thrips counted (Figure 10B) or damage observed per fruit on the cleared *vs*. control alleys (counts: Kruskal-Wallis chi-squared = 0.014162, df = 1, p-value = 0.9053; damage: Kruskal-Wallis chi-squared = 1, df = 1, p-value = 0.3173).

The conditions for thrips were favourable in both the treated alleys especially the plots where there were mainly bare soil and the control that comprised of weeds and grass. Past studies have revealed the positive effects of cover crops in alleys of orchards to be effective in the reduction of thrips during flowering seasons on vineyards, apple and avocado orchards (Nichollas *et al*., 2000; Bone *et al*., 2009). These effects have shown to improve fruit setting leading to increase yield and less fruit damage.

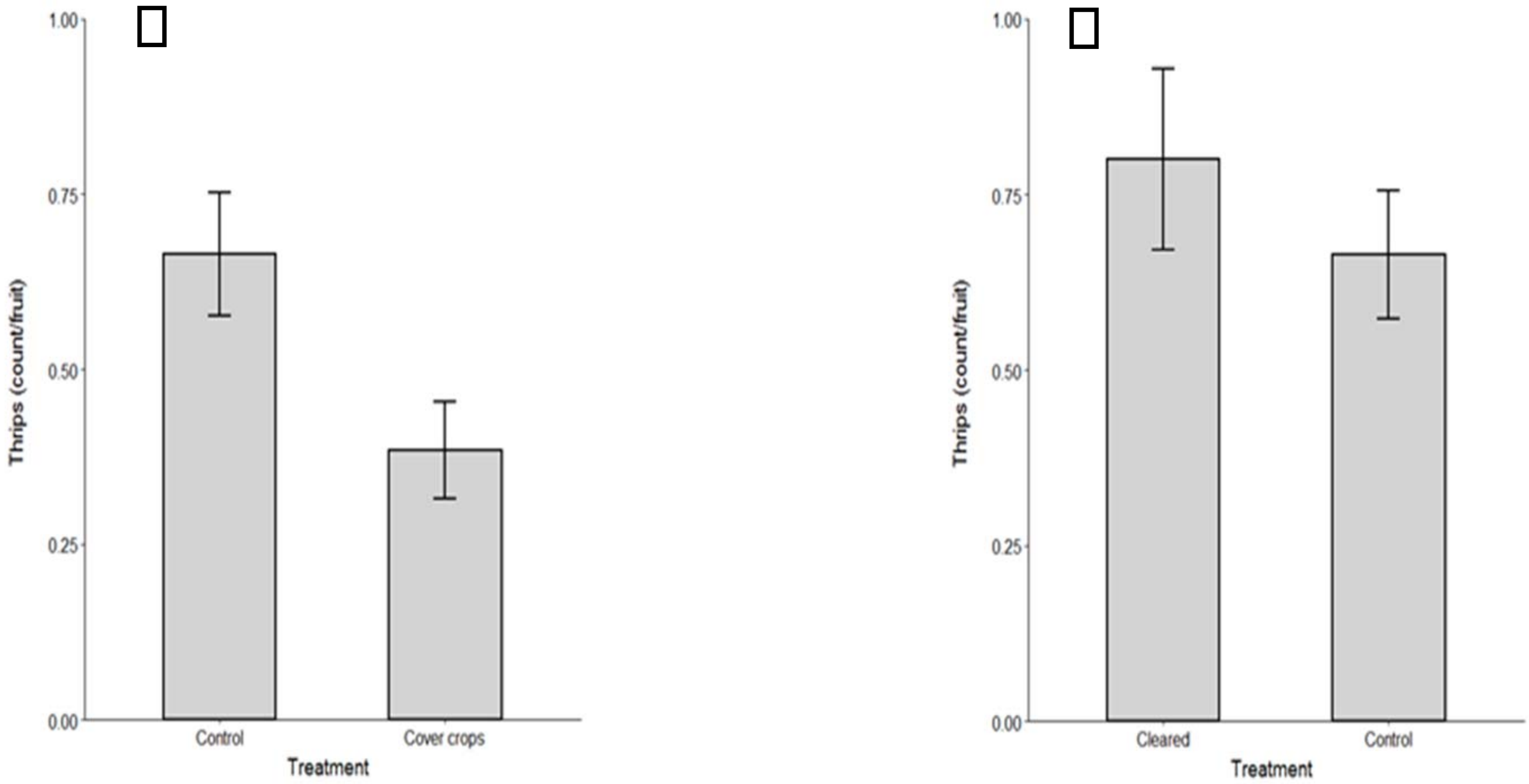

Figure 10. A comparison of thrips presence on avocado fruit in (A) treatment of cover crops & control and (B) treatment of cleared soil & control.

6.6 Sucking bug fruit damage

The results showed a significant difference in the damage by sucking bugs observed on fruit in the cover crop treatment (0.05 ± 0.02 fruit damaged) *vs.* the control (no damage observed) (Kruskal-Wallis chi-square = 6.123, df = 1, p = 0.01334), being very low but higher on the cover cropped alley fruit than the control. There was no sucking bug damage observed on fruit from the cleared alleys or the control.

The cover crops did not reduce sucking bug damage; on the contrary, a significantly higher number of fruits had sucking bug damage in the trees bordering covered alleys. These results may have been due to the higher number of sucking bugs present in the cover crops. These results did not reflect the potential effect of cover crops to aid in the reduction and complete eradication of sucking bugs on fruit. Assessments were conducted during the early fruit development of avocados. Feeding marks on avocado fruit caused by insect pests make it unattractive for export. Although studies by Bones *et al.,* (2009) showed a significant decrease in fruit damage in apple orchards intercropped with cover crop this was not the case with the avocado orchard with cover crops.

6.7 Soil health and nutrient status

A comparison was conducted on the soil health status between cover crop alleys and control alleys (natural vegetation).

6.7.1 Bacterial community

The overall bacterial community of the soil analyses revealed high levels of bacterial diversity (species richness) as well as high levels of evenness (Shannon index), indicating a well-balanced bacterial community for both the cover crop treated alleys and the control alleys. There were significant differences in the bacterial community compositions between the control and the cover crop treatment, confirmed by the bacterial beta diversity plot showing that the control and cover crop samples are far apart on the NMDS1 scale. The cover cropped alley analyses resulted in a maximum CO_2 burst of 102.81 ppm with a strong nitrogen mineralization potential and biomass description relating to a typically high biology soil. The control alley analyses resulted in a maximum CO_2 burst of 74.6 ppm with some mineralization potential and biomass description relating to a medium biology soil.

6.7.2 Fungal community

The overall fungal community displayed high levels of fungal diversity (species richness) as well as high levels of evenness (Shannon index). The fungal communities were balanced in the cover crop treated alley and control. The differences in the fungal community structures between the cover crop treatment and control were not significant.

6.7.3 Urease and phosphatase enzyme

Overall, the microbial community showed high urease and phosphatase activity for the cover crop treatment and control. This type of analysis indicates the soil's ability to convert urea and phosphates to an available form for plant use. The results showed a potential for microbial communities to convert urea and phosphates to an available form for plant use if it is available.

6.7.4 Nutrient status of the soil

There were 4.67 ± 2.29 % soil organic matter (SOM) in the cover cropped alleys and 6.48 ± 0.14 % SOM in the control alley. There was no significant difference in the SOM between the cover cropped alley and control alley (Welch Two Sample t-test: t = -0.080646, df = 1.007, p-value = 0.9487). Soil carbon contents were not significantly different either. There were 2.71 ± 1.33 % carbon in the cover cropped alleys and 2.61 ± 0.08 % in the control alley (Welch Two Sample t-test: t = -0.075052, df = 1.0072, p-value = 0.9522). There was no significant difference in the soil pH between the cover cropped alley ($pH_{(water)}$ = 5.88 ± 0.23) and control alley ($pH_{(water)}$ = 6.07 ± 0.09) (Welch Two Sample t-test: t = 0.75346, df = 2.5578, p-value = 0.5144). There was no significant difference in the soil density between the cover cropped alley (0.91 ± 0.01 g/ml) and control alley (0.93 ± 0.02 g/ml) (Welch Two Sample t-test: t = 0.79057, df = 3.4483, p-value = 0.4800). There was no significant difference in the soil calcium content between the cover cropped alley (850.67 ± 199.33 mg/kg) and control alley (1211.67 ± 143.09 mg/kg) (Welch Two Sample t-test: t = 1.4712, df = 3.6287, p-value = 0.2222). There was no significant difference in the soil magnesium content between the cover cropped alley (237.33 ± 65.90 mg/kg) and control alley (315.00 ± 29.60 mg/kg) (Welch Two Sample t-test: t = 1.075, df = 2.7752, p-value = 0.3668). There was no significant difference in the soil potassium content between the cover cropped alley (167.67 ± 26.19 mg/kg) and control alley (298.67 ± 42.75 mg/kg) (Welch Two Sample t-test: t = 2.6129, df = 3.3163, p-value = 0.07169). There was no significant difference in the soil sodium content between the cover cropped alley (61.00 ± 20.21 mg/kg) and control alley (41.67 ± 2.33 mg/kg) (Kruskal-Wallis rank sum test: Kruskal-Wallis chi-squared = 0.44118, df = 1, p-value = 0.5066). There was no significant difference in the soil iron content between the cover cropped alley (29.01 ± 1.09 mg/kg) and control alley (27.49 ± 0.70 mg/kg) (Welch Two Sample t-test: t = -1.1799, df = 3.4314, p-value

= 0.3133). There was no significant difference in the soil manganese content between the cover cropped alley (22.14 ± 3.12 mg/kg) and control alley (20.86 ± 1.55 mg/kg) (Welch Two Sample t-test: t = -0.36849, df = 2.933, p-value = 0.7375). There was no significant difference in the soil copper content between the cover cropped alley (14.53 ± 0.67 mg/kg) and control alley (8.79 ± 0.67 mg/kg) (Kruskal-Wallis rank sum test: Kruskal-Wallis chi-squared = 0.047619, df = 1, p-value = 0.8273). There was no significant difference in the soil zinc content between the cover cropped alley (1.21 ± 0.31 mg/kg) and control alley (1.01 ± 0.26 mg/kg) (Welch Two Sample t-test: t = -0.50675, df = 3.8715, p-value = 0.6398). There was no significant difference in the soil boron content between the cover cropped alley (0.95 ± 0.06 mg/kg) and control alley (0.78 ± 0.09 mg/kg) (Welch Two Sample t-test: t = -1.5229, df = 3.4641, p-value = 0.2131). There was no significant difference in the soil sulphur content between the cover cropped alley (17.89 ± 4.26 mg/kg) and control alley (6.88 ± 0.56 mg/kg) (Welch Two Sample t-test: t = -2.5633, df = 2.068, p-value = 0.1204). There was no significant difference in the soil phosphate content between the cover cropped alley (7.00 ± 1.00 mg/kg) and control alley (5.00 ± 0.58 mg/kg) (Welch Two Sample t-test: t = -1.7321, df = 3.2, p-value = 0.1759). There was no significant difference in the soil aluminium content between the cover cropped alley (1551.33 ± 41.80 mg/kg) and control alley (1477.67 ± 10.93 mg/kg) (Welch Two Sample t-test: t = -1.705, df = 2.2721, p-value = 0.2151).

6.8 Fruit yield

A comparison was done for fruit yield from the cover crop treatment and the control. The harvested avocado quantities per treatment were measured at the packing facility from the same number of trees in the orchards per treatment. The data from the packing facility indicated that there were more avocados delivered from the cover crop treatment (256.25 ± 4.12 kg) than from the control treatment (250.34 ± 3.61 kg). The total weight of the fruit harvested from the cover crop treatment was 17 303 kg and the weight from the control was 14 790 kg. Harvesting were done in bins and the bins were delivered to the packing facility on three trailer loads per treatment.

The statistical analyses showed no significant difference in average bin weights between the treatments (Welch Two Sample t-test: t = -1.0791, df = 4.9755, p-value = 0.33), average weights of each delivery to the packing facility (Welch Two Sample t-test: t = 0.51784, df = 4.8298, p-value = 0.6274), (Figure 11) and no significant difference in the actual pack out figures measured in 4kg or equivalent cartons (Kruskal-Wallis rank sum test: Kruskal-Wallis chi-squared = 1.7366, df = 1, p-value = 0.1876). The half of the orchard that was planted with cover crops delivered 2 724 equivalent 4kg cartons and the control half of the block delivered 3 451 equivalent 4kg cartons.

A study conducted by Cruz *et al.,* (2014) on the effects of cover crops planted in between the alleys of papaya (*Carica papaya* L.) resulted in an improvement in yield. The results indicated that mixtures of cover crop treatments improved organic matter content that helps improve fruit yield. This study achieved similar results on the avocados grown with mixtures of cover crops in the alleys for improved yield.

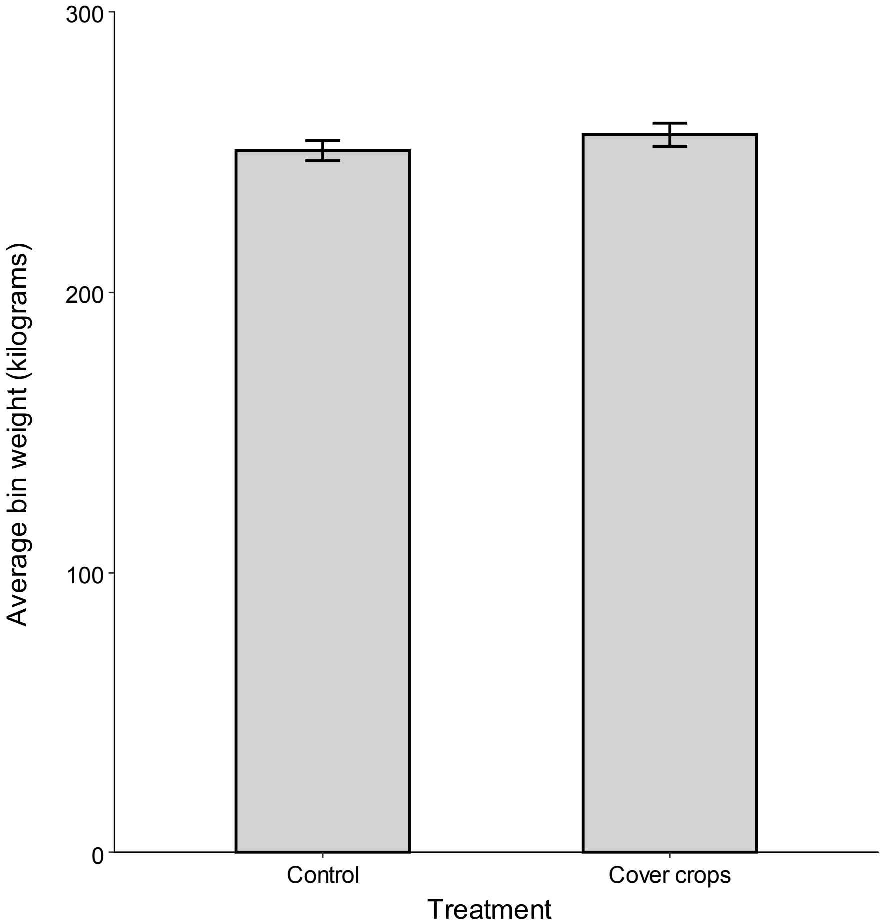

Figure 11. A comparison of the average bin weights as harvested avocado arrived at the packing facility from the control and cover crop treatments in a commercial orchard.

7 CHAPTER SEVEN: CONCLUSION AND RECOMMENDATIONS

7.1 Conclusions

Cover cropping is a good and highly recommended land use management strategy that leads to improved biodiversity in commercial orchards including avocado orchards (Akbulut *et al,* 2003; Sullivan, 2003). The transition to these types of practices, however, may take time to be fully functional. For the planting of cover crops, literature reviews further suggest the use of no till planters for better sustainability (Sullivan, 2003). Planting of mixtures and /or a single cover crop in the alleys between orchard trees may also require specific techniques that may determine the success of the operation.

The study found a lower abundance, diversity and species richness of insect arthropods in the mechanically cleared soil plots compared to the control (natural vegetation). The lower abundance may have resulted from the lack of vegetation and flowering plants which are supposed to attract insects in general. The significant higher numbers of arthropods that were counted on the control plots compared to the cleared bare soil alley, may have been as a result of weed flowering plants that occurred on the control (natural vegetation). The flowering weed species may have also led to the attraction of arthropods which led to the recording of significant numbers in the control.

Higher abundance, diversity and richness in species of arthropod occurred in the cover crop treated plots compared to the control (natural vegetation) and this showed the true effect of cover crops positively influencing and improving biodiversity of orchard alleys.

The study also revealed that cover cropping may have negatively impacted the avocado trees in some instances where, for example, in the treated alleys pests were more abundant than on the control. Damage-causing pests that were found in the study area are believed to have contributed to damages on fruit, although the results were not significant enough to draw such conclusions. In contrast to many of these studies we found no increase in the number of predators and pollinators in the cover crop treatments. Assumptions are that the lower number of predators could have led to an increase in the number of pests. Cover cropping systems are supposed to support a conducive environment for predatory species to thrive and increase in numbers. Studies have shown that an increase in predator numbers lead to reductions in pest numbers and pressure on fruit trees.

Higher pollinator species that should have been attracted by the flowers would have increased pollination activities that would have improved yield but was not the case for this study.

Pollinators were found abundant in the control plots and these may have been due to the flowering weeds attracting pollinators.

The study also revealed that cover cropping reduced avocado scale insect infestation. There was a significant difference between the cover crop system and the control. No significant difference was found between the treatments with regard to heart-shaped scale.

The number of thrips present on fruit along the cover cropped alleys had significantly less thrips than the control. Cover crop treatments, like the findings of Nicholls *et al*., 2000 and Bone *et al*., 2009, resulted in a reduction of thrips. These results were however, only found in the block that had a vigorous growth of cover crops.

The study did not show any general trend for either the cover crop or control plots regarding pest damage on fruit. It is not possible to state whether the cover crop management system may have had an impact on the pest diversity that caused damage on fruit. The conclusion was drawn from the fact that plots that had mature cover crops may have had an indirect impact on the number of pests.

The overall improvement in soil health is an indication that cover crop systems positively affect soil biological composition. There were positive results in terms of the changes in the soil health aspects. Cover crop treatments positively affected the diversity and evenness of bacteria in the soil: bacterial diversity was richer in the treatment than in the control. Bacteria are an important factor in the functioning of healthy ecosystems, and these results revealed a positive effect of cover crops on the diversity of bacterial community. Cruz *et al.*, (2014) suggests that mixtures of cover crops improve soil health and provide other benefits such as protection of soil against erosion and prevents degradation.

This study further suggests that cover cropping as a soil management system positively affects the diversity of soil fungal communities. This was concluded after the results revealed a higher level and evenness of fungal diversity on the treated plots, although the control plots that comprised of flowering weed also had a positive influence on the same aspects.

Although the overall results for the enzymatic activities on both the treated and control showed higher urease and phosphatase, the true effect of the cover crops mixtures on urease and phosphatase was not significant. There were no significant differences between the cover crop treated alley and control, contrary to the expectation that cover crops would benefit enzyme activities.

These alternative practices of cover cropping can be beneficial in different aspects within the farming industry. The impact on the yield improvement and high exports would not only increase the profitability for commercial farmers, boosting the economy of the country, but it will also increase the number of people employed by a commercial farmer. There would be direct employment of permanent and short-term contracts both in the farm and at the packing houses.

7.2 Recommendations

More scientific research should provide more evidence on the significance and impact of cover crops in orchards. These studies need to provide evidence on the impact that cover cropping has on the biodiversity of the orchard landscapes. More evidence is needed to demonstrate that cover cropping enhances biodiversity of flora and fauna. Evidence is needed that cover cropping will increase predatory species leading to a reduced pest infestation, hence better fruit yield without damage. Evidence is needed that will reveal that cover cropping will attract and increase beneficial insects due to its flowering nature, hence increased pollinators leading to higher fruit yield.

Research results should be able to encourage policy makers and the avocado industry to design orchards that will function in healthier and more sustainable ways. There should be an encouragement to farmers to implement these interventions in their orchards (Herz *et al.*, 2019). The end results should be that there is significant reduction or perhaps even a total prohibition on the use of inorganic agrochemicals to improve yield. The total ban of these chemicals will lead to more sustainable agricultural practices that do not have dire consequences on the health of humans, that will not contaminate freshwater bodies and that will not degrade our topsoil base.

Such information should be able to reach farmers both informal and commercial so that in future they are able to practice sustainable farming for the benefit of everyone. Constant use of cover crops planted in the alleys between avocado trees should be practiced by farmers. The most important factor for this practice is to have enough knowledge on the selection and management practices of the cover crop that will suite the objectives to be met by the farmer.

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